Facility Location Modeling:

Decentralization of Saskatoon Homecare Agency

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By

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Abstract

Saskatoon Health Region (SHR) is encountering a facility location problem for its centralized homecare agency which currently is located in Idylwyld Center close to the city's downtown. Through their homecare program, they provide various home/nursing services to the elderly and patients discharged from acute care. Reducing time wasted on the road and travel expenditures, increasing hands-on-time and covering the increasing demand for homecare services are a few of SHR's motivations to assess the project of decentralization of their home base. They have determined a set of potential sites for their new offices which are scattered all over the city. The purpose of this research is to model their facility location problem using a quantitative method, with the objective of determining the optimal set of sites that leads to minimizing overall cost. In addition to identifying the best locations, the size of each facility in terms of required staff is also determined.

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1.0 Introduction

Saskatoon Health Region (SHR), a health delivery agency responsible for providing healthcare services to residents of Saskatchewan, is encountering a facility location problem for its homecare agency. There are two groups of services provided by Saskatoon homecare program to the elderly and patients discharged from acute care; one group of services are home services provided by Home Health Aides (HHAs) and the other are nursing services provided by Registered Nurses (RNs). Idylwyld Center is the only homecare agency in the city of Saskatoon and HHAs and RNs are required to start their day from this home base and pick up required supplies along with their schedule for that day. During their day time work, if a client cancels her appointment or if by any reason a HHA or an RN is free, they should travel back to home base till their next appointment. They also have to come back to home base by the end of their shift to do all the related paper works for that day. Due to high inefficiency in the system and redundant traveling, SHR is exploring the feasibility of adding a multiple set of locations to this particular system. We wish to apply quantitative methods to analyze this particular problem.

A number of factors are currently promoting SHR to study the feasibility of decentralization of its home base operations, including the reduction in traveling time and cost, permitting the healthcare workers to increase their average hands-on-time (the actual time of the service provided to the client by HHAs and RNs excluding breaks and traveling times), covering the increasing demand in more efficient ways, and dealing with the lack of parking capacity due to 25^{th} Street extension.

SHR's homecare program is willing to find the best sites, if any, from five proposed locations (Appendix A). These potential locations include:

- Lawson Heights Mall,
- Confederation Park Mall,
- University Heights Square,
- Market Mall, and
- Avenue H South

Besides determining the number of opened satellites and their optimum locations, it is also desirable to establish the size of each facility in terms of required staff for covering the demand. Another alternative for decentralization of home base would be providing technology such as Blackberry mobile devices or tablets. Therefore, they are performing cost analysis of both projects, decentralization of homecare and providing technology, simultaneously to see which alternative works best for them to reduce the cost.

The purpose of this research is to model their facility location problem using a quantitative method, with the objective of determining the optimal set of sites that leads to minimizing overall cost. This cost minimization includes reducing the total fixed costs (construction and operating cost) and variable costs (employees traveling to clients' houses). The quantitative model should be able to determine the required staff level for each site and also the number of staff that should be sent to different neighborhoods to cover the demand. It is possible that our quantitative model finds more than one good location for optimization objective, and it is also possible that SHR would have neither the budget nor the ability for decentralizing the home base into so many places. Therefore, using another quantitative method, the feasibility of adding just one new site in the east side of the city (which has the highest demand for homecare services) will be investigated.

The format of the thesis is as follows. In chapter 2, general review of the literature regarding facility location problems is presented as well as real-world applications of location-allocation problems in healthcare. In chapter 3, Saskatoon Health Region's homecare program and the overall flow in the system is introduced briefly. Moreover, the current motivations for decentralization of homecare are discussed. Data and required information for this thesis are explained in chapter 4. In chapter 5, two different operations research methods, Center of Gravity and P-median model, are implemented for solving the decentralization problem and the results are discussed followed by several scenario analyses. A comparison of two mentioned models is made in chapter 6 and in chapter 7, the assumptions and limitations in this work are provided along with a couple of suggestions as future directions. The thesis is finalized in the last chapter with a conclusion and summary.

2.0 Literature review

In this section, we divide the reviewed literature into two parts as follows. The first section is a review of general facility location literature. It covers different types of spaces and distance measures which are used in any facility location problems. Some examples of different effective factors on location decisions as well as different optimization objectives are explained in this section along with an introduction of basic facility location models used in different spaces. Then some application of operation research in healthcare delivery is discussed. In the last section of this part, we review some real world applications of facility location problems.

2.1 Review of general facility location literature

For nearly sixty years, facility location decisions have been studied by researchers from several academic disciplines including economics, engineering, mathematics and operations research. With the growth of research in this area, the complexity of the problems that investigators could tackle has grown. In fact, nowadays, facility location decision makers should consider multi-objective aspects of this problem. These objectives can fit in different categories but the most popular are cost minimization (which minimizes fixed cost such as construction and operating cost, and variable costs such as transportation costs) and demand coverage (especially for healthcare system for which enhancing the quality of living is their main target and increasing the coverage as much as possible).

Finding the location of facilities in both industry and healthcare is a critical issue. Using too few facilities or any imperfect location of these facilities in healthcare can lead to an increase of mortality and morbidity. On the other hand, having too many facilities would lead to idle or poorly used resources. And in both cases, total system costs increases. Therefore, facility

location gains importance when it comes to health and healthcare. In location decisions, feasible sites are studied and best locations for facilities are selected such that either a single or multi-objective function is met subject to a set of constraints.

2.1.1 Objective functions and influential factors in facility location problems

Current et al (1990) reviewed 45 journal articles related to facility location problems and assessed the objective in all of the presented papers. They concluded from the articles that this problem is widespread and multi-objective analysis can yield beneficial results by including various disciplines into the analysis. They classified the objectives into four categories:

- Cost minimization
- Demand oriented
- Profit maximization
- Environmental concerns

Based on their research, each of these categories was subsequently divided into 25 subcategories. The main subcategories for cost and demand oriented were distance and coverage respectively. A few articles had chosen profit maximization as their objective; in this particular case, the subcategory was rate of return. Finally, only four articles had used environmental protection as the objective of their model. Air quality, quality of life, risk to surrounding populations and low-flow stream augmentations are environmental issues studied in these four articles (Current et al, 1990).

Although Current et al (1990) provided a comprehensive review of mostly-used objective functions in different papers, the objective functions are not still limited to those mentioned above. For example, Schultz (1970) introduced a logical model for the location problem where

the objective was maximization of net social benefit (Schultz, 1970). In addition, the focus of the author's model is on the degree of decentralization in facility locations which is important since it affects the following:

- Costs of producing services such as cost of labor
- Traveling costs to consumers and medical providers
- Demand for healthcare facilities in a region. The main reason for such impact on demand is that when the number of facilities increases due to decentralization, the accessibility of the facility and consequently, clients' participation and demand increases. In other words, the increase in demand stems from the famous economic model of Supply and Demand in which an increase in supply of the services or products are followed by an increase in the quantity demanded. However, demand will not increase for all types of surgeries but only for "optional services such as physical checkups, preventive treatment and treatment of minor alignments" (Schultz, 1970, 386). Therefore, Schultz explains that the benefit of such services to the users is lower than the cost of using the facility. In contrast, for those demanding necessary services such as surgeries, the benefit received is higher than the cost.
- Induced cost to the society due to increased travel such as air pollution and traffic congestion.

Except for objective function which is very important in facility location models, there are other qualitative factors affecting location/allocation decisions. MacCarthy et al (2003) named a list of factors which affect location decisions. These may include:

- Cost,
- "Labor characteristic" (e.g. the availability of the labor near the facility location and labor skills and productivity),
- Suppliers' characteristics (e.g. closeness to suppliers, quality and responsiveness of the suppliers),
- Closeness to raw materials and customers,
- Tax and insurance, environmental characteristics (e.g. climate) and "government and political factors" (e.g. government stability) (MacCarthy et al, 2003 (797)).

Invariably, each of these factors has an impact on facility location decisions. (MacCarthy et al, 2003)

2.1.2 Facility location problems in different spaces

As described in Hale and Moberg (2003), there are three basic spaces on which facility location problems are solved. These spaces include spatial (continuous space), discrete space and network space. The first space which can exist in one, two or three dimensions is used when any location is feasible to be chosen for new facility. In discrete space, there is a finite list of candidate locations from which open sites should be selected. The network space is the same as discrete space, except that only candidate sites are the nodes of an underlying network. Among these approaches, discrete location models have been used more in healthcare location problems (Daskin and Dean (2004)). Evidently, not all the locations are feasible for locating new facilities even if they are the optimal solution in a continuous space. In other words, when the optimal point is located in the middle of the street or in a residential building, it cannot be used for optimization purposes since it is not feasible. Moreover, most of the discrete models have the

ability to investigate adding multiple facility locations while most of the continuous space models can only be used for single facility location problems. These shortcomings of the continuous space approach are the main reasons why researchers investigate discrete space models instead of continuous space cases.

Different ways that distance can be measured in continuous space models are Manhattan distance metric (which is also called rectilinear or right angle distance metrics) and Euclidean distance metric (which is the straight line connecting the two facilities) (Heragu, 2006). For facility location problems which should be solved in continuous space, coordinates of different demand points should be calculated and distance between the new facility and demand points should be minimized (Klose and Drexl 2003).

2.1.3 Discrete space models

Based on Daskin and Dean (2004), there are three basic facility location models in discrete space; namely, the Set Covering, the Maximal Covering, and the *P*-median model. The authors also described the application of these models in healthcare locations problems.

The objective in Set Covering models, which are also referred as minimax or P-center models, is to minimize the maximum traveling distance between facility sites and demand points (Daskin and Dean, 2004). A real world application of minimax modeling is presented by Malczewski and Ogryczak (1990) for locating pediatric hospitals in Warsaw. The set covering problem was first formulated by Toregas et al (1971) with the purpose of "covering each of the user nodes with one of the facility nodes" (Toregas et al 1971, 1364). This model was stated to be mostly applicable to emergency services location such as fire stations (Toregas et al, 1971). The assumptions that they made for this model are:

- The cost for all possible facility locations are identical
- Potential facility locations are a finite set of points
- Minimum distance between any node and facility location is known

Based on Set Covering model, a demand point with high volume is treated the same as a demand point with low volume (Daskin and Dean, 2004). Besides, since this model is trying to cover all demand nodes and minimize the maximum coverage distances (or in other words, minimize the radius of the circle within which all the demand nodes lie) , the cost of covering all the demand points is usually very high which is considered as a drawback of set covering model (Daskin and Dean, 2004).

Church and ReVelle (1974) formulated Maximal Covering location model to deal with the mentioned problem with Set Covering models. The objective of the Maximal Covering model is to cover the demand as much as possible for healthcare facilities regardless of the increase or decrease in total cost (Daskin and Dean, 2004). With this model we try to maximize the number of demands covered, not the covered demand nodes. Therefore, some demands (especially those with low volume of demand) may remain uncovered.

The P-median problem, which is also referred as Weber problem or minisum models, can be used with the objective of locating *P* number of facilities such that the sum of the demand weighted distance between facilities and clients are minimized. Usually, the number of facilities to be located is certain in the covering models as well as P-median models.

Teixeira and Antunes (2008) applied a discrete hierarchical location model using minisum objective for planning a school network in Coimbra, Portugal. Also, Rahman and Smith (2000) used all the mentioned models to find the best locations of hospitals in developing countries such

as Bangladesh. Later on, this model is used to find a solution for homecare decentralization problem in Saskatoon.

Sule (2001) also added three other groups of facility location problems to the basic ones described before:

- Uncapacitated facility location problem
- Capacitated facility location problem
- Quadratic assignment problem

The author states that in uncapacitated facility location problems, there is no limitation on the capacity of each facility. Therefore, it is not efficient to "assign a demand to more than one supply point" (Sule, 2001, 17). The objective of this problem is the same as that of P-median problem and the objective function contains both fixed (depending on the location) and variable (depending on the travelled distance) costs. If there is a limitation on the capacity of the facilities, the capacitated facility location problem can be used. The author states that in contrast to the previous problem, assigning a demand to more than one supply point can also lead to an efficient solution. When there is flow among facilities (or machines), quadratic assignment problems can be used to minimize the total cost. However, this type of model usually leads to many solutions. The reason is that when there are n machines to be located, there is the $n!$ possible solutions which gets difficult and time consuming to find the solution for large number of machines.

2.1.4 Continuous space models

There are different models which can be used for single facility location problems in continuous space. One of these models is Center of Gravity method which is described as follow:

"The Center of Gravity model minimizes the demand-weighted average distance between a facility that can be located anywhere in the plane and a discrete set of points" (Daskin and Dean, 2004, 54)

Based on Sule (2001), a Center of Gravity model with rectilinear distance can be formulated as follow:

$$Minimize\ TC = \sum_{i=1}^{m} w_i[(x - x_i)^2 + (y - y_i)^2]$$

w_i : Demand weight of point *i*

x_i and y_i : the coordinates of demand point *i*

x and y: The best coordinates of the new location in the space

Optimal solution can be derived by taking the partial derivatives of the objective function with respect to x and y and setting the resulting equations equal to zero which leads to the following solution:

$$x = \frac{\sum_{i=1}^{n} w_i x_i}{\sum w_i} \quad , \quad y = \frac{\sum_{i=1}^{n} w_i y_i}{\sum w_i}$$

2.1.5 Time horizon and uncertainty

Based on Wesolowsky (1973), considering the time horizon of study, facility location problems can be divided into static and dynamic models. Although it is expected that facilities serve over a long time, constant components of the problem such as demand and cost change over time. In such cases, dynamic models come to rescue. However, static facility location models have been more studied and developed than dynamic models since they do not deal with the uncertainty associated with real life problems and are more straightforward to formulate. An

example of real world application of a dynamic model is the dynamic redeployment of ambulances as described by Rajagopalan et al (2008). In this work, the demand for ambulances is dynamic and fluctuates during the week and even during the day. The objective function is to find the minimum number of ambulances and their locations.

Based on Owen and Daskin (1998), facility location models also can be divided into stochastic and deterministic models. Similar to static models, most research in facility location problems is devoted to deterministic problems rather than stochastic models since it is the simpler to model. In the former, demands, travel times and distances are assumed to be known. Although these types of models are easier to deal with, they cannot properly take real world uncertainties in to account. However, in stochastic models, some parameters have probability distributions. One of the real world applications of stochastic models is presented by Listes and Dekker (2005) who used stochastic approach on recycling sand from demolition waste in The Netherlands. There is always uncertainty involved in product recovery networks. For instance, the amount and quality of the returned sands may be uncertain in their case study.

2.2 Application of Operations Research (OR) in healthcare delivery

In operations research, problems in healthcare are analytically the same as problems in other industries. However, there is no doubt that there are characteristics exclusive to healthcare which makes it unique such as probability of death or low quality of life. For instance, accessibility gains importance while dealing with preventive healthcare programs. Generally, detecting a disease at its early stage can help the patient to be cured more successfully and the quality of life improves. Accessibility is also important in finding the best location for ambulance stations. Large-scale emergencies are another example of healthcare services with exclusive

characteristics which should be investigated carefully in order to save more lives. Based on Daskin and Dean (2004) healthcare facilities should be sited in places which can maximize accessibility, adaptability and availability of the services. Accessibility shows the ability of the patient or healthcare providers to reach the other one in case of emergency. Adaptability refers to the ability to adapt existing space to operational changes such as workplace practices. The last component is that services are not always available. For instance, an ambulance may still receive calls while it is taking a patient to a hospital. Therefore, maximizing the availability of the services should be an important component of emergency services provision.

Verter and Lapierre (2002) described the preventive healthcare facilities location. The main objective of the paper was to maximize participation. The authors considered that the major factor which defines the probability of participation of a patient in a preventive healthcare unit is the distance (from patient location to healthcare unit) and the patient chooses the closest facility location. The underlying assumption for this hypothesis is that the quality of the services is the same at each facility center. Therefore, in terms of quality of services, patients are indifferent between facility centers. The Maximal Covering model has been used by authors for this location problem. As authors mention, one of the shortcomings of this article is that they assumed that the probability of participation is a linear function of distance while this is not necessarily true since there are other factors except for the distance which affect the probability of participation. They state that a patient with a history of a specific disease in her family is more likely to participate in preventive care regardless of the distance. Moreover, some tests which are prescribed by a doctor to be done at a specific center are not the closest to the patient but it is the center with which the doctor collaborates. However, since there are not any empirical studies using nonlinearity of

relationship between probability of participation and distance, authors made the assumption of linear relationship between these two factors.

2.3 Application of location-allocation problems in healthcare

As mentioned before, problems in healthcare are solved the same as problems in other industries. Therefore, there is no difference in the models used for modeling facilities whether in healthcare or other industries. In the following sections, some real-world applications of facility location problems in healthcare are discussed in more details. Based on the characteristics of the studied health service provider, the authors of these papers employed different models such as Center of Gravity, Set Covering, Maximal Covering and P-median model to solve a facility location problem in healthcare.

2.3.1 Blood bank location in Quebec

Price et al (1986) studied the relocation of the blood bank in Quebec City. Due to increases in population, the demand for required services increased and since the blood donor clinic was located in downtown, there was no space for expansion.

The authors gathered data related to mobile clinics, blood deliveries and donors who go to clinic centers. They measured the activity of the mobile clinics based on the number of days it lasted and also the number of donors who used mobile clinics. For blood deliveries, they gathered data related to the number of deliveries and the number of total items delivered. For donor population, they distributed questionnaires to 1500 donors and asked them about their transportation modes. After gathering the data and comparing it with the data from “a survey taken by the public transport authority” which was done for the whole population, they realized

that donor populations have almost the same transportation preferences as that of the whole population (Price et al, 1986, 22).

Afterwards, they performed a series of gravity models to find a group of location options. Center of Gravity was calculated for:

- Donor population who go to the clinic center and donor population who go to clinic center or mobile clinics. The geocenter of these two models where almost the same (within 500 metres of each other).
- Mobile clinics held in the Quebec urban community weighted by the number of days it operated and also weighted by the number of donors who go to that mobile. Again, these two models had the same geocenters within one kilometre of each other.
- Blood deliveries considering the number of delivered items and also the number of deliveries. The results of these models were also the same.
- Forecasted population as well as the current population which both gave the same center of gravity.

The authors argue that these series of models provided four geocenters based on Center of Gravity model which were not feasible. Therefore, they found the nearest feasible sites to the center of gravity of these four groups. Since they only had to choose one best location and also wanted to incorporate other important factors in facility location decisions, they used a simple qualitative method to rank the sites and pick the best one in the end. These important factors which were used for ranking are:

- Closeness to the center of gravity.

- Accessibility to the public transportation network. For this criterion, they used the number of trips made to and from the candidate site zone to total trips made using public transportation.
- Road network accessibility. Sites closer to the freeway network got a higher rank.
- Availability of a vacant lot or an appropriate building which was investigated informally without consulting a real estate agent.

2.3.2 Location of medical services for large-scale emergencies in Los Angeles

Jia et al (2005) used different facility location models such as P-median, Set Covering and Maximal Covering model to plan the locations of Emergency Medical Services (EMS) for large scale emergencies (such as terrorist attacks, hurricanes and earthquakes) in the Los Angeles area. Since these events happen rarely and have huge influence on demand for medical services, these models should consider the optimum number of facilities, the distance from these facilities to demand point, and appropriate use of facilities. Therefore, there should be backup and scattered EMS facilities from which more medical services are distributed in case of large-scale emergencies. This is especially the case for large-scale emergencies like earthquakes, since they can cut the access to medical facilities or may destroy some facilities. Another important factor which should be considered in modeling the location of EMS facilities is that the chance of a different large-scale emergency happening and their impacts varies in different areas. The authors divided facility deployment strategies into two groups of:

1) Proactive facility deployment; in this strategy the location of facilities and medical supplies are determined before any emergency happens. For incidents such as a dirty

bomb terrorist attacks in which many people are infected and need immediate EMS response, proactive deployment of facilities is the best strategy.

2) Reactive facility deployment; in this strategy, medical supplies are not inventoried at demand points before occurrence of incident but are requested from Strategic National Stockpiles (SNS) during the emergency. Therefore, the staging centers should be located optimally for receiving and distributing medical supplies to the demand points. Unlike the former strategy, reactive strategy is appropriate for emergencies for which delay is permitted and for those instances that require greater amounts of supplies.

The authors have also prioritized objectives for facility location of EMS to minimize the loss of life. Having access to more than one highway and being safe from incidents' damages are other criteria which the authors defined.

Described earlier, one of the characteristics of large-scale emergencies is the uncertainty of demand. In order to control for this uncertainty, authors use Failure Modes and Effect Analysis (FMEA) technique. "The FMEA process is a way to identify the failures, effects, and risks within a process or product, and then eliminate or reduce them" (McDermott et al, 2008, 10). FMEA process follows several steps, including:

- identifying potential failures
- determining the potential effects of each failure mode
- ranking the effects based on severity
- giving occurrence likelihoods to each failure mode
- allocating detection likelihood (to determine how likely it is to detect a failure or its effect), and

- Computing the risk priority number for each failure mode which is the multiplication of severity, occurrence likelihood and detection likelihood (McDermott et al, 2008).

For this purpose, two parameters of β_{ik} and e_{ik} are introduced (Jia et al, 2005). The former is the occurrence likelihood of large scale emergency *k* in a certain demand point of *i*. The latter is the impact of the emergency *k* on demand point *i*. While M_i is the population demand point *i*, the expected demand at point *i* in case of large emergency *k* can be calculated by $\beta_{ik} \times e_{ik} \times M_i$. To implement their studies, authors divided Los Angeles area to seven demand zones in order to solve the facility location problem for three different large scale emergencies based on their characteristics. The demand for each zone is aggregated in the center of that zone. Furthermore, it was assumed that only four locations can be opened anywhere among these seven demand zones. Based on Jia et al (2005), the three large scale emergencies are dealt with as follows:

- Dirty bomb attack: in case of such an emergency which has a radiological contamination risk, it is better to use proactive approach to stock up anti-radioactive drugs at facility site. Moreover, Maximal Covering model is the best solution for dirty bomb attacks since the objective is to cover the demand as much as possible. After defining the demand weight of each seven zones (based on likelihood, impact and the population of each demand point), the required number of facilities for each zone and its maximum distance to demand point are estimated. In the end, optimization software is used to solve the Maximal Covering model.
- Anthrax terrorist attack: the best approach for this emergency is reactive approach since there are different types of anthrax which all needs different kind of medications and treatment. Therefore, federal government should first find out the

type of anthrax infection and then provide services. Moreover, it is possible that infectious materials will be sent to different parts to increase the threat because anthrax is not a contagious infection. Hence, the P-center model can be used to minimize the maximum coverage distance and avoid the worst case. However, the total distance traveled from demand points to distribution stages should be minimized by P-median problem if it takes a long time for federal government to detect the type of infection (and therefore, a larger area get involved in anthrax infection due to people's movements). The rest of procedure is the same as the dirty bomb attack procedure.

- Smallpox terrorist attack: smallpox is a contagious disease and spreads quickly. First responders such as medical personnel should vaccinate themselves instantly. Therefore, the proactive approach should be used for the first responders. On the other hand, a mass vaccination should be provided for the whole population which makes it impossible to stock up the supplies. Therefore, a reactive approach should be implemented for the whole population except for first responders. The suitable model for first responders is P-center but the best model for other population is P-median (due to quick spread in larger area). Since the whole population should be vaccinated in this example, the impact and the likelihood of this emergency is equal to 1 for all demand zones. Again, the best locations are determined by using optimization software.

2.3.3 Location of a pediatric hospital in Warsaw

Malczewski and Ogryczak (1990) employed an interactive approach to find best locations for a pediatric hospital in Warsaw. In their approach, analysts and decision makers can impose their

preferences in an optimization problem in order to get the best feasible option. They deployed a multi-objective analysis consisting of minimizing factors such as travel cost, investment cost, operating cost and the environmental pollution of the hospital as well as maximizing users' satisfaction.

At the first stage of their work, they solved each of the optimization functions separately, and investigated the impacts that each optimized function had on the payoffs of the rest of the functions. After providing the payoff matrix, it turned out that there were conflicts among objectives. In other words, when the travel cost was at the lowest (best) possible value, the investment and operating costs had the highest (worst) value in their payoffs indicating that all objectives cannot be optimized at the same time and optimizing some of them makes others worse off. The decision makers can use this payoff matrix to find boundaries for their preferences. In fact, they can find the best value (utopia) and the worst value (nadir) of each objective and based on some prior knowledge, they can set the aspiration (or desired outcome) and reservation (or minimum requirements) levels between utopia and nadir points.

In the second stage of the work, multi-objective optimization narrows to single-objective optimization. In other words, the optimization problem, which should be solved by the computer, is now minimizing the deviations from decision makers' expectations. If the decision maker finds the solution unsatisfactory, they can change the aspiration and reservation levels until an efficient solution is determined.

2.3.4 Facility location of preventive healthcare in Alberta

Gu et al (2010) investigated the best location for breast cancer screening program in Alberta. Increasing patients' participation gains importance in the Preventive Health Care Facility

Location (PHCFL) problems since it promotes individuals' quality of life. Hence, accessibility of preventive healthcare services should be increased in order to maximize participation. The authors have defined the accessibility in two following steps. In the first step, the ratio R_j which is the facility-to-client ratio should be calculated for each candidate facility locations as follow:

$$R_j = \frac{1}{\sum_{d_{ij} \leq d_0} P_i}$$

P_i : is the clients from demand zone *i*,

d_{ij}: is the distance between facility at candidate site *j* and demand point *i*

d_0: is the maximum distance that a client would travel

This equation is an indicator of regional availability of facilities (Gu et al, 2010). As the number of clients increases, the facility-to-client ratio drops. In the next step, the accessibility can be calculated for each demand point from the following formula:

$$A_i = \sum_{d_{ij} \leq d_0} \frac{R_j}{d_{ij}} Y_j$$

Y_j: is equal to 1 if a facility is located at site *j*; otherwise, is equal to zero

The authors state that the inverse relation between the traveling distance and accessibility explains that not all the clients living within d_0 kilometres from the facility share it the same as each other. In fact, as the distance to facility increases, the clients use that facility less. Therefore, if the number of facilities located within d_0 kilometres from the population center increases, the probability of participation goes up.

Afterwards, the authors used two optimization objectives, efficiency and coverage, in order to solve this PHCFL problem. Maximizing efficiency means maximizing "social welfare" and maximizing the coverage means maximizing the number of clients served (Gu et al, 2010, 6). The bi-objective problem is formulated as follow:

$$Max(\sum A_i P_i + \alpha \sum P_i)$$

The first part of the objective function is to optimize the efficiency by "maximizing the population-weighted accessibility" (Gu et al, 2010, 6). The second part involves maximizing the covered population. The coefficient α shows the degree of importance for coverage or efficiency. In other words, if the efficiency is the only important objective in PHCFL problem, then α should be equal to zero and as the α increases, coverage gains importance.

3.0 Saskatoon Health Region's homecare program and the overall flow in the system

SHR's homecare program is responsible for providing a variety of services for elderly as well as recently discharged patients from acute care. These services can be divided to two groups of home services (such as personal care, in-home respite, meal preparation, security calls and home management) and nursing (such as caring for discharged patients from acute, providing treatment and intravenous for patients, taking care of wounds and medications)[1].

The eligibility of the client for the use of homecare services is determined by Client/Patient Access Services (CPAS) division. At the first stage of the flow, the client is introduced to CPAS by community (his/her families, friends, or physicians) or by hospital (after being discharged from acute hospital). After assessing each client needs, CPAS staff recognize the best caring option which meets clients' needs. In other words, CPAS staff members provide access to and determine eligibility for:

Special Care Homes:

- *Permanent admission*
- *Planned respite*
- *Unplanned respite*
- *Community Day Programs*

Home Care:

- *Nursing*
- *Home Services*
- *In Home Respite*
- *Meal Preparation*
- *Nutrition*

[1] For more information regarding Saskatoon Homecare program services, please refer to Saskatoon Health Region. " Homecare Support Services, http://www.saskatoonhealthregion.ca

Community Therapies:

- *Physical Therapy*
- *Occupational Therapy*
- *Social Work*

Community Volunteer Services:

- *Meals on Wheels*
- *Transportation* **(Source: http//www.saskatoonhealthregion.ca)**

If a client is admitted for homecare services, his/her preliminary care plan will be determined by CPAS staff. Afterwards, CPAS sends clients' care plan to information staff that are responsible for entering the information in to homecare data base (Procura). This information then will be sent to each quadrant manager.

SHR scope includes city of Saskatoon, Martensville, Warman, Borden, Langham, Delisle and Dundurn but excludes Rosthern, Duck Lake, Humboldt, Nokomis and Lanigan. In order to manage the demand effectively, this scope is divided to four quadrants (North West (NW), North East (NE), South West (SW) and South East (SE) (Appendix B)). SHR's homecare program has assigned two managers to each quadrant for morning shift and one to all quadrants for evening shift. Quadrant managers reassess each care plan in more depth to decide which clients remain in the homecare for service and also prioritize clients based on their requirements so that whenever they are facing lack of caregiver, they send staff to clients with highest priority. They also build a more detailed care plan for each client which includes such details as the required services, client's preferences for caregiver gender, the time that client wants to be visited, the types of equipment which client needs for convenience, and the length of time that client needs the service.

Determined care plans go to quadrant schedulers. Each quadrant is divided to several caseloads to which both staff and clients are assigned. Since clients are willing to be visited by the same nurse or HHA every day, staff members are permanently booked for each neighborhood.

At the beginning of each shift, HHAs and nurses come to home base in Idylwyld Center to pick up their schedules and by the end of the day come back to home base. There are times that some staff are not available or the demand volume is so high that schedulers face difficulties in meeting the demand. This problem is such that sometimes they cannot assign another staff working in the same caseload or even neighborhood. Therefore, it sometimes occurs that a staff should travel from west all the way to east and visit the client and again travel back to his/her own assigned neighborhood. Also, every time that a client cancels his/her appointment and the assigned staff becomes free, he/she should call back the home base to see if there are any urgent calls from other clients or any unscheduled visits to take care of. If there were no other demands they are required to come back to home base until their next appointment. Whether they use their own car or company designated taxi, all employees are paid based on the travelled mileage. The rate of traveling is different for HHAs and RNs. For any traveled distance up to 9.12 kilometres, HHAs are paid a fixed amount of $3.50 and above that, the rate is $0.38 per kilometres. Nurses are paid a fixed amount of $4.50 for traveled distances below 11.37 kilometres and for higher mileage, the rate is $0.40 per kilometres. All nurses and HHAs have 15 minutes time to leave one client's home and get to the other one.

The last stage of the process is billing. Timekeepers receive the information and data related to the visits made by staff, check any changes in the visit durations and other adjustments and

finally, send the verified and adjusted information to accountants for billing the clients (for the process map of the overall flow in the SHR's homecare program, please refer to Appendix C).

3.1 Motivations for decentralizing home base

There are several reasons which create the need for decentralization of homecare:

1) Reducing traveling time and cost. Based on the information provided by Saskatoon Homecare director, Home Health Aides (HHA), nurses and CPAS staff members are traveling about 3,000,000 kilometres per year which reflects the high volume of redundant traveling. There is a large variation in the length of the trips for the first and the last trip of the day. It can be less than one kilometre or more than 50 kilometres. But its median is between 15 to 18 kilometres per day. The average length of trips from one client's house to the other is 4 kilometres and the average total number of visits completed by HHAs is 950 per day, and that by RNs is 575 per day. As mentioned before, the staff members are reimbursed based on traveled mileage. Based on the information provided by the director of Saskatoon Homecare program, they are spending almost $2,000,000 per year above the assigned budget. By decentralizing the current homecare, staff can provide more of high quality services, save more time and increase the client load while the traveling cost is diminished significantly.

2) Reducing downtime and increasing efficiency. Due to difficulties in staff's scheduling and sending them from the only existing center to the clients' homes, there are 50% hands-on-time on average. This percentage includes only the time which takes to provide service. The other 50% which is considered as downtime includes traveling time to clients' homes, coffee and lunch breaks. Since traffic is increasing in Saskatoon, the

average hands-on-time is decreasing over time which is why Saskatoon Health Region is assessing different projects to increase the average hands-on-time to at least 60%. The 60% average hands-on-time is not based on a national standard or benchmark but simply, a goal for Health Region to strive to achieve. By adding new locations, scheduling gets easier since staff who are working for each location can be effectively scheduled to serve the surrounding neighborhoods and possibly, traveling time and downtime would be reduced.

3) Covering the demand and dealing with population growth in Saskatoon. Based on the City of Saskatoon website, the estimated population of Saskatoon in 2011 is 234,200 and it is projected that the population will reach 303,444 by 2026. Therefore, traffics are expected to be heavier and time wasted on the road in the traffic is increasing because of the population growth. Moreover, based on Saskatoon Speaks (2011), the percentage of senior residents over the age of 65 in Saskatoon will almost double and increase from 13% in 2011 to 24% in 2026. Therefore, the aging population of Saskatoon results in a growing demand for homecare services. The current home base which is located in Idylwyld Drive also does not have the potential for expansion. Based on statistics provided by Homecare, from 2008 to 2010, the demand for Registered Nurses (RNs) and HHAs is increased by almost 20% and 15% respectively. In order to cover more demand from different parts of the city, SHR is considering increasing the capacity by adding clinic space to its potential locations. Hence, mobile clients can come to caregivers and staff will be sent only to immobile clients. In this way, less time will be wasted on the road and more clients can be visited per day.

4) 25th Street extension and lack of parking stalls. SHR also wants to avoid problems associated with the extension of 25th Street such as reduction in the number of parking spaces for staff and increase in the traffic of the mentioned district.

5) Staff members' satisfaction. Most of HHAs and RNs use their own car to travel to clients' houses. Although they are reimbursed for their traveling, based on Canadian Automobile Association (CAA), the reimbursement they receive is less than the average cost of operating, ownership and maintenance of the car[2]. Based on a research done by Canadian Union of Public Employees (CUPE) in 2002, the mentioned amount is approximately, $5,600 per year. Therefore, poor scheduling or excessive traveling brings dissatisfaction to HHAs and RNs. By reducing the distance traveled either by decentralization or by improving the scheduling, staff can be more satisfied.

SHR's homecare program is willing to find the best sites, if any, from five proposed locations. These potential locations include Lawson Heights Mall, Confederation Park Mall, University Heights Square, Market Mall and Avenue H South (Appendix A). Except for the number of opened satellites and their optimum lactations, determining the capacity and the volume of required staff are also desirable.

Along with the decentralization project, Saskatoon Health Region is also considering another alternative for decentralization which is implementing technology such as BlackBerrys or tablet PCs. Nurses and HHAs who go to the field can receive updated schedules and any information related to the client. Therefore, they only have to go to home base one time by the end of the day to just pick up the required supplies. In this way, more time can be saved on the road and more

[2] Based on Canadian Union of Public Employees (CUPE) website: http://cupe.ca/homecare/saskhomecare

clients can be visited. This is considered as another cost and benefit study which is out of the scope of this thesis project.

4.0 Data and Variables

In order to proceed with finding the best set of locations, the first step is to identify residential neighborhoods in Saskatoon. The whole studied neighborhoods sum to 64 from which 32 are located on the east side of the Saskatchewan river (eastside neighborhoods) and the rest are on the west side of the river (Westside neighborhoods). There are five proposed locations for the new homecare office. Using Google map, the distance travelled between any of the proposed locations and the center of each neighborhood is computed assuming that the demand at each neighborhood is aggregated at its center. The reason for aggregating the demand at the center of each neighborhood is to deal with variation in clients over time. For destinations with more than one route, the minimum travelled distance is used assuming that staff members pick the shortest path to destination. Moreover, the coordinates of the center of each neighborhood is determined using a City of Saskatoon's map and is reported in centimetres. This information is useful when we use the Center of Gravity method to find the best location in space.

Another piece of data which is important for choosing the best locations from proposed sites is the lease cost per square foot of space for each site. For this purpose, we use information from two different Saskatoon real estate websites[3]. First, we identify all properties available for lease which are located in any of the five proposed locations. Then, we estimate the lease cost for each location by taking the average of lease costs per square foot for all the properties in that location.

Another important piece of information is each neighborhood's demand for services of HHAs and RNs. This was provided by the Saskatoon Homecare director and financial assistant. The client loads for both HHAs and RNs are reported based on annual number of visits. They

[3]The two mentioned websites used for estimating the lease cost per square foot are:
http://www.collierscanada.ca/en/Offices/Saskatoon and http://www.icrcommercial.com/

also provided information such as average number of visits per day, fixed and variable travel rate and minimum kilometre required for HHAs and RNs as well as total number of currently working HHAs and RNs. The daily average visits are about 9.5 and 12 for HHAs and RNs respectively. For any traveled distance below 9.12 kilometres, a HHA is paid $3.50 and above that minimum required kilometre, the variable traveling rate is approximately $0.38. Likewise, the minimum required traveled distance for nurses is 11.37 and fixed and variable travel rate are $4.50 and $0.40 respectively. The daily average of HHAs currently working at Saskatoon Health Region is 218.4 as well as 88.4 RNs.

5.0 Implementing OR methods for solving the facility location problem

In this section, two different OR methods are used in order to decentralize the current homecare in Saskatoon. In the first method, we want to find one best location in space using the Center of Gravity and the formulation provided by Sule (2001). In the next part, by using a P-median model, different best locations are determined considering different number of open sites allowed. The procedures and formulation of P-median model is inspired from Daskin and Dean (2004). As mentioned before, the current location of Saskatoon homecare is on Idylwyld Street. Based on the current information and assumptions, the traveling cost for both HHAs and nurses from the current home base to different neighborhoods is approximately $377,883 per year and the traveling distance is estimated to be 820,155 kilometres per year. In each proceeding sections, the effects of decentralization on cost is assessed and compared to the situation in which Health Region stays with a centralized home base for its homecare.

5.1 Center of Gravity method

Based on Center of Gravity method, we only want to minimize the demand-weighted average distance between center of each neighborhood and the homecare site (Daskin and Dean 2004). Therefore, the only required variables in this method are demand at each neighborhood (aggregated at the center of the neighborhood) and their coordinates in the plane. The notations for discussed variables are as follows:

d_i : Aggregated demand in the neighborhood *i*

x_i and y_i : the coordinates of demand point *i*

x and y: The best coordinates of the new location in the space

Using the procedure from Sule (2001), the best location for homecare in Saskatoon can be found using the following formula:

$$x = \frac{\sum_{i=1}^{n} d_i x_i}{\sum d_i} \quad , \quad y = \frac{\sum_{i=1}^{n} d_i y_i}{\sum d_i}$$

After using the formula, we realize that current Idylwyld Center is not the best location which minimizes the demand-weighted average distance. The best site is located close to Varsity View neighborhood within 3 kilometres from current homecare (Appendix D). If the home base was located in this neighborhood instead of Idylwyld Drive, there would have been about $15,934 less annual expenditure on traveling and about 21,754 kilometres less traveling per year between neighborhoods and the home base. With the assumption that staff members travel with a speed range of 30 to 50 kilometres per hour, the saved traveling distance would be equivalent to 435 to 725 hours saved per year which can be devoted to more clients. However, since Health Region owns the current site and is not planning to sell or rent out the place, two other options are evaluated. The first option is to rent an office on the east side of the city which would be responsible for providing services to the east while Idylwyld Center takes care of demands from west. The second option is to open two sites on the east; one would cover the demand from northeast and the other one from southeast, while Idylwyld Center is still responsible for the demand from west.

In the first option, the Center of Gravity method chooses Brevoort Park neighborhood as an appropriate location for providing services to the clients residing in the east side of the city (Appendix E). This option reduces annual distance travelled by 311,996 kilometres and saves $48,851 on traveling per year. However, lease cost for this option should be considered. Based on homecare director's suggestion, all sections in current home base will be decentralized and if

they open one new site, that site will approximately have a half of Idylwyld Center square foot area (which is currently 17912 square feet). Considering an average lease cost of $25 per square foot for the site in Brevoort Park neighborhood, the reduction in driving distance does not cover the lease cost for the new location. However, it cannot be denied that the reduction in traveled distance is equivalent to reduction in the annual hours wasted on the road by 6,240 to 10,400 hours (with the assumption that staff travel with a speed range of 30 to 50 kilometres per hour). Using a rough estimation for average length of visit (provided by Saskatoon homecare director), which is about 0.5 hour, the number of visits per year can increase by 16,640. Moreover, there would be an increase of 3.25% in capacity and an average of 2.70 % increase in hands on time which is lower than what they are aiming for.

In the second option, the demand from northeast can be covered by the site in University of Saskatchewan South Management area and that from southeast can be covered by an office located in Nutana S.C. neighborhood (Appendix F). With this option, annual traveled distance decreases by 290,066 kilometres, traveling cost is saved by $52,850 and 5,801 to 9,669 hours is saved per year. Again, based on homecare director's suggestion, the square foot area of each of these sites will be a quarter of the square foot area of the current home base. Therefore, the lease cost is $255,246 per year which obviously exceeds the reduction in traveling cost. However, the increase in capacity (which is about 3.02%) along with reduction in traveling cost might cover the lease cost. As expected, the traveling expenses reduce when the number of open facilities increases. In this especial case, the distance travelled increases when we switch from two to three open facilities. The main reason for this is inefficient assignment of neighborhoods to open facilities. In other words, since we assumed that the facility located in Nutana S.C. is responsible for providing services to the southeast of the city, even if a neighborhood is closer to Idylwyld

Center, we still assign staff members from the facility in Nutana S.C. to cover for that neighborhood. The table in Appendix G summarizes all the related information such as annual traveling, lease and total costs, annual travelled distances, hours saved on the road compared to the current situation and the percentage change in capacity.

5.2 P-median model

As described before, the three major facility location models in discrete space are Set Covering model, Maximal Covering model and P-median model. The first model is appropriate for determining the location of an emergency service facility, where the objective is to minimize the maximum distance traveled between the facility and any customer and consequently, increasing the accessibility for customers. Since Homecare program is not dealing with any emergencies, this model is not used for current homecare issue. In addition, minimizing the maximum distance does not necessarily minimize the cost of sum of travelled distances which is necessary for cost minimization. In other words, if we assume that a facility is located in the center of a circle and covers the demand for all neighborhoods which lie within a given radius from that facility, the Set Covering model chooses the best location such that all the neighborhoods can be located within the area of that circle. Therefore, it only minimizes the maximum distance between facility and demand points regardless of all required traveling between them. That is why this model is not used for cost minimization of our problem.

In the second facility location model, the objective is to maximize the demand covered. The main reason that this model is not chosen for finding the best locations for new facilities is that the objective function differs from the objective of SHR which is minimizing total cost.

Therefore, maximizing the covered demand does not necessarily mean that total cost is minimized.

The location-allocation model used for this purpose is P-median model which is appropriate for determining the location of facilities, where the objective is to minimize total distance traveled between facilities and any clients. The P-median model described by (Daskin and Dean, 2004) is developed based on our facility location model requirements and assumptions as follows:

$$Minimize\ z = \sum_{j=1}^{6}(C_{ij}{}^{HHA}S_{ij}{}^{HHA} + C_{ij}{}^{RN}S_{ij}{}^{RN}) \times 365 + \sum_{j=1}^{6} L_j X_j \quad (1)$$

Subject to:

$$\sum_j S_{ij}{}^{HHA} \geq d_i{}^{HHA} \qquad \forall\ i \in I \quad (2)$$

$$\sum_j S_{ij}{}^{RN} \geq d_i{}^{RN} \qquad \forall\ i \in I \quad (3)$$

$$Min_j^{HHA} X_j \leq \sum_i S_{ij}{}^{HHA} \leq Max_j^{HHA} X_j \qquad \forall\ j \in J \quad (4)$$

$$Min_j^{RN} X_j \leq \sum_i S_{ij}{}^{RN} \leq Max_j^{RN} X_j \qquad \forall\ j \in J \quad (5)$$

$$\sum_i \sum_j S_{ij}^{HHA} \leq 128 \qquad \forall\ j \in J\ ,\ \forall\ i \in I \quad (6)$$

$$\sum_i \sum_j S_{ij}^{RN} \leq 88 \qquad \forall\ j \in J\ ,\ \forall\ i \in I \quad (7)$$

$$\sum_{j=1}^{6} X_j = P \qquad P \in \mathbb{N}[1,6] \quad (8)$$

$$S_{ij}{}^{HHA} \in \mathbb{N}^0 \qquad \forall\ j \in J\ ,\ \forall\ i \in I \quad (9)$$

$$S_{ij}{}^{RN} \in \mathbb{N}^0 \qquad \forall\ j \in J\ ,\ \forall\ i \in I \quad (10)$$

$$X_j \in \{0\ ,1\} \qquad \forall\ j \in J \quad (11)$$

where:

C_{ij}^{HHA}: Cost of traveling from facility site *j* to demand point *i* for a HHA

C_{ij}^{RN}: Cost of traveling from facility site *j* to demand point *i* for a registered nurse

S_{ij}^{HHA}: Number of HHAs should be sent from facility site *j* to demand point *i* each day

S_{ij}^{RN}: Number of registered nurses should be sent from facility site *j* to demand point *i* each day

Max_j^{HHA} and Max_j^{RN}: Maximum number of HHAs and RNs considered for facility site *j*

Min_j^{HHA} and Min_j^{RN}: Minimum number of HHAs and RNs considered for facility site *j*

$X_j = 1$ *:* if facility is placed at location j; otherwise it is 0

L_j : Annual lease cost associated with location *j*

d_i^{HHA}: Daily demand for HHAs from neighborhood *i*

d_i^{RN}: Daily demand for RNs from neighborhood *i*

P: Number of open facilities

In order to minimize the objective function, Premium Solver finds the best location, as well as the number of RNs and HHAs that should be sent from each facility location to the center of each neighborhood. The fixed and variable traveling cost for HHAs and RNs differs from each other and is calculated based on the following cost function:

$$C_{ij}^{HHA} = \begin{cases} \$3.5 & 2\,y_{ij} \leq 9.12 \\ \$3.5 + (2\,y_{ij} - 9.12) \times \$0.38 & 2\,y_{ij} > 9\,.12 \end{cases}$$

$$C_{ij}^{RN} = \begin{cases} \$4.5 & 2\,y_{ij} \leq 11.37 \\ \$4.5 + (2\,y_{ij} - 11.37) \times \$0.40 & 2\,y_{ij} > 11.37 \end{cases}$$

y_{ij} is the distance traveled from facility location j to demand point i in kilometres. Since scheduling, sequencing and vehicle routing is not in the scope of this thesis, for calculating transportation cost, it is assumed routes that staff members choose are random and are not predetermined. So , if demand per day at neighborhood A was smaller than the average demand that a HHA covers on average per day, then the HHA should go from neighborhood A to B, to visit other clients. However, we are calculating round trip from Idylwyld Center to neighborhood A plus round trip from Idylwyld Center to neighborhood B while the actual way of evaluating distance would be to calculate distance from Idylwyld Center to neighborhood A, plus the distance from neighborhood A to neighborhood B, plus the distance from neighborhood B back to Idylwyld Center. Considering a round trip instead of one way trip is necessary since all staff members are required to come back to Idylwyld Center at the end of the day or when their appointments are canceled. Therefore, the calculation of traveling cost gives us an approximation of the transportation.

Another assumption which is made is that the only fixed cost which we consider is the lease cost. The operating cost is assumed to be the same for all six locations. As mentioned before, the lease cost per square foot is the average of available costs of similar properties located near each of six potential locations which were found in two Saskatoon real estate websites. The total area

required for each facility location depends on the number of open facilities as well as the maximum number of staff required to cover the demand for the close neighborhoods. For example, if it is desired to open four facilities, first, all different combinations are considered (which in this example is 15 different combinations). Then, the size for each site in any of those combinations is determined. After assessing all of these combinations, we find the maximum size that a facility should have. By dividing the derived size to 211 (which is the sum of 128 HHAs and 83 RNs) and multiplying it by 17912 (which is the current square feet area in Idylwyld Center) the square foot area for each location is determined.

Constraints (2) and (3) are used to make sure that the number of staff sent from all open locations to each neighborhood is such that the demand of that neighborhood is fully covered. The annual demand from each neighborhood is provided by the Saskatoon homecare program as well as the average number of visits per day made by HHAs and RNs. Therefore, the daily demand is calculated as follows:

$$d_i{}^{HHA} = \frac{Annual\ (d_i{}^{HHA})}{365\times 9.45}$$

$$d_i{}^{RN} = \frac{Annual\ (d_i{}^{RN})}{365\times 12.09}$$

9.45 and 12.09 in denominators show the average daily number of clients visited by a HHA and an RN respectively. In constraints (4) and (5), we want to prevent assigning the demand to a location without any facilities in it. Moreover, a maximum and a minimum bound have been defined for each open facility. We calculated the upper bound by multiplying the maximum capacity of facility at location *j* by the decision variable X_j. As explained before, the maximum and the minimum number of staff required are derived by comparing different combinations of

open facilities and finding the minimum and maximum demand covered by each facility for each different number of open facilities. In order to avoid the inefficiency in assigning just a few staff to an open facility with a large square foot area, the lower bound is calculated for each facility in a similar way (multiplying the minimum capacity of facility at site j by decision variable X_j). However, if there is no facility located at site j, both upper and lower bounds are zero (since X_j is equal to zero) and the model will not assign any staff to that facility location. Constraints (6) and (7) are also used to limit the total number of HHAs and RNs sent from all open facilities to all neighborhoods.

Variable P shows the number of facilities which are required to be open and constraint (8) is used to ensure that the number of facilities to be open meets this requirement. From now on, all of the sensitivity analysis as well as the main model are performed for P from one to six in order to determine the best number of facilities which ought to be open.

Constraints (9) and (10) are used to assign natural numbers instead of decimal fractions when finding the best number of staff to be sent from each location. Finally, bound (11) is about the binary open-close decision variable.

The best locations for different numbers of P, annual cost, allocation of staff members to different facilities, the hours saved per year and the percentage increase in capacity by choosing each option are shown in Appendix H. As was expected, the annual transportation cost, as well as traveled distances, decreases as the number of open facilities goes up. However, we cannot determine with certainty the effects of increasing the number of open facilities on the lease cost. On the one hand, it can increase the lease cost because of having more open facilities, but on the

other hand, it can reduce the lease cost since the lease cost is also related to the maximum size of the facility (which decreases as the number of open facilities increases).

No matter how many facilities are open, since Saskatoon Health Region owns Idylwyld Center and as they do not incur any lease cost for that site, this location is always one of the best locations to keep open. In terms of annual cost, the best number of open facilities is one since the total annual cost is the least for one open facility. However, if Saskatoon Health Region wants to decrease time spent on the road and increase the capacity, they should definitely decentralize to more than one location and the best number of open facilities can be based on their budgets and the revenue that decentralization brings to them. Annual transportation cost is the highest when there is only one facility open ($377,883) and the lowest when all of the six facilities are open ($301,375). After the Idylwyld Center, the University Heights Square (located on east side of the city) is the second best location for new facilities due to its lowest lease cost among all. Since the demand covered by the facility on this site is lower than that of the other sites, the maximum facility size is lowest for University Heights Square. That is the reason for having the lowest lease cost for the facility on University Heights Square. By the same logic, the last suitable place for new facility is Market Mall. Although facility located in Market Mall covers a huge portion of demand and can decrease the traveling cost significantly, high facility size increases the lease cost such that it is not beneficial to open a new facility in this location which is why Market Mall is the sixth best location for a new facility. The third best place for new facilities is located on the west side of the city and is Confederation Mall. Although it might look like having one location is still the most advantageous option for Health Region in terms of cost, we cannot make such a conclusion with certainty since the revenue caused by the increase in demand coverage (as a result of decrease in the traveled distance and wasted time on the road) cannot be calculated and

is out of the scope of this project. However, comparing P=1 and P=6, we can see that 431,467 kilometres would be saved during the year which is equal to 8,629 to 14,382 saved hours if the staff travel with 30 to 50 kilometres per hour. As a result of decentralizing in all of the six locations, the average number of visits increases by 4.5% per year and the average hands on time increases by 3.73%.

5.3 Sensitivity analyses

Due to limitations in the study of the current homecare decentralization problem, it is appropriate to perform a few related sensitivity and scenario analyses. These analyses can help to predict the potential locations assuming increase or decrease in demand, increase or decrease in the capacity and increase or decrease in the lease cost. In addition, we would perform a couple of tests to see where the best locations would have been if we had ignored the lease cost or assumed that there was no current location available on Idylwyld Drive. All the sensitivity analyses are also redone for two other models; one is without any minimum constraint for facility size and the other is with a fixed minimum facility size. The results of the last two models are described briefly at the end of this chapter.

5.3.1 Average daily number of visits

In this section, an increase and decrease of 20% as well as 10% in the capacity is tested to see if the optimum locations would remain the same or not. All the related information such as best locations for different numbers of P, annual cost, allocation of staff members to different facilities, the hours saved per year and the percentage increase in capacity by choosing each option is provided in Appendices I, J and K.

The results show that by increasing or decreasing the average number of visits per day by 10% or 20%, the best locations and the lease cost do not change. However, allocation of the staff, traveling cost and distances as well as the percentage change in the capacity vary. If the average daily visits increases by 10%, number of RNs and HHAs required is 82 and 120 respectively and if it increases by 20%, those would be 79 RNs and 113 HHAs. Considering the traveling cost, the best number of facilities to be open is still six in all of the mentioned sensitivity analyses regarding variation in average daily number of visits. And Idylwyld Center is still the best site while Market Mall is the worst for locating new facilities due to the previously mentioned reasons.

If the average daily capacity decreases by 10%, 86 RNs and 134 HHAs are needed to cover the demand and if it decreases by 20%, the number of RNs and HHAs should be 92 and 149, respectively. Since there are already 218 HHAs working per day, there would not be any problems in covering the demand for HHAs in both scenarios. However, the demand coverage for nurses would be problematic in case of 20% reduction in average daily visits covered by RNs. Due to this reason the model cannot find any feasible solution to meet all the requirements which means that in this case, homecare program should employ more nurses to cover the demand.

5.3.2 Annual lease cost

One of the important factors in facility location problems is lease cost which is imposed to lots of fluctuations and uncertainties. In this sensitivity analysis, the impact of increase and decrease of 20% in lease cost is examined. In this section, the selections of locations as well as traveling cost are the same for both decrease and increase of the lease cost and all are similar to

those in the main model. Moreover, the increase in capacity also remains the same in both cases. Decentralizing into six locations still can reduce the traveling cost by $76,508 compared to having a single home base in the city. In this case, the average hands on time increases by 3.73% and the average covered demand increases by 4.50%. Deriving similar results is suggesting that if Health Region locates new facilities in the best sites determined by the model, they can be sure that fluctuations in lease cost will not make them relocate to another location down the road. For further information regarding best locations for different numbers of P, annual cost, allocation of staff members to different facilities, the hours saved per year and the percentage increase in capacity by choosing each option, please refer to Appendices L and M.

5.3.3 Future demand change

As mentioned before, Saskatoon has an aging population (Saskatoon Speaks, 2010). Some neighborhoods have higher rates of demand growth than other regions in the city, but it is nearly impossible to predict the rate of growth for each neighborhood. However, Homecare program has a rough estimation of the annual increase in total demand for RNs and HHAs which is approximately, 4% and 12% respectively. Therefore, the next sensitivity analysis is about the impact of demand increase on the location of the new facilities. By increasing the demand of HHAs (by 12%) and RNs (by 4%), 131 HHAs and 86 RNs are required to be working for Health Region. Since currently they have enough working staff, they do not need to increase the labor work in short-term and since the best locations remained the same after increasing the demand, they can rely on the locations found by the original model to establish their new facilities. Based on the results, if they decentralize into six locations, the annual traveled distance would be halved, the capacity increases by 4.71% and the average hands on time increases by 3.91%. Similar to the main model, since Idylwyld Center does not incur any lease cost, it has the lowest

annual total cost of $388,930 among all of the different numbers of P. As mentioned before, if Saskatoon Health Region wants to decrease time spent on the road and increase the capacity, they should consider decentralization provided that the increase in revenue covers the increase in cost. Please refer to Appendix N for any information about best locations for different numbers of P, annual cost, allocation of staff members to different facilities, the hours saved per year and the percentage increase in capacity by choosing each option.

5.3.4 Greenfield project

In this section, we want to know where the best locations are if we assume that there are no existing constructions (and therefore, no lease cost) and we only have to take traveling cost into account. For analyzing the results driven from this section, it is appropriate to know from which neighborhoods the highest demands for homecare services come. By looking at the Pareto chart provided in Appendix T, it can be observed that 70% of the demand comes from 30% of the neighborhoods in the city. Based on Saskatoon Speaks (2011), Nutana S.C., which is on the southeast side of the city, has the highest senior population and based on the data from Health Region, the annual demand for this neighborhood is approximately 83,800 (16.37% of the total annual demand). Central Business District is the second neighborhood with highest demand (46,690 visits per year) which is located in the center of the city. After that, Hudson Bay Park and Mount Royal are two other neighborhoods on the west side of the city which accounts for 41,848 visits per year. Lawson Heights S.C. comes in the fourth place and has an annual visit of 22,460. For more information regarding senior population in the City of Saskatoon refer to Appendix U.

From the results we can observe that for single facility location problem, Idylwyld Drive is still the best option even if there is no lease cost for any of the locations. This is mainly because Idylwyld Drive is closer to the Center of Gravity of the whole city (which is Varsity View neighborhood) compared to other locations. Moreover, it is the closest location to the Central Business District which was the second neighborhood with highest demand.

When two facilities should be open, except for Idylwyld Center, Market Mall is another good location. The main reason that was making Market Mall the least attractive option in previous analyses was that there is a high lease cost associated with this location. Moreover, since the size of the facility is linked to the maximum demand coverage, and also Market Mall has the highest demand to cover, the square foot area of the facility in this location should be the largest. However, when we ignore the lease cost, Market Mall is one of the best locations in multi-facility location problems since it is located in Nutana S.C. neighborhood with highest senior population and highest demand for homecare.

For P equal to three, the best three locations are Market Mall on the southeast (due to mentioned reasons above), Confederation Park on the west and Lawson Heights Mall on the north. From this selection we can conclude that the best locations are scattered around the city for minimizing the traveling cost. Besides, Confederation Park is the closest to Hudson Bay Park and Mount Royal. Lawson Heights Mall is also located in Lawson Heights S.C. which has a high senior population. All of the mentioned neighborhoods (Nutana S.C., Lawson Heights S.C., Hudson Bay park and Mount Royal) accounts for 29% of the total annual visits which means that by locating new facilities in these locations, traveled distances reduce significantly (dropping from 820,155 to 495,634 kilometres). In this case, the average capacity increases by 3.38% and the average hands on time goes up by 2.81%.

When four facilities are required to be open, the best sites are Market Mall, Lawson Heights Mall, Confederation Park and University Heights Square. By adding University Heights Square to the mentioned three best locations, demand from the northeast is also covered and the annual travelled distance reduces by 56,502 kilometres.

By decentralizing into six locations, the traveling cost drops from $377,883 to $301,375 per year and the average hands on time increases by 3.73%. From the tables provided in Appendix O, it can be observed that the cost of traveling for five and six open facilities does not differ from each other. The reason is that the last two locations are Idylwyld Center and Avenue H South which are very close to each other and the allocation of staff is such that only a few HHAs and RNs are sent from Idylwyld Center to Avenue H South. Therefore, the cost of traveling is the same whether there are five or six facilities open. However, the traveling distance reduces slightly when there are six open facilities. The reason that the traveling distance reduces while traveling cost remains unchanged is that the traveling cost function consists of both a fixed and a variable rate of traveling. In other words, as long as the traveled distance falls below the required kilometres (which are 9.12 and 11.37 kilometres for HHAs and RNs respectively) staff members are reimbursed a fixed minimum amount. Since Avenue H South is very close to Idylwyld Center, the traveling cost remains unchanged while the traveling distance decreases.

5.3.5 Omitting Idylwyld Center

In this analysis, it is assumed that there is no current facility and Idylwyld Center is closed. From the tables in Appendix P, it can be observed that Avenue H South is the best location if Idylwyld Center is shut down. The main reason for this selection is that after Idylwyld Center, Avenue H South is the closest location to the Center of Gravity of the whole city. Therefore, by

opening the new facility in this location, annual traveling cost is lower compared to any other location. In addition, the annual lease cost of Avenue H South is very low which makes it an attractive option. After Avenue H South, University Heights Square is the best second option because of its low annual lease cost. Confederation Mall, Lawson Heights Mall and Market Mall all come after University Heights Square. For single facility location problem, the annual transportation cost is $414,389 which decreases as the number of open facilities increases. The transportation cost drops to $301,414 when there are five facilities running in each of the proposed locations. Compared to single facility located on Avenue H South, by decentralizing into five locations, the increase in number of visits will be approximately 5.55% which is equal to 28,381 more clients per year. The travelled distance will be almost halved if we switch from single facility to five open facilities (travelled distance drops from 938,999 to 406,866 kilometres per year) and the average hands on time increases by 4.61%.

5.3.6 Round trip per client analysis

In this section, the goal is to find an upper bound for the cost of traveling and the mileage. Previously, we assumed that each HHA and RN makes a round trip per day to visit as many clients as she/he can. We also assumed that all of the clients in the same neighborhood are aggregated in the center of that neighborhood. Therefore, a part of the traveling distances is ignored due to these assumptions. In this analysis, we assume that for each client in a neighborhood, a round trip is required. In other words, the staff should make a round trip for each of the clients that she/he visits per day. In order to derive feasible solution for this model, maximum and minimum facility size constraints have to be changed. In the tables provided in Appendix Q, it can be observed that the selection of best location changes in this model. The main reason is that more weight is put on traveling cost compared to lease cost since the number

of trips has significantly increased in this analysis. Therefore, Market Mall is the second best location in this analysis since it is located in Nutana S.C. and it can effectively minimize the traveling cost. If we consider round trip per client, the annual transportation cost is $2,583,807 for a single facility located on Idylwyld Drive which is very close to the estimated traveling cost by SHR. The annual transportation cost drops to $2,087,074 by opening six facilities and the covered demand can be increased by 30%. There is also a significant reduction in traveled distance (2,838,970 kilometres per year) if SHR decentralizes the homecare office into six locations.

5.3.7 P-median model without minimum constraint for facility size

In this section, we solve the original model as well as all previous sensitivity and scenario analyses without considering any minimum size for facilities in order to compare its result with that of the main model. Even after omitting the minimum constraint for facility size, the selection of best locations, annual lease and traveling cost remained unchanged for all of the sensitivity and scenario analyses (Appendix R). The reason that the selection of best locations and even the costs did not change in this model is that in the original model, we are imposing variable minimum and maximum facility size which is linked to the minimum and the maximum demand from closest neighborhood to each facility covered by that facility. Therefore, it is inefficient if a facility covers demand above its maximum amount since in that case, it is covering demand from a neighborhood which is not the closest to that facility and increases traveling cost. In this model, Idylwyld Center still is the best location for one to six open facilities and after that are University Heights Square, Confederation Mall, Lawson Heights Mall, Avenue H South and Market Mall. The allocation of staff and the change in capacity varies slightly from the model with minimum facility size constraint which is negligible and similar to them, the most increase in annual visits

happens when there are six open facilities, each in one of the potential locations. With respect to transportation cost and increase in average hands on time, having six open facilities is the best option for SHR. However, the lease cost makes this option less attractive compared to single facility location. This similarity between two models certifies the validity of the selection of best locations.

5.3.8 P-median model with a fixed minimum constraint for facility size

In order to avoid inefficient assignment of staff to open facilities, putting a minimum constraint on the number of staff working at each site is required. As mentioned before, it is not efficient to open a new facility and incur a huge lease cost while only a few staff members are sent to work in that facility. Since the results of the main model and that of the model without any minimum facility size constraint are the same, we decided to run the model with a minimum facility size which is fixed and in most cases is more than the previous minimum number of staff used in the original model. For this purpose, it is assumed that the minimum number of HHAs and RNs allowed working at each location are one sixths of the total number of HHAs and RNs required each day which is 21 and 14, respectively. From the tables provided in Appendix S, it can be observed that the selection of best locations is the same as that of the original model (with variable constraint for minimum facility size). The only difference in the selection of best locations is in Greenfield project (for four and five open facilities) in which we do not consider any lease cost for any locations. When we have four open facilities and we solve the model with a fixed minimum size constraint, the annual cost of traveling is $311,746 and the best locations are Idylwyld Center, Confederation Mall, Lawson Heights Mall and Market Mall. But when we solve the same model with a variable minimum constraint for facility size, we realize that the annual transportation cost is less and about $301,929 and instead of Idylwyld Center, University

Heights Square is chosen as the best location. A similar result can be observed when five facilities are open. In this case, the annual transportation cost for the original model is $301,375 which is less than that of the model with fixed minimum facility size by $10,438. As mentioned before, the way that the variable minimum size is defined is that for any number of open facilities, different combinations of locations are assessed and the minimum possible number of staff required for each location is found. The reason for the increase in the annual transportation cost in the second model is that a fixed minimum facility size is determined for the model which in some cases is higher than the variable minimum size. In order to meet the minimum size constraint, some inefficiency emerges in staff allocation. When it is required to have an open facility in each of the six locations, Premium Solver cannot find any feasible solution since minimum facility size exceeds the maximum facility size.

6.0 Comparing results from Center of Gravity and P-median model

For single facility location problem, the results derived by two models are almost the same. The limitation in comparing these two models is that in P-median model, there are six locations determined beforehand but in Center of Gravity there is no limitation and the facility can be located anywhere in the plane. Based on the Center of Gravity, the best location is in Varsity View neighborhood which is closest to Idylwyld Center (the best location using P-median model) compared to other five proposed locations. Compared to Idylwyld Center, $15,934 can be saved annually, if the facility was located in Varsity View. Moreover, the traveling distance could be less by 21,754 kilometres per year. This reduction in distance travelled is equivalent to 0.23% increase in demand coverage which is negligible.

For multiple facilities location problems, these two models cannot be compared since Center of Gravity model is only used for single facility problems and in order to find the other best location by this model, some other assumptions should be made. For example, we assumed that Idylwyld Center would be responsible for covering the demand from west side of the city therefore, we ignore the west side to find Center of Gravity for east side of the city. Beside these assumptions, the lease cost cannot be taken into account when Center of Gravity model is used and the way the lease cost is calculated in this method differs from that in P-median model. Lease cost is an important factor which makes University Heights Square an attractive location for opening the second new facility using P-median model. And for three open facilities, the other location based on P-median model is Confederation Mall. The transportation cost for P-median model turns out to be higher than Center of Gravity method when two or three facilities are open which is due to opening new facilities in locations not close to Center of Gravity. When two facilities are open, based on the Center of Gravity method, those two locations are Idylwyld

Center and Brevoort Park neighborhood on east (close to Market Mall) and the transportation cost is $329,032 which is less than that of P-median model by $25,176. Moreover, the increase in capacity for this case in Center of Gravity method is 3.25% while for P-median model is 0.93%. For three open facilities also the transportation cost is $24,101 less for Center of Gravity compared to P-median model.

7.0 Assumptions, limitations and future work

There are several limitations while solving facility location problems. One of the most challenging limitations is predicting each neighborhood's demand for Homecare services. As mentioned previously, the demand growth rate is not the same for different neighborhoods and if Health Region had access to that information, more precise results could be derived by using facility location models. By performing the sensitivity analysis related to increase in demand, we can be confident that our sites determined by the original model are indeed accurate. Recall that we are assuming the demand increases are the same for all neighborhoods.

Regarding the traveled distances we have to assume that staff pick the shortest route when they are traveling from Idylwyld Center to clients' home and back again to Idylwyld Center. Besides, we assume that the shortest path is always fixed and they do not waste any time on the road except for traveling time. In reality, however, it is possible that staff pick a different and probably longer route in days with higher traffic or when there is a construction along the shortest route.

Moreover, we assume that routes are chosen randomly and they are not predetermined since scheduling, sequencing and vehicle routing is not in the scope of this thesis. For example, assume that a HHA should go to neighborhood A to cover the demand which is lower than the average number of visits she makes per day. Essentially, she should travel from there to neighborhood B to cover the demand for remaining time of the day and then travel back to home base. Due to the mentioned limitation, we can only assume that she travels a round trip to neighborhood A and then another round trip to neighborhood B. In addition, since we are not dealing with scheduling inefficiencies, we ignore the traveling costs along the way to different clients' homes. Another assumption we make is that if a demand from a neighborhood is below

the average visits per day, only one staff will be sent to that neighborhood. However in reality, sometimes more than one staff are sent to that neighborhood to cover the demand due to inefficiencies in staff scheduling. The main reason for this inefficiency is that matching the schedule of client with that of a HHA or an RN is a difficult task especially when clients are dynamically changing and some new clients enter to the system or some others leave it. Moreover, sometimes there are canceled appointments or emergencies to be covered which makes it even more difficult to schedule staff effectively.

Another assumption which should be made is about the speed that staff are traveling. It is highly uncertain due to traffic and time of the day they are traveling. In order to calculate the hours saved, we consider traveling speed from 30 to 50 kilometres per hour and performed our analysis over that range of speeds.

There are several other assumptions made. For example, we assume that the operating costs are the same for all six proposed locations. Therefore, the only fixed cost that is taken into account for analysis is lease cost. Moreover, the traveling rates (both fixed and variable rates) are considered to be fixed over the time. Ignoring the limitation of space at each potential location is another assumption which is made. In other words, we assumed that no matter which location is picked for opening the new facility, there is always enough space for that facility.

Decentralization is only one of the options that Health Region can consider for improvement. They can also consider adding clinic sites to the new facilities. In this way, HHAs and RNs only need to travel to visit immobile clients. Among other options, they can assess costs and benefits of implementing technology such as BlackBerrys or tablet PCs. In this case, staff can receive updated schedules so there would be no need to start the day from home base or travel back to

the home base frequently. Only one trip would be required for traveling to home base which would involve the picking up of required supplies.

Another project that is worth considering is regarding their scheduling problems. By improving their scheduling, they can reduce the redundant traveling caused by sending out multiple staff to the same neighborhood while only one is enough. Moreover, the sequencing of the clients' visits can be such that staff will not need to travel back and forth between different neighborhoods to visit clients. For this purpose, it is appropriate to develop a scheduling model which deals with the mentioned inefficiencies.

8.0 Conclusion and summary

Saskatoon Health Region (SHR) is encountering a facility location problem for its one and the only homecare agency which is located on Idylwyld Drive. The main motivation for SHR for decentralization is that on average, there are only 50% hands on time which is even getting worse due to expansions of the city, population growth and increase in traffic. Moreover, their current expenditures are exceeding the assigned budget. Dealing with lack of parking stalls due to 25th Street extension, covering the increasing demand and staff dissatisfaction of excessive and unorganized travels around the city are other motivations for decentralization.

In this thesis, two quantitative methods are employed to find the best locations for new facilities. In the first method, we use the Center of Gravity which is only suitable for single facility location problems. This approach finds the best location based on minimized demand weighted average distance between center of each neighborhood and the homecare site. In the second method, we use the P-median model which is suitable for both single and multiple facility location problems. This approach attempts to minimize the total annual cost subject to a set of constraints. As opposed to Center of Gravity model in which the new location can be anywhere in plane, in P-median model, there should be a set of potential locations to choose the best site from. Based on Health Region suggestions, the other five proposed locations were Market Mall, Lawson Heights Mall, Confederation Mall, Avenue H South, and University Heights Square. The P-median model also defines the number of staff that should be sent from each open location to each neighborhood.

After performing a series of sensitivity analyses, the preferred locations in descending order were typically Idylwyld Center, University Heights Square, Confederation Mall, Lawson Heights Mall, Ave. H South and Market Mall.

Based on the P-median model, the best site for single facility location problem is Idylwyld Center. Since Health Region owns this center, there is no lease cost associated with this site and therefore, it is the first best location among all. Moreover, Idylwyld Center is closest to the Center of Gravity of the whole city. In all scenarios such as Greenfields, increased demand, increased or decreased lease cost and increased and decreased average demand coverage, Idylwyld Drive remained the best site for single facility location problems. It is also repeatedly selected as one of the best locations in multiple-facility location problems except for a couple of cases in Greenfields project scenario analysis (for three and four open facilities). The second best location is University Heights Square since it has the lowest maximum facility size and consequently, the lowest lease cost among those proposed locations. Using the same logic, Market Mall is the least attractive location although it is located in a neighborhood with highest demand (Nutana S.C.) for homecare services. In all the models and sensitivity analyses the selection of best locations are the same which is suggesting that if the Health Region locates new facilities in the best sites identified by the model, they can be sure that fluctuations in demand, lease cost, average number of visits per day will not make them relocate to another location down the road.

By decentralizing into two locations, hands on time increases by 0.8% on average. However, hands on time increases by 3.8% on average when a facility is open in each of six locations. Since SHR aims to decrease time spent on the road and increase the capacity, they should definitely decentralize into more than one location and the best number of open facilities would

be six. Although it might be argued that the lease cost for six open facilities is high, the reduction in travel expenses as well as the revenue brought to SHR due to increase in demand coverage is the highest among all. Moreover, the lease cost is calculated based on maximum facility size. Since none of the open facilities are using their maximum size, after finding the actual number of staff required for each facility, the size of each facility can be adjusted accordingly which means that there would be further reduction in lease cost too.

The main limitation of the thesis is that scheduling, sequencing and vehicle routing were out of the scope of the thesis. One recommendation for Health Region is to solve the problem of scheduling and save more time wasted on the road. Another project that they should check its costs and benefits is implementation of technology such as BlackBerrys or tablet PCs. It is possible that if staff members are equipped with these technologies, they would not need to travel back to home base more than one time per day and in this case, they can easily receive updated schedules.

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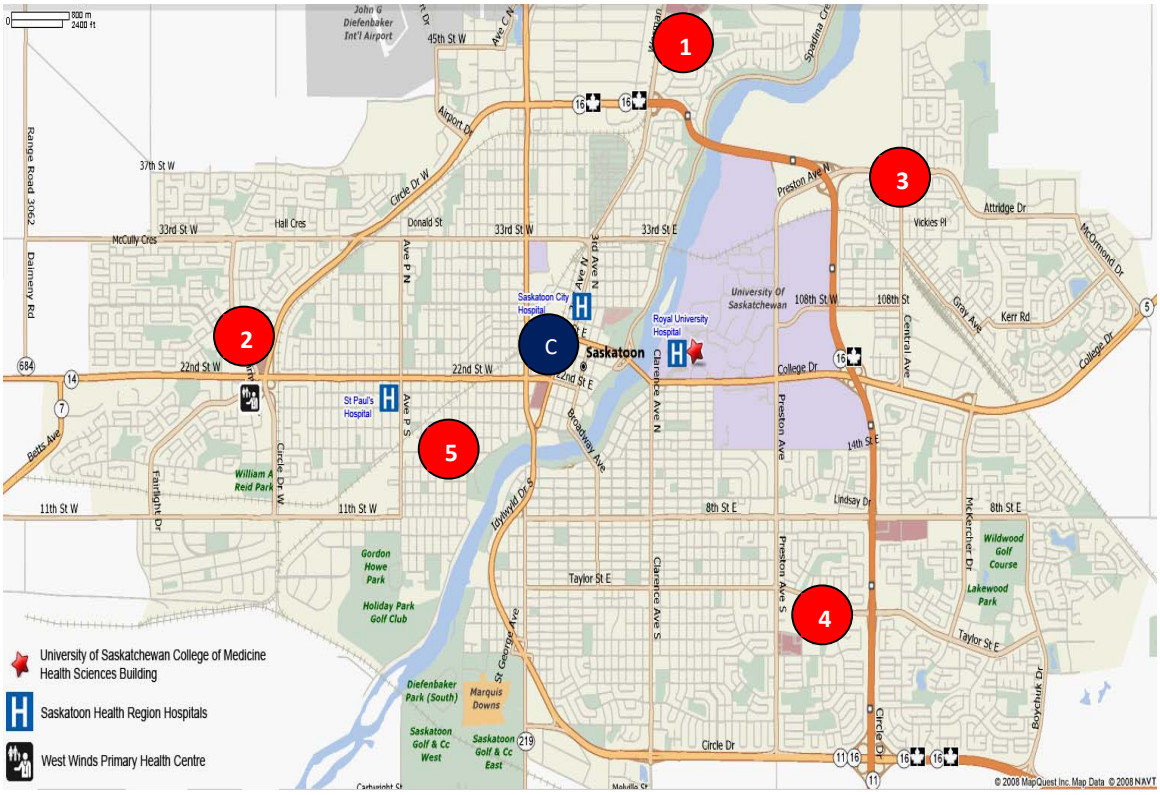
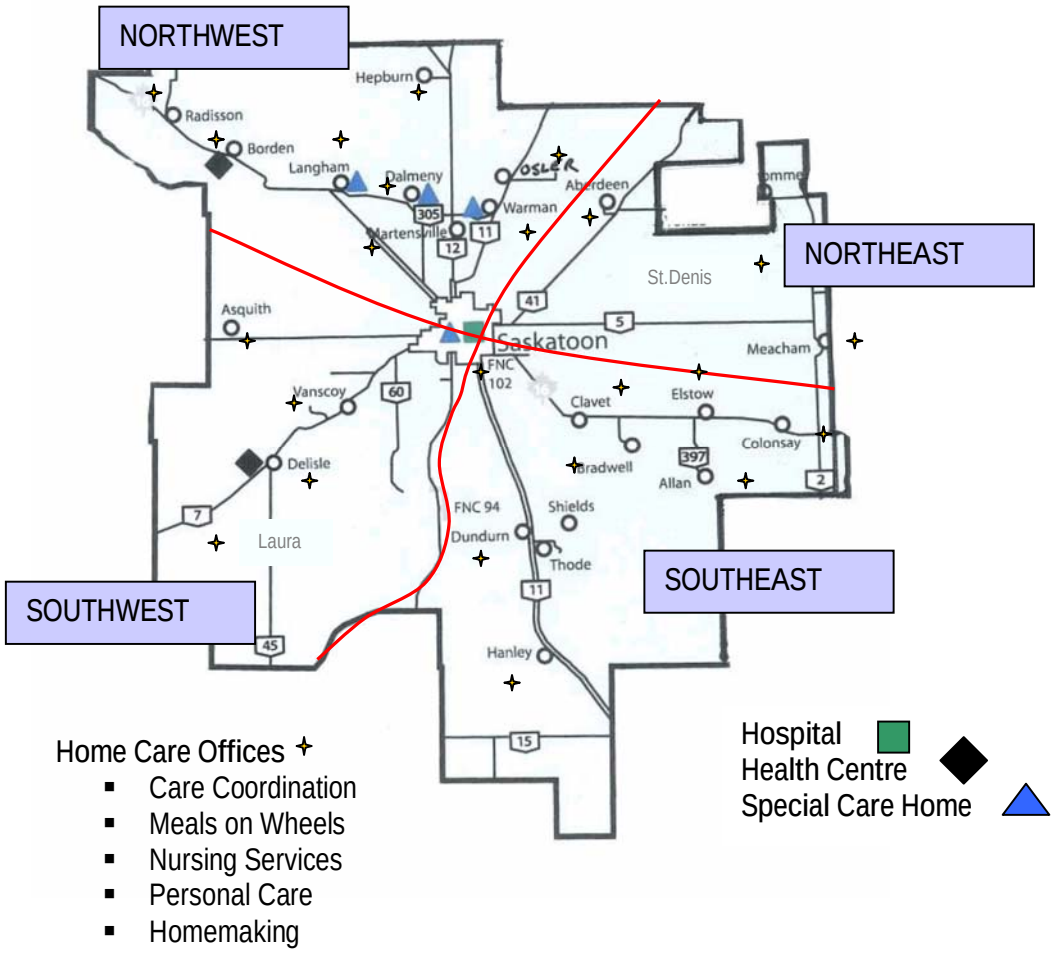
Appendices

Appendix A: Potential sites for decentralization

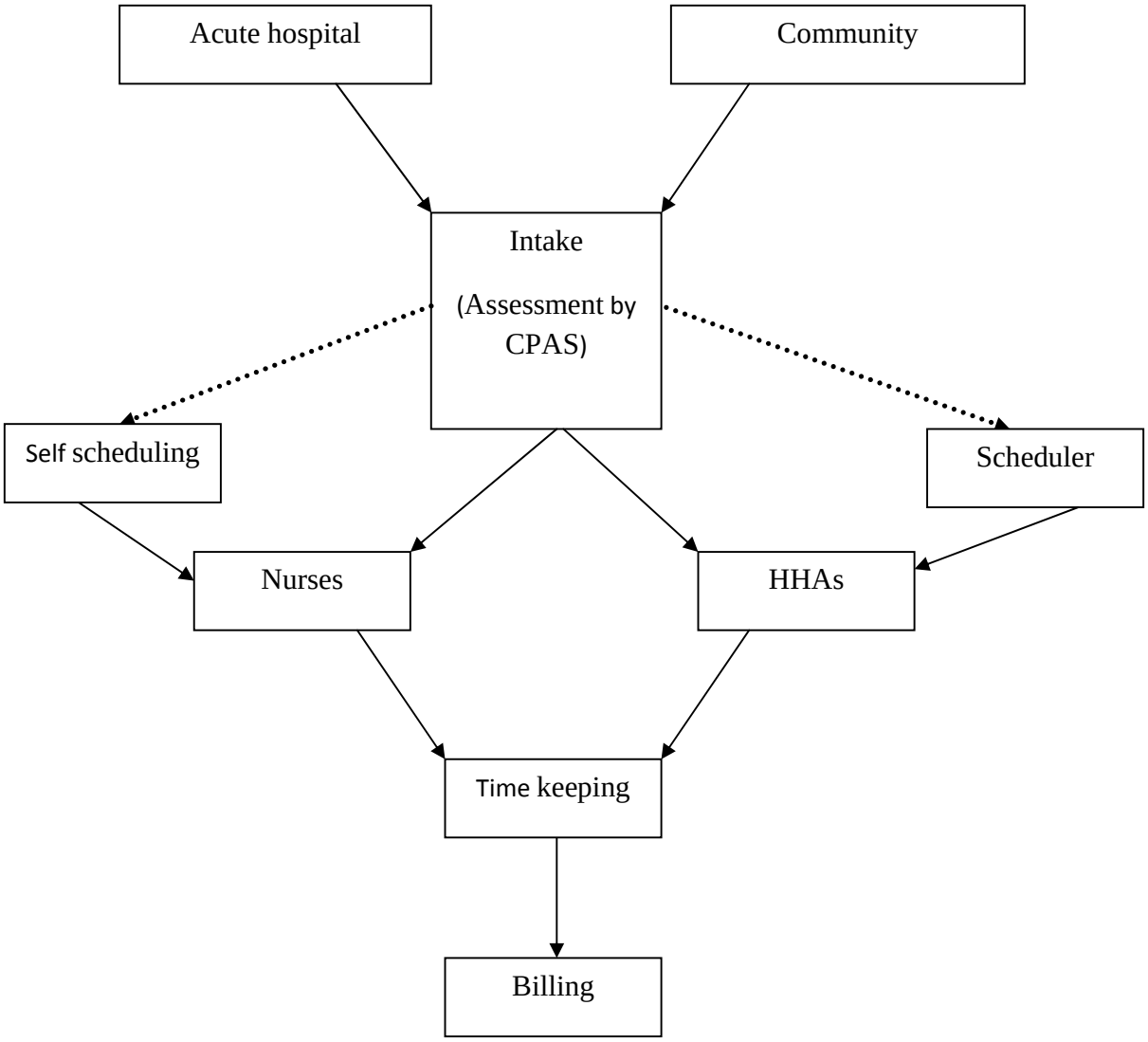
The location of all five proposed sites by Saskatoon Health Region is indicated by numbers which are Lawson Heights Mall (1), Confederation Mall (2), University Heights Square (3), Market Mall (4) and Avenue H South (5). Letter C shows the location of current homecare office which is located on Idylwyld Drive.



Appendix B: City of Saskatoon four quadrants

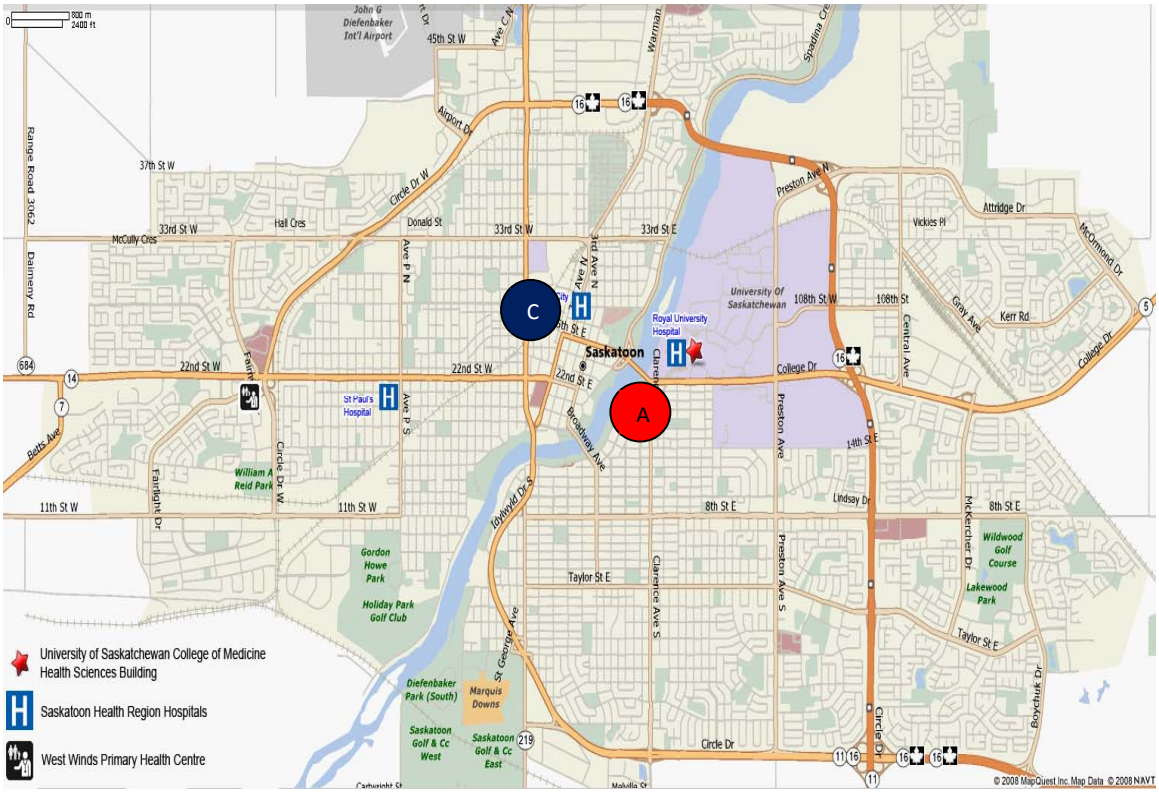


Appendix C: Overall flow in the SHR's homecare program



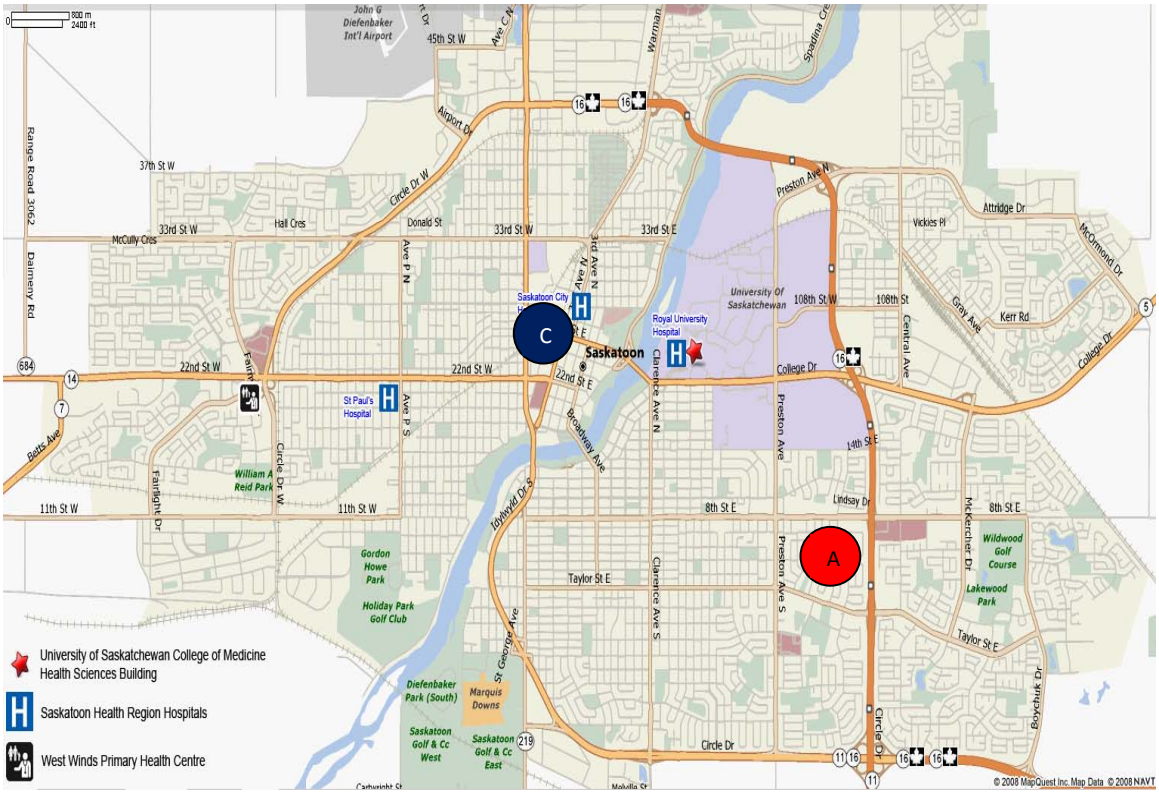
Appendix D: CoG of city of Saskatoon

Based on Center of Gravity method, Letter A shows the best location for a homecare office in the city of Saskatoon. The mentioned site is located in Varsity View neighborhood which is within 3 kilometres from current home base.



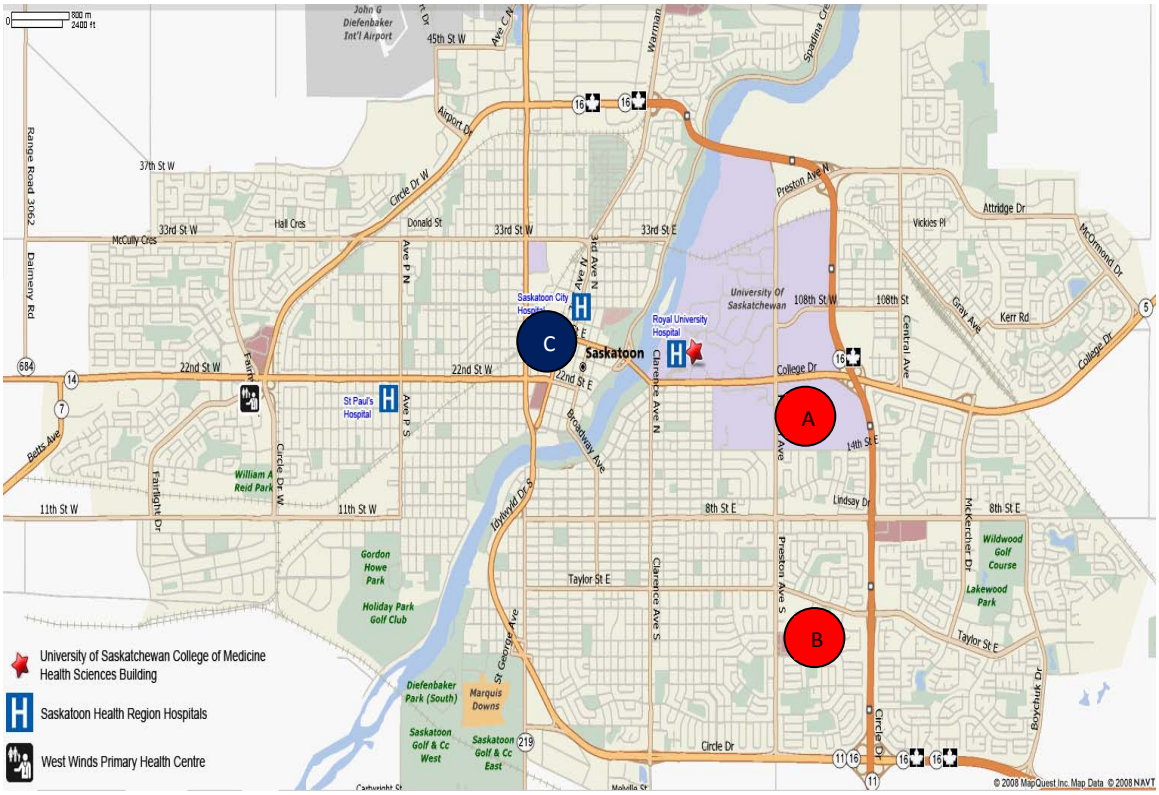
Appendix E: CoG for the East

Letter A shows the Brevoort Park neighborhood which is the Center of Gravity for the east side of the city.



Appendix F: CoG of northeast and southeast side of the city

Center of Gravity of the northeast side is located in University of Saskatchewan Management area (letter A) and that of the southeast is in Nutana S.C. neighborhood (letter B).



Appendix G: Comparison of costs and traveled distances in CoG

In the following table, annual costs and distances are calculated for Center of Gravity locations. The results are compared with the current Idylwyld Center.

Open facilities	annual transportation cost	annual lease cost	total annual cost	traveled km per year	saved kilometres	hrs saved (spd=30km/hr)	hrs saved (spd=50km/hr)	avg # of visits change	avg capacity changed
Varsity View	$361,949	$465,712	$827,661	798,401	21,754	725	435	1,160	0.23%
Idylwyld center & Brevoort Park	$329,032	$223,900	$552,932	508,159	311,996	10,400	6,240	16,640	3.25%
Idylwyld Center, Nutana SC. & U of S south management area	$325,033	$255,246	$580,279	$530,090	290,066	9,669	5,801	15,470	3.02%

Appendix H: P-median model

H1) Annual cost, distance travelled and capacity changed

# of open facilities	annual transportation cost	annual lease cost	total annual cost
1	$377,883	$0	$377,883
2	$354,208	$182,516	$536,724
3	$349,134	$302,212	$651,346
4	$341,393	$280,989	$622,382
5	$340,176	$287,089	$627,265
6	$301,375	$333,965	$635,339

# of open facilities	traveled km per year	saved km	hrs saved (spd=30 km/hr)	hrs saved (spd=50 km/hr)	avg hands on time changed	avg # of visits changed	avg capacity changed
1	820,155	0	0	0	0	0	0.00%
2	730,657	89,498	2,983	1,790	0.77%	4,773	0.93%
3	688,317	131,838	4,395	2,637	1.14%	7,031	1.37%
4	645,174	174,981	5,833	3,500	1.51%	9,332	1.82%
5	633,202	186,953	6,232	3,739	1.62%	9,971	1.95%
6	388,689	431,467	14,382	8,629	3.73%	23,012	4.50%

H2) best locations and staff allocation

Number of nurses allocated to each location:

	number of facilities to open					
proposed locations	**1**	**2**	**3**	**4**	**5**	**6**
Idylwyld Center	83	67	45	26	19	16
University Heights Square		16	15	15	15	7
Confederation Mall			23	26	16	15
Lawson Heights Mall				16	15	10
Ave H south					18	6
Market Mall						29

Number of HHAs allocated to each location:

	number of facilities to open					
proposed locations	**1**	**2**	**3**	**4**	**5**	**6**
Idylwyld Center	128	107	80	56	41	31
University Heights Square		21	21	21	21	7
Confederation Mall			27	29	23	21
Lawson Heights Mall				22	22	17
Ave H south					21	6
Market Mall						46

Appendix I: P-median model for 10% increase in capacity

I1) Annual cost, distance travelled and capacity changed

# of open facilities	annual transportation cost	annual lease cost	total annual cost
1	$363,945	$0	$363,945
2	$340,270	$182,516	$522,786
3	$335,196	$302,212	$637,408
4	$327,455	$280,989	$608,444
5	$326,322	$287,089	$613,411
6	$289,512	$333,965	$623,477

# of open facilities	traveled km per year	saved km	hrs saved (spd=30 km/hr)	hrs saved (spd=50 km/hr)	avg hands on time changed	avg # of visits changed	avg capacity changed
1	790,225	0	0	0	0	0	0.00%
2	700,727	89,498	2,983	1,790	0.77%	4,773	0.93%
3	669,775	120,450	4,015	2,409	1.04%	6,424	1.26%
4	607,506	182,719	6,091	3,654	1.58%	9,745	1.90%
5	603,126	187,099	6,237	3,742	1.62%	9,979	1.95%
6	377,593	412,633	13,754	8,253	3.57%	22,007	4.30%

I2) best locations and staff allocation

Number of nurses allocated to each location:

	number of facilities to open					
proposed locations	**1**	**2**	**3**	**4**	**5**	**6**
Idylwyld Center	82	66	39	29	20	16
University Heights Square		16	15	15	15	7
Confederation Mall			28	21	16	15
Lawson Heights Mall				17	15	10
Ave H south					16	6
Market Mall						28

Number of HHAs allocated to each location:

	number of facilities to open					
proposed locations	**1**	**2**	**3**	**4**	**5**	**6**
Idylwyld Center	120	99	74	55	38	28
University Heights Square		21	21	21	21	7
Confederation Mall			25	26	23	21
Lawson Heights Mall				18	22	17
Ave H south					16	6
Market Mall						41

Appendix J: P-median model for 10% decrease in capacity

J1) Annual cost, distance travelled and capacity changed

# of open facilities	annual transportation cost	annual lease cost	total annual cost
1	$393,737	$0	$393,737
2	$372,696	$182,516	$555,212
3	$364,596	$302,212	$666,808
4	$356,536	$280,989	$637,525
5	$355,113	$287,089	$642,202
6	$318,514	$333,965	$652,478

# of open facilities	traveled km per year	saved km	hrs saved (spd=30 km/hr)	hrs saved (spd=50 km/hr)	avg hands on time changed	avg # of visits changed	avg capacity changed
1	854,319	0	0	0	0.00%	0	0.00%
2	772,705	81,614	2,720	1,632	0.71%	4,353	0.85%
3	734,672	119,647	3,988	2,393	1.04%	6,381	1.25%
4	674,447	179,872	5,996	3,597	1.56%	9,593	1.87%
5	663,643	190,676	6,356	3,814	1.65%	10,169	1.99%
6	420,188	434,131	14,471	8,683	3.76%	23,154	4.52%

J2) best locations and staff allocation

Number of nurses allocated to each location:

	number of facilities to open					
proposed locations	**1**	**2**	**3**	**4**	**5**	**6**
Idylwyld Center	86	68	42	32	20	16
University Heights Square		18	15	16	16	10
Confederation Mall			29	21	15	15
Lawson Heights Mall				17	16	10
Ave H south					20	6
Market Mall						29

Number of HHAs allocated to each location:

	number of facilities to open					
proposed locations	**1**	**2**	**3**	**4**	**5**	**6**
Idylwyld Center	134	107	80	61	46	31
University Heights Square		27	22	21	21	13
Confederation Mall			32	29	23	21
Lawson Heights Mall				23	22	17
Ave H south					22	6
Market Mall						46

Appendix K: P-median model for 20% increase in capacity

K1) Annual cost, distance travelled and capacity changed

# of open facilities	annual transportation cost	annual lease cost	total annual cost
1	$347,453	$0	$347,453
2	$324,619	$182,516	$507,134
3	$319,096	$302,212	$621,308
4	$311,702	$280,989	$592,692
5	$310,962	$287,089	$598,051
6	$275,642	$333,965	$609,607

# of open facilities	traveled km per year	saved km	hrs saved (spd=30 km/hr)	hrs saved (spd=50 km/hr)	avg hands on time changed	avg # of visits changed	avg capacity changed
1	761,317	0	0	0	0.00%	0	0.00%
2	674,009	87,308	2,910	1,746	0.76%	4,656	0.91%
3	640,721	120,596	4,020	2,412	1.04%	6,432	1.26%
4	584,803	176,514	5,884	3,530	1.53%	9,414	1.84%
5	574,364	186,953	6,232	3,739	1.62%	9,971	1.95%
6	368,650	392,667	13,089	7,853	3.40%	20,942	4.09%

K2) best locations and staff allocation

Number of nurses allocated to each location:

	number of facilities to open					
proposed locations	**1**	**2**	**3**	**4**	**5**	**6**
Idylwyld Center	79	63	37	28	18	16
University Heights Square		16	16	16	15	7
Confederation Mall			26	18	16	15
Lawson Heights Mall				17	15	10
Ave H south					15	6
Market Mall						25

Number of HHAs allocated to each location:

	number of facilities to open					
proposed locations	**1**	**2**	**3**	**4**	**5**	**6**
Idylwyld Center	113	92	64	47	34	24
University Heights Square		21	20	20	20	7
Confederation Mall			29	29	23	21
Lawson Heights Mall				17	20	17
Ave H south					16	6
Market Mall						38

Appendix L: P-median model for 20% increase in lease cost

L1) Annual cost, distance travelled and capacity changed

# of open facilities	annual transportation cost	annual lease cost	total annual cost
1	$377,883	$0	$377,883
2	$354,208	$219,019	$573,227
3	$349,134	$362,654	$711,788
4	$341,393	$337,187	$678,580
5	$340,176	$344,506	$684,682
6	$301,375	$400,757	$702,132

# of open facilities	traveled km per year	saved km	hrs saved (spd=30 km/hr)	hrs saved (spd=50 km/hr)	avg hands on time changed	avg # of visits changed	avg capacity changed
1	820,155	0	0	0	0.00%	0	0.00%
2	730,657	89,498	2,983	1,790	0.77%	4773	0.93%
3	688,317	131,838	4,395	2,637	1.14%	7031	1.37%
4	645,174	174,981	5,833	3,500	1.51%	9332	1.82%
5	631,888	188,267	6,276	3,765	1.63%	10041	1.96%
6	388,689	431,467	14,382	8,629	3.73%	23012	4.50%

L2) best locations and staff allocation

Number of nurses allocated to each location:

	number of facilities to open					
proposed locations	**1**	**2**	**3**	**4**	**5**	**6**
Idylwyld Center	83	67	45	26	19	16
University Heights Square		16	15	15	15	7
Confederation Mall			23	26	16	15
Lawson Heights Mall				16	15	10
Ave H south					18	6
Market Mall						29

Number of HHAs allocated to each location:

	number of facilities to open					
proposed locations	**1**	**2**	**3**	**4**	**5**	**6**
Idylwyld Center	128	107	80	56	41	31
University Heights Square		21	21	21	21	7
Confederation Mall			27	29	23	21
Lawson Heights Mall				22	22	17
Ave H south					21	6
Market Mall						46

Appendix M: P-median model for 20% decrease in lease cost

M1) Annual cost, distance travelled and capacity changed

# of open facilities	annual transportation cost	annual lease cost	total annual cost
1	$377,883	$0	$377,883
2	$354,208	$146,013	$500,221
3	$349,134	$241,770	$590,903
4	$341,393	$224,791	$566,184
5	$340,176	$229,671	$569,847
6	$301,375	$267,172	$568,547

# of open facilities	traveled km per year	saved km	hrs saved (spd=30 km/hr)	hrs saved (spd=50 km/hr)	avg hands on time changed	avg # of visits changed	avg capacity changed
1	820,155	0	0	0	0.00%	0	0.00%
2	730,657	89,498	2,983	1,790	0.77%	4,773	0.93%
3	699,121	121,034	4,034	2,421	1.05%	6,455	1.26%
4	645,393	174,762	5,825	3,495	1.51%	9,321	1.82%
5	632,983	187,172	6,239	3,743	1.62%	9,983	1.95%
6	388,689	431,467	14,382	8,629	3.73%	23,012	4.50%

M2) best locations and staff allocation

Number of nurses allocated to each location:

	number of facilities to open					
proposed locations	**1**	**2**	**3**	**4**	**5**	**6**
Idylwyld Center	83	67	39	25	19	16
University Heights Square		16	16	16	15	7
Confederation Mall			28	25	16	15
Lawson Heights Mall				17	15	10
Ave H south					18	6
Market Mall						29

Number of HHAs allocated to each location:

	number of facilities to open					
proposed locations	**1**	**2**	**3**	**4**	**5**	**6**
Idylwyld Center	128	107	75	56	41	31
University Heights Square		21	21	21	21	7
Confederation Mall			32	29	23	21
Lawson Heights Mall				22	22	17
Ave H south					21	6
Market Mall						46

Appendix N: 4% and 12% increase in demand for RNs and HHAs

N1) Annual cost, distance travelled and capacity changed

# of open facilities	annual transportation cost	annual lease cost	total annual cost
1	$388,930	$0	$388,930
2	$366,544	$182,516	$549,060
3	$359,789	$302,212	$662,001
4	$352,076	$280,989	$633,065
5	$350,653	$287,089	$637,742
6	$310,135	$333,965	$644,099

# of open facilities	traveled km per year	saved km	hrs saved (spd=30 km/hr)	hrs saved (spd=50 km/hr)	avg hands on time changed	avg # of visits changed	avg capacity changed
1	844,245	0	0	0	0.00%	0	0.00%
2	759,127	85,118	2,837	1,702	0.74%	4,540	0.89%
3	723,795	120,450	4,015	2,409	1.04%	6,424	1.26%
4	670,943	173,302	5,777	3,466	1.50%	9,243	1.81%
5	657,219	187,026	6,234	3,741	1.62%	9,975	1.95%
6	392,412	451,834	15,061	9,037	3.91%	24,098	4.71%

N2) best locations and staff allocation

Number of nurses allocated to each location:

	number of facilities to open					
proposed locations	**1**	**2**	**3**	**4**	**5**	**6**
Idylwyld Center	86	68	41	28	20	18
University Heights Square		18	16	15	15	7
Confederation Mall			29	26	16	15
Lawson Heights Mall				17	15	11
Ave H south					20	6
Market Mall						29

Number of HHAs allocated to each location:

	number of facilities to open					
proposed locations	**1**	**2**	**3**	**4**	**5**	**6**
Idylwyld Center	131	107	77	59	44	31
University Heights Square		24	22	21	21	7
Confederation Mall			32	29	23	22
Lawson Heights Mall				22	22	18
Ave H south					21	6
Market Mall						47

Appendix O: Greenfield project

O1) Annual cost, distance travelled and capacity changed

# of open facilities	annual transportation cost	annual lease cost	total annual cost
1	$377,883	$0	$377,883
2	$326,781	$0	$326,781
3	$312,301	$0	$312,301
4	$301,929	$0	$301,929
5	$301,375	$0	$301,375
6	$301,375	$0	$301,375

# of open facilities	traveled km per year	saved km	hrs saved (spd=30 km/hr)	hrs saved (spd=50 km/hr)	avg hands on time changed	avg # of visits changed	avg capacity changed
1	820,155	0	0	0	0.00%	0	0.00%
2	555,640	264,516	8,817	5,290	2.29%	14,107	2.76%
3	495,634	324,522	10,817	6,490	2.81%	17,308	3.38%
4	439,132	381,024	12,701	7,620	3.30%	20,321	3.97%
5	393,361	426,795	14,226	8,536	3.69%	22,762	4.45%
6	388,689	431,467	14,382	8,629	3.73%	23,012	4.50%

O2) best locations and staff allocation

Number of nurses allocated to each location:

	number of facilities to open					
proposed locations	**1**	**2**	**3**	**4**	**5**	**6**
Idylwyld Center	83	49			16	16
University Heights Square				7	7	7
Confederation Mall			23	26	16	15
Lawson Heights Mall			24	16	13	10
Ave H south						6
Market Mall		34	36	34	31	29

Number of HHAs allocated to each location:

	number of facilities to open					
proposed locations	**1**	**2**	**3**	**4**	**5**	**6**
Idylwyld Center	128	77			37	31
University Heights Square				7	7	7
Confederation Mall			42	42	21	21
Lawson Heights Mall			29	24	17	17
Ave H south						6
Market Mall		51	57	55	46	46

Appendix P: P-median model without Idylwyld center

P1) Annual cost, distance travelled and capacity changed

# of open facilities	annual transportation cost	annual lease cost	total annual cost
1	$414,389	$244,857	$659,246
2	$366,800	$384,436	$751,236
3	$363,082	$468,158	$831,240
4	$342,445	$405,158	$747,604
5	$301,414	$397,277	$698,691

# of open facilities	traveled km per year	saved km	hrs saved (spd=30 km/hr)	hrs saved (spd=50 km/hr)	avg hands on time changed	avg # of visits changed	avg capacity changed
1	938,999	0	0	0	0.00%	0	0.00%
2	787,816	151,183	5,039	3,024	1.31%	8,063	1.58%
3	761,901	177,098	5,903	3,542	1.53%	9,445	1.85%
4	655,321	283,678	9,456	5,674	2.46%	15,129	2.96%
5	406,866	532,134	17,738	10,643	4.61%	28,380	5.55%

P2) best locations and staff allocation

Number of nurses allocated to each location:

	number of facilities to open				
proposed locations	**1**	**2**	**3**	**4**	**5**
Ave H south	83	67	38	27	16
University Heights Square		16	16	16	7
Confederation Mall			29	23	15
Lawson Heights Mall				17	14
Market Mall					31

Number of HHAs allocated to each location:

	number of facilities to open				
proposed locations	**1**	**2**	**3**	**4**	**5**
Ave H south	128	107	86	52	31
University Heights Square		21	21	21	7
Confederation Mall			21	32	22
Lawson Heights Mall				23	19
Market Mall					49

Appendix Q: P-median model for round trip per client

Q1) Annual cost, distance travelled and capacity changed

# of open facilities	annual transportation cost	annual lease cost	total annual cost
1	$2,583,807	$0	$2,583,807
2	$2,229,855	$382,773	$2,612,628
3	$2,180,203	$362,060	$2,542,263
4	$2,120,062	$369,531	$2,489,593
5	$2,087,074	$406,628	$2,493,702
6	$2,087,074	$333,965	$2,421,039

# of open facilities	traveled km per year	saved km	hrs saved (spd=30 km/hr)	hrs saved (spd=50 km/hr)	avg # of visits changed	avg capacity changed
1	5,477,409	0	0	0	0	0.00%
2	3,548,530	1,928,879	64,296	38,578	102,874	20.10%
3	3,252,442	2,224,967	74,166	44,499	118,665	23.19%
4	2,771,883	2,705,526	90,184	54,111	144,295	28.19%
5	2,714,505	2,762,904	92,097	55,258	147,355	28.79%
6	2,638,439	2,838,970	94,632	56,779	151,412	29.58%

Q2) best locations and staff allocation

Number of nurses allocated to each location:

	number of facilities to open					
proposed locations	**1**	**2**	**3**	**4**	**5**	**6**
Idylwyld Center	83	52	51	35	5	12
University Heights Square			4	5	6	5
Confederation Mall					27	6
Lawson Heights Mall				15	14	9
Ave H south						23
Market Mall		31	28	28	31	28

Number of HHAs allocated to each location:

	number of facilities to open					
proposed locations	**1**	**2**	**3**	**4**	**5**	**6**
Idylwyld Center	128	68	80	64	21	23
University Heights Square			4	5	4	4
Confederation Mall					32	17
Lawson Heights Mall				15	23	15
Ave H south						20
Market Mall		60	44	44	48	49

Appendix R: P-median model without min constraint for facility size

R1) P-median model

R1i) Annual cost, distance travelled and capacity changed

# of open facilities	annual transportation cost	annual lease cost	total annual cost
1	$377,883	$0	$377,883
2	$354,208	$182,516	$536,724
3	$349,134	$302,212	$651,346
4	$341,393	$280,989	$622,382
5	$340,176	$287,089	$627,265
6	$301,375	$333,965	$635,339

# of open facilities	traveled km per year	saved km	hrs saved (spd=30 km/hr)	hrs saved (spd=50 km/hr)	avg # of visits changed	avg capacity changed
1	820,155	0	0	0	0	0.00%
2	730,657	89,498	2,983	1,790	4,773	0.93%
3	699,121	121,034	4,034	2,421	6,455	1.26%
4	639,480	180,675	6,023	3,614	9,636	1.88%
5	635,465	184,690	6,156	3,694	9,850	1.92%
6	388,689	431,467	14,382	8,629	23,012	4.50%

R1ii) best locations and staff allocation

Number of nurses allocated to each location:

	number of facilities to open					
proposed locations	**1**	**2**	**3**	**4**	**5**	**6**
Idylwyld Center	83	67	39	27	16	16
University Heights Square		16	16	16	16	7
Confederation Mall			28	23	16	15
Lawson Heights Mall				17	15	10
Ave H south					20	6
Market Mall						29

Number of HHAs allocated to each location:

	number of facilities to open					
proposed locations	**1**	**2**	**3**	**4**	**5**	**6**
Idylwyld Center	128	107	75	53	27	31
University Heights Square		21	21	21	21	7
Confederation Mall			32	32	23	21
Lawson Heights Mall				22	22	17
Ave H south					35	6
Market Mall						46

R2) P-median model for 10% increase in capacity

R2i) Annual cost, distance travelled and capacity changed

# of open facilities	annual transportation cost	annual lease cost	total annual cost
1	$363,945	$0	$363,945
2	$340,270	$182,516	$522,786
3	$335,196	$302,212	$637,408
4	$327,455	$280,989	$608,444
5	$326,322	$287,089	$613,411
6	$289,512	$333,965	$623,477

# of open facilities	traveled km per year	saved km	hrs saved (spd=30 km/hr)	hrs saved (spd=50 km/hr)	avg # of visits changed	avg capacity changed
1	790,225	0	0	0	0	0.00%
2	700,727	89,498	2,983	1,790	4,773	0.93%
3	669,483	120,742	4,025	2,415	6,440	1.26%
4	609,842	180,383	6,013	3,608	9,620	1.88%
5	604,878	185,347	6,178	3,707	9,885	1.93%
6	375,403	414,823	13,827	8,296	22,124	4.32%

R2ii) best locations and staff allocation

Number of nurses allocated to each location:

	number of facilities to open					
proposed locations	**1**	**2**	**3**	**4**	**5**	**6**
Idylwyld Center	82	66	38	26	15	15
University Heights Square		16	16	16	16	7
Confederation Mall			28	23	16	15
Lawson Heights Mall				17	15	10
Ave H south					20	6
Market Mall						29

Number of HHAs allocated to each location:

	number of facilities to open					
proposed locations	**1**	**2**	**3**	**4**	**5**	**6**
Idylwyld Center	120	99	69	47	19	23
University Heights Square		21	21	21	21	7
Confederation Mall			30	30	23	21
Lawson Heights Mall				22	22	17
Ave H south					35	6
Market Mall						46

R3) P-median model for 10% decrease in capacity

R3i) Annual cost, distance travelled and capacity changed

# of open facilities	annual transportation cost	annual lease cost	total annual cost
1	$393,737	$0	$393,737
2	$372,696	$182,516	$555,212
3	$364,596	$302,212	$666,808
4	$356,536	$280,989	$637,525
5	$355,113	$287,089	$642,202
6	$314,360	$333,965	$648,324

# of open facilities	traveled km per year	saved km	hrs saved (spd=30 km/hr)	hrs saved (spd=50 km/hr)	avg # of visits changed	avg capacity changed
1	854,319	0	0	0	0	0.00%
2	772,705	81,614	2,720	1,632	4,353	0.85%
3	733,869	120,450	4,015	2,409	6,424	1.26%
4	671,381	182,938	6,098	3,659	9,757	1.91%
5	660,504	193,815	6,461	3,876	10,337	2.02%
6	399,821	454,498	15,150	9,090	24,240	4.74%

R3ii) best locations and staff allocation

Number of nurses allocated to each location:

	number of facilities to open					
proposed locations	**1**	**2**	**3**	**4**	**5**	**6**
Idylwyld Center	86	68	41	27	19	15
University Heights Square		18	16	16	16	7
Confederation Mall			29	26	16	16
Lawson Heights Mall				17	15	11
Ave H south					20	7
Market Mall						30

Number of HHAs allocated to each location:

	number of facilities to open					
proposed locations	**1**	**2**	**3**	**4**	**5**	**6**
Idylwyld Center	134	107	80	58	33	32
University Heights Square		27	22	21	21	8
Confederation Mall			32	32	23	22
Lawson Heights Mall				23	22	18
Ave H south					35	7
Market Mall						47

R4) P-median model for 20% increase in capacity

R4i) Annual cost, distance travelled and capacity changed

# of open facilities	annual transportation cost	annual lease cost	total annual cost
1	$347,453	$0	$347,453
2	$324,171	$182,516	$506,686
3	$319,096	$302,212	$621,308
4	$311,702	$280,989	$592,692
5	$310,962	$287,089	$598,051
6	$275,642	$333,965	$609,607

# of open facilities	traveled km per year	saved km	hrs saved (spd=30 km/hr)	hrs saved (spd=50 km/hr)	avg # of visits changed	avg capacity changed
1	761,317	0	0	0	0	0.00%
2	672,841	88,476	2,949	1,770	4,719	0.92%
3	640,721	120,596	4,020	2,412	6,432	1.26%
4	583,270	178,047	5,935	3,561	9,496	1.86%
5	582,467	178,850	5,962	3,577	9,539	1.86%
6	364,051	397,266	13,242	7,945	21,188	4.14%

R4ii) best locations and staff allocation

Number of nurses allocated to each location:

	number of facilities to open					
proposed locations	**1**	**2**	**3**	**4**	**5**	**6**
Idylwyld Center	79	63	37	25	12	12
University Heights Square		16	16	16	16	7
Confederation Mall			26	21	16	15
Lawson Heights Mall				17	15	10
Ave H south					20	6
Market Mall						29

Number of HHAs allocated to each location:

	number of facilities to open					
proposed locations	**1**	**2**	**3**	**4**	**5**	**6**
Idylwyld Center	113	93	64	44	15	16
University Heights Square		20	20	20	20	7
Confederation Mall			29	29	23	21
Lawson Heights Mall				20	20	17
Ave H south					35	6
Market Mall						46

R5) P-median model for 20% increase in lease cost

R5i) Annual cost, distance travelled and capacity changed

# of open facilities	annual transportation cost	annual lease cost	total annual cost
1	$377,883	$0	$377,883
2	$354,208	$219,019	$573,227
3	$349,134	$362,654	$711,788
4	$341,393	$337,187	$678,580
5	$340,176	$344,506	$684,682
6	$301,375	$400,757	$702,132

# of open facilities	traveled km per year	saved km	hrs saved (spd=30 km/hr)	hrs saved (spd=50 km/hr)	avg # of visits changed	avg capacity changed
1	820,155	0	0	0	0	0.00%
2	730,657	89,498	2,983	1,790	4,773	0.93%
3	699,121	121,034	4,034	2,421	6,455	1.26%
4	639,480	180,675	6,023	3,614	9,636	1.88%
5	635,465	184,690	6,156	3,694	9,850	1.92%
6	388,689	431,467	14,382	8,629	23,012	4.50%

R5ii) best locations and staff allocation

Number of nurses allocated to each location:

	number of facilities to open					
proposed locations	**1**	**2**	**3**	**4**	**5**	**6**
Idylwyld Center	83	67	39	27	16	16
University Heights Square		16	16	16	16	7
Confederation Mall			28	23	16	15
Lawson Heights Mall				17	15	10
Ave H south					20	6
Market Mall						29

Number of HHAs allocated to each location:

	number of facilities to open					
proposed locations	**1**	**2**	**3**	**4**	**5**	**6**
Idylwyld Center	128	107	75	53	27	31
University Heights Square		21	21	21	21	7
Confederation Mall			32	32	23	21
Lawson Heights Mall				22	22	17
Ave H south					35	6
Market Mall						46

R6) P-median model for 20% decrease in lease cost

R6i) Annual cost, distance travelled and capacity changed

# of open facilities	annual transportation cost	annual lease cost	total annual cost
1	$377,883	$0	$377,883
2	$354,208	$146,013	$500,221
3	$349,134	$241,770	$590,903
4	$341,393	$224,791	$566,184
5	$340,176	$229,671	$569,847
6	$301,375	$267,172	$568,547

# of open facilities	traveled km per year	saved km	hrs saved (spd=30 km/hr)	hrs saved (spd=50 km/hr)	avg # of visits changed	avg capacity changed
1	820,155	0	0	0	0	0.00%
2	730,657	89,498	2,983	1,790	4,773	0.93%
3	699,121	121,034	4,034	2,421	6,455	1.26%
4	640,064	180,091	6,003	3,602	9,605	1.88%
5	635,465	184,690	6,156	3,694	9,850	1.92%
6	388,689	431,467	14,382	8,629	23,012	4.50%

R6ii) best locations and staff allocation

Number of nurses allocated to each location:

	number of facilities to open					
proposed locations	**1**	**2**	**3**	**4**	**5**	**6**
Idylwyld Center	83	67	39	25	16	16
University Heights Square		16	16	16	16	7
Confederation Mall			28	25	16	15
Lawson Heights Mall				17	15	10
Ave H south					20	6
Market Mall						29

Number of HHAs allocated to each location:

	number of facilities to open					
proposed locations	**1**	**2**	**3**	**4**	**5**	**6**
Idylwyld Center	128	107	75	53	27	31
University Heights Square		21	21	21	21	7
Confederation Mall			32	32	23	21
Lawson Heights Mall				22	22	17
Ave H south					35	6
Market Mall						46

R7) 4% and 12% increase in demand for RNs and HHAs

R7i) Annual cost, distance travelled and capacity changed

# of open facilities	annual transportation cost	annual lease cost	total annual cost
1	$388,930	$0	$388,930
2	$366,544	$182,516	$549,060
3	$359,789	$302,212	$662,001
4	$352,076	$280,989	$633,065
5	$350,653	$287,089	$637,742
6	$310,135	$333,965	$644,099

# of open facilities	traveled km per year	saved km	hrs saved (spd=30 km/hr)	hrs saved (spd=50 km/hr)	avg # of visits changed	avg capacity changed
1	844,245	0	0	0	0	0.00%
2	759,127	85,118	2,837	1,702	4,540	0.89%
3	723,795	120,450	4,015	2,409	6,424	1.26%
4	664,811	179,434	5,981	3,589	9,570	1.87%
5	658,241	186,004	6,200	3,720	9,920	1.94%
6	395,624	448,622	14,954	8,972	23,926	4.68%

R7ii) best locations and staff allocation

Number of nurses allocated to each location:

	number of facilities to open					
proposed locations	**1**	**2**	**3**	**4**	**5**	**6**
Idylwyld Center	86	68	41	27	19	15
University Heights Square		18	16	16	16	7
Confederation Mall			29	26	16	16
Lawson Heights Mall				17	15	11
Ave H south					20	7
Market Mall						30

Number of HHAs allocated to each location:

	number of facilities to open					
proposed locations	**1**	**2**	**3**	**4**	**5**	**6**
Idylwyld Center	131	107	77	56	30	30
University Heights Square		24	22	21	21	7
Confederation Mall			32	32	23	22
Lawson Heights Mall				22	22	18
Ave H south					35	7
Market Mall						47

R8) Greenfield project

R8i) Annual cost, distance travelled and capacity changed

# of open facilities	annual transportation cost	annual lease cost	total annual cost
1	$377,883	$0	$377,883
2	$326,781	$0	$326,781
3	$312,301	$0	$312,301
4	$301,929	$0	$301,929
5	$301,375	$0	$301,375
6	$301,375	$0	$301,375

# of open facilities	traveled km per year	saved km	hrs saved (spd=30 km/hr)	hrs saved (spd=50 km/hr)	avg # of visits changed	avg capacity changed
1	820,155	0	0	0	0	0.00%
2	567,247	252,909	8,430	5,058	13,488	2.64%
3	493,444	326,712	10,890	6,534	17,425	3.40%
4	439,862	380,294	12,676	7,606	20,282	3.96%
5	391,901	428,255	14,275	8,565	22,840	4.46%
6	388,689	431,467	14,382	8,629	23,012	4.50%

R8ii) best locations and staff allocation

Number of nurses allocated to each location:

	number of facilities to open					
proposed locations	**1**	**2**	**3**	**4**	**5**	**6**
Idylwyld Center	83	55			14	16
University Heights Square				7	7	7
Confederation Mall			28	25	16	15
Lawson Heights Mall			19	17	15	10
Ave H south						6
Market Mall		28	36	34	31	29

Number of HHAs allocated to each location:

	number of facilities to open					
proposed locations	**1**	**2**	**3**	**4**	**5**	**6**
Idylwyld Center	128	69			37	31
University Heights Square				7	7	7
Confederation Mall			42	42	23	21
Lawson Heights Mall			29	24	12	17
Ave H south						6
Market Mall		59	57	55	49	46

R9) P-median model without Idylwyld center

R9i) Annual cost, distance travelled and capacity changed

# of open facilities	annual transportation cost	annual lease cost	total annual cost
1	$414,389	$244,857	$659,246
2	$366,800	$384,436	$751,236
3	$363,082	$468,158	$831,240
4	$342,445	$405,158	$747,604
5	$301,414	$397,277	$698,691

# of open facilities	traveled km per year	saved km	hrs saved (spd=30 km/hr)	hrs saved (spd=50 km/hr)	avg # of visits changed	avg capacity changed
1	938,999	0	0	0	0	0.00%
2	787,816	151,183	5,039	3,024	8,063	1.58%
3	758,689	180,310	6,010	3,606	9,617	1.88%
4	655,321	283,678	9,456	5,674	15,129	2.96%
5	407,596	531,404	17,713	10,628	28341.5	5.54%

R9ii) best locations and staff allocation

Number of nurses allocated to each location:

	number of facilities to open				
proposed locations	**1**	**2**	**3**	**4**	**5**
Ave H south	83	67	38	27	15
University Heights Square		16	16	16	6
Confederation Mall			29	23	16
Lawson Heights Mall				17	15
Market Mall					31

Number of HHAs allocated to each location:

	number of facilities to open				
proposed locations	**1**	**2**	**3**	**4**	**5**
Ave H south	128	107	88	52	27
University Heights Square		21	21	21	7
Confederation Mall			19	32	23
Lawson Heights Mall				23	22
Market Mall					49

Appendix S: P-median model with fixed min constraint for facility size

S1) P-median model

S1i) Annual cost, distance travelled and capacity changed

# of open facilities	annual transportation cost	annual lease cost	total annual cost
1	$377,883	$0	$377,883
2	$354,208	$182,516	$536,724
3	$349,134	$302,212	$651,346
4	$341,393	$280,989	$622,382
5	$340,176	$287,089	$627,265
6	NA	NA	NA

# of open facilities	traveled km per year	saved km	hrs saved (spd=30 km/hr)	hrs saved (spd=50 km/hr)	avg # of visits changed	avg capacity changed
1	820,155	0	0	0	0	0.00%
2	730,657	89,498	2,983	1,790	4,773	0.93%
3	688,901	131,254	4,375	2,625	7,000	1.37%
4	639,480	180,675	6,023	3,614	9,636	1.88%
5	636,414	183,741	6,125	3,675	9,800	1.91%
6	NA	NA	NA	NA	NA	NA

S1ii) best locations and staff allocation

Number of nurses allocated to each location:

	number of facilities to open					
proposed locations	**1**	**2**	**3**	**4**	**5**	**6**
Idylwyld Center	83	67	43	27	16	N/A
University Heights Square		16	16	16	16	N/A
Confederation Mall			24	23	16	N/A
Lawson Heights Mall				17	15	N/A
Ave H south					20	N/A
Market Mall						N/A

Number of HHAs allocated to each location:

	number of facilities to open					
proposed locations	**1**	**2**	**3**	**4**	**5**	**6**
Idylwyld Center	128	107	75	53	27	N/A
University Heights Square		21	21	21	21	N/A
Confederation Mall			32	32	23	N/A
Lawson Heights Mall				22	22	N/A
Ave H south					35	N/A
Market Mall						N/A

S2) P-median model for 10% increase in capacity

S2i) Annual cost, distance travelled and capacity changed

# of open facilities	annual transportation cost	annual lease cost	total annual cost
1	$363,945	$0	$363,945
2	$340,270	$182,516	$522,786
3	$335,196	$302,212	$637,408
4	$327,455	$280,989	$608,444
5	$326,322	$287,089	$613,411
6	N/A	N/A	N/A

# of open facilities	traveled km per year	saved km	hrs saved (spd=30 km/hr)	hrs saved (spd=50 km/hr)	avg # of visits changed	avg capacity changed
1	790,225	0	0	0	0	0.00%
2	700,727	89,498	2,983	1,790	4,773	0.93%
3	669,483	120,742	4,025	2,415	6,440	1.26%
4	609,842	180,383	6,013	3,608	9,620	1.88%
5	602,031	188,194	6,273	3,764	10,037	1.96%
6	N/A	N/A	N/A	N/A	N/A	N/A

S2ii) best locations and staff allocation

Number of nurses allocated to each location:

	number of facilities to open					
proposed locations	**1**	**2**	**3**	**4**	**5**	**6**
Idylwyld Center	82	66	38	26	19	N/A
University Heights Square		16	16	16	15	N/A
Confederation Mall			28	23	14	N/A
Lawson Heights Mall				17	14	N/A
Ave H south					20	N/A
Market Mall						N/A

Number of HHAs allocated to each location:

	number of facilities to open					
proposed locations	**1**	**2**	**3**	**4**	**5**	**6**
Idylwyld Center	120	99	69	47	34	N/A
University Heights Square		21	21	21	21	N/A
Confederation Mall			30	30	21	N/A
Lawson Heights Mall				22	21	N/A
Ave H south					23	N/A
Market Mall						N/A

S3) P-median model for 10% decrease in capacity

S3i) Annual cost, distance travelled and capacity changed

# of open facilities	annual transportation cost	annual lease cost	total annual cost
1	$393,737	$0	$393,737
2	$372,696	$182,516	$555,212
3	$364,596	$302,212	$666,808
4	$356,536	$280,989	$637,525
5	$355,113	$287,089	$642,202
6	N/A	N/A	N/A

# of open facilities	traveled km per year	saved km	hrs saved (spd=30 km/hr)	hrs saved (spd=50 km/hr)	avg # of visits changed	avg capacity changed
1	854,319	0	0	0	0	0.00%
2	772,705	81,614	2,720	1,632	4,353	0.85%
3	723,649	130,670	4,356	2,613	6,969	1.36%
4	672,184	182,135	6,071	3,643	9,714	1.90%
5	667,585	186,734	6,224	3,735	9,959	1.95%
6	N/A	N/A	N/A	N/A	N/A	N/A

S3ii) best locations and staff allocation

Number of nurses allocated to each location:

	number of facilities to open					
proposed locations	**1**	**2**	**3**	**4**	**5**	**6**
Idylwyld Center	86	68	45	28	19	N/A
University Heights Square		18	16	15	16	N/A
Confederation Mall			25	26	16	N/A
Lawson Heights Mall				17	15	N/A
Ave H south					20	N/A
Market Mall						N/A

Number of HHAs allocated to each location:

	number of facilities to open					
proposed locations	**1**	**2**	**3**	**4**	**5**	**6**
Idylwyld Center	134	107	80	58	33	N/A
University Heights Square		27	22	21	21	N/A
Confederation Mall			32	32	23	N/A
Lawson Heights Mall				23	22	N/A
Ave H south					35	N/A
Market Mall						N/A

S4) P-median model for 20% increase in capacity

S4i) Annual cost, distance travelled and capacity changed

# of open facilities	annual transportation cost	annual lease cost	total annual cost
1	$347,453	$0	$347,453
2	$324,619	$182,516	$507,134
3	$319,544	$302,212	$621,756
4	$312,190	$280,989	$593,179
5	$311,449	$287,089	$598,538
6	N/A	N/A	N/A

# of open facilities	traveled km per year	saved km	hrs saved (spd=30 km/hr)	hrs saved (spd=50 km/hr)	avg # of visits changed	avg capacity changed
1	761,317	0	0	0	0	0.00%
2	674,009	87,308	2,910	1,746	4,656	0.91%
3	641,889	119,428	3,981	2,389	6,369	1.24%
4	585,387	175,930	5,864	3,519	9,383	1.83%
5	579,036	182,281	6,076	3,646	9,722	1.90%
6	N/A	N/A	N/A	N/A	N/A	N/A

S4ii) best locations and staff allocation

Number of nurses allocated to each location:

	number of facilities to open					
proposed locations	**1**	**2**	**3**	**4**	**5**	**6**
Idylwyld Center	79	63	37	25	21	N/A
University Heights Square		16	16	16	15	N/A
Confederation Mall			26	21	14	N/A
Lawson Heights Mall				17	14	N/A
Ave H south					15	N/A
Market Mall						N/A

Number of HHAs allocated to each location:

	number of facilities to open					
proposed locations	**1**	**2**	**3**	**4**	**5**	**6**
Idylwyld Center	113	92	63	42	29	N/A
University Heights Square		21	21	21	21	N/A
Confederation Mall			29	29	21	N/A
Lawson Heights Mall				21	21	N/A
Ave H south					21	N/A
Market Mall						N/A

S5) P-median model for 20% increase in lease cost

S5i) Annual cost, distance travelled and capacity changed

# of open facilities	annual transportation cost	annual lease cost	total annual cost
1	$377,883	$0	$377,883
2	$354,208	$219,019	$573,227
3	$349,134	$362,654	$711,788
4	$341,393	$337,187	$678,580
5	$340,176	$344,506	$684,682
6	N/A	N/A	N/A

# of open facilities	traveled km per year	saved km	hrs saved (spd=30 km/hr)	hrs saved (spd=50 km/hr)	avg # of visits changed	avg capacity changed
1	820,155	0	0	0	0	0.00%
2	730,657	89,498	2,983	1,790	4,773	0.93%
3	688,901	131,254	4,375	2,625	7,000	1.37%
4	639,480	180,675	6,023	3,614	9,636	1.88%
5	637,509	182,646	6,088	3,653	9,741	1.90%
6	N/A	N/A	N/A	N/A	N/A	N/A

S5ii) best locations and staff allocation

Number of nurses allocated to each location:

	number of facilities to open					
proposed locations	**1**	**2**	**3**	**4**	**5**	**6**
Idylwyld Center	83	67	43	27	16	N/A
University Heights Square		16	16	16	16	N/A
Confederation Mall			24	23	16	N/A
Lawson Heights Mall				17	15	N/A
Ave H south					20	N/A
Market Mall						N/A

Number of HHAs allocated to each location:

	number of facilities to open					
proposed locations	**1**	**2**	**3**	**4**	**5**	**6**
Idylwyld Center	128	107	75	53	27	N/A
University Heights Square		21	21	21	21	N/A
Confederation Mall			32	32	23	N/A
Lawson Heights Mall				22	22	N/A
Ave H south					35	N/A
Market Mall						N/A

S6) P-median model for 20% decrease in lease cost

S6i) Annual cost, distance travelled and capacity changed

# of open facilities	annual transportation cost	annual lease cost	total annual cost
1	$377,883	$0	$377,883
2	$354,208	$146,013	$500,221
3	$349,134	$241,770	$590,903
4	$341,393	$224,791	$566,184
5	$340,176	$229,671	$569,847
6	N/A	N/A	N/A

# of open facilities	traveled km per year	saved km	hrs saved (spd=30 km/hr)	hrs saved (spd=50 km/hr)	avg # of visits changed	avg capacity changed
1	820,155	0	0	0	0	0.00%
2	731,460	88,695	2,957	1,774	4,730	0.92%
3	699,121	121,034	4,034	2,421	6,455	1.26%
4	640,283	179,872	5,996	3,597	9,593	1.87%
5	637,509	182,646	6,088	3,653	9,741	1.90%
6	N/A	N/A	N/A	N/A	N/A	N/A

S6ii) best locations and staff allocation

Number of nurses allocated to each location:

	number of facilities to open					
proposed locations	**1**	**2**	**3**	**4**	**5**	**6**
Idylwyld Center	83	68	39	28	16	N/A
University Heights Square		15	16	15	16	N/A
Confederation Mall			28	23	16	N/A
Lawson Heights Mall				17	15	N/A
Ave H south					20	N/A
Market Mall						N/A

Number of HHAs allocated to each location:

	number of facilities to open					
proposed locations	**1**	**2**	**3**	**4**	**5**	**6**
Idylwyld Center	128	107	75	53	27	N/A
University Heights Square		21	21	21	21	N/A
Confederation Mall			32	32	23	N/A
Lawson Heights Mall				22	22	N/A
Ave H south					35	N/A
Market Mall						N/A

S7) 4% and 12% increase in demand for RNs and HHAs

S7i) Annual cost, distance travelled and capacity changed

# of open facilities	annual transportation cost	annual lease cost	total annual cost
1	$388,930	$0	$388,930
2	$366,544	$182,516	$549,060
3	$359,789	$302,212	$662,001
4	$352,076	$280,989	$633,065
5	$350,653	$287,089	$637,742
6	N/A	N/A	N/A

# of open facilities	traveled km per year	saved km	hrs saved (spd=30 km/hr)	hrs saved (spd=50 km/hr)	avg # of visits changed	avg capacity changed
1	844,245	0	0	0	0	0.00%
2	759,127	85,118	2,837	1,702	4,540	0.89%
3	713,575	130,670	4,356	2,613	6,969	1.36%
4	665,614	178,631	5,954	3,573	9,527	1.86%
5	662,256	181,989	6,066	3,640	9,706	1.90%
6	N/A	N/A	N/A	N/A	N/A	N/A

S7ii) best locations and staff allocation

Number of nurses allocated to each location:

	number of facilities to open					
proposed locations	**1**	**2**	**3**	**4**	**5**	**6**
Idylwyld Center	86	68	45	28	19	N/A
University Heights Square		18	16	15	16	N/A
Confederation Mall			25	26	16	N/A
Lawson Heights Mall				17	15	N/A
Ave H south					20	N/A
Market Mall						N/A

Number of HHAs allocated to each location:

	number of facilities to open					
proposed locations	**1**	**2**	**3**	**4**	**5**	**6**
Idylwyld Center	131	107	77	56	30	N/A
University Heights Square		24	22	21	21	N/A
Confederation Mall			32	32	23	N/A
Lawson Heights Mall				22	22	N/A
Ave H south					35	N/A
Market Mall						N/A

S8) Greenfield Project

S8i) Annual cost, distance travelled and capacity changed

# of open facilities	annual transportation cost	annual lease cost	total annual cost
1	$377,883	$0	$377,883
2	$326,781	$0	$326,781
3	$312,301	$0	$312,301
4	$311,746	$0	$311,746
5	$311,813	$0	$311,813
6	N/A	N/A	N/A

# of open facilities	traveled km per year	saved km	hrs saved (spd=30 km/hr)	hrs saved (spd=50 km/hr)	avg # of visits changed	avg capacity changed
1	820,155	0	0	0	0	0.00%
2	561,115	259,041	8,635	5,181	13,815	2.70%
3	493,444	326,712	10,890	6,534	17,425	3.40%
4	468,551	351,605	11,720	7,032	18,752	3.66%
5	463,514	356,642	11,888	7,133	19,021	3.72%
6	N/A	N/A	N/A	N/A	N/A	N/A

S8ii) best locations and staff allocation

Number of nurses allocated to each location:

	number of facilities to open					
proposed locations	**1**	**2**	**3**	**4**	**5**	**6**
Idylwyld Center	83	55		14	14	N/A
University Heights Square						N/A
Confederation Mall			28	26	15	N/A
Lawson Heights Mall			19	17	15	N/A
Ave H south					14	N/A
Market Mall		28	36	26	25	N/A

Number of HHAs allocated to each location:

	number of facilities to open					
proposed locations	**1**	**2**	**3**	**4**	**5**	**6**
Idylwyld Center	128	79		21	21	N/A
University Heights Square						N/A
Confederation Mall			42	28	21	N/A
Lawson Heights Mall			29	24	21	N/A
Ave H south					21	N/A
Market Mall		49	57	55	44	N/A

S9) P-median model without Idylwyld center

S9i) Annual cost, distance travelled and capacity changed

# of open facilities	annual transportation cost	annual lease cost	total annual cost
1	$414,389	$244,857	$659,246
2	$366,800	$384,436	$751,236
3	$363,082	$468,158	$831,240
4	$342,445	$405,158	$747,604
5	$314,320	$397,277	$711,597

# of open facilities	traveled km per year	saved km	hrs saved (spd=30 km/hr)	hrs saved (spd=50 km/hr)	avg # of visits changed	avg capacity changed
1	938,999	0	0	0	0	0.00%
2	787,816	151,183	5,039	3,024	8,063	1.58%
3	764,894	174,105	5,804	3,482	9,286	1.81%
4	655,321	283,678	9,456	5,674	15,129	2.96%
5	457,017	481,983	16,066	9,640	25705.7	5.02%

S9ii) best locations and staff allocation

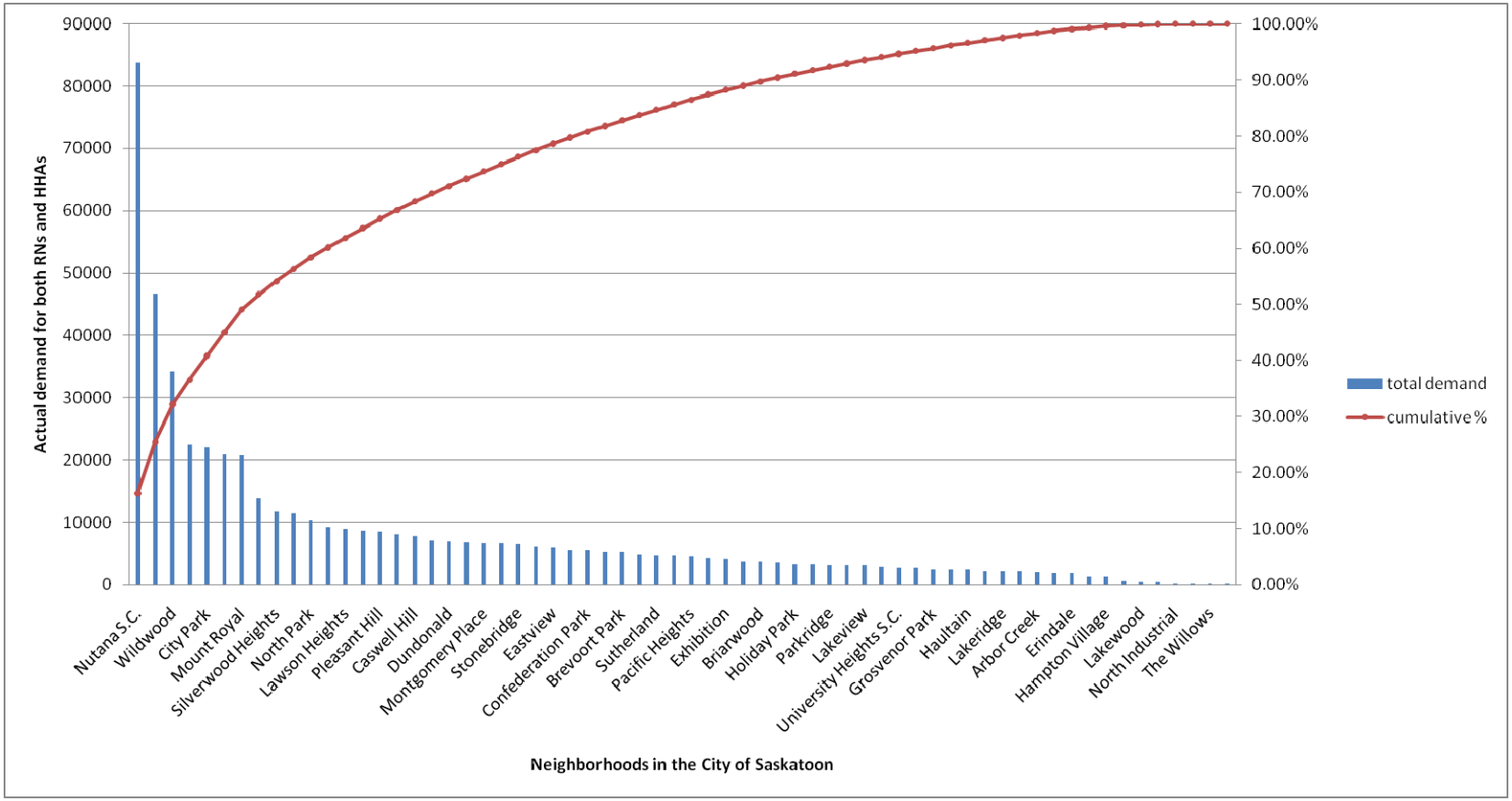
Number of nurses allocated to each location:

	number of facilities to open				
proposed locations	**1**	**2**	**3**	**4**	**5**
Ave H south	83	67	38	27	20
University Heights Square		16	16	16	14
Confederation Mall			29	23	16
Lawson Heights Mall				17	14
Market Mall					19

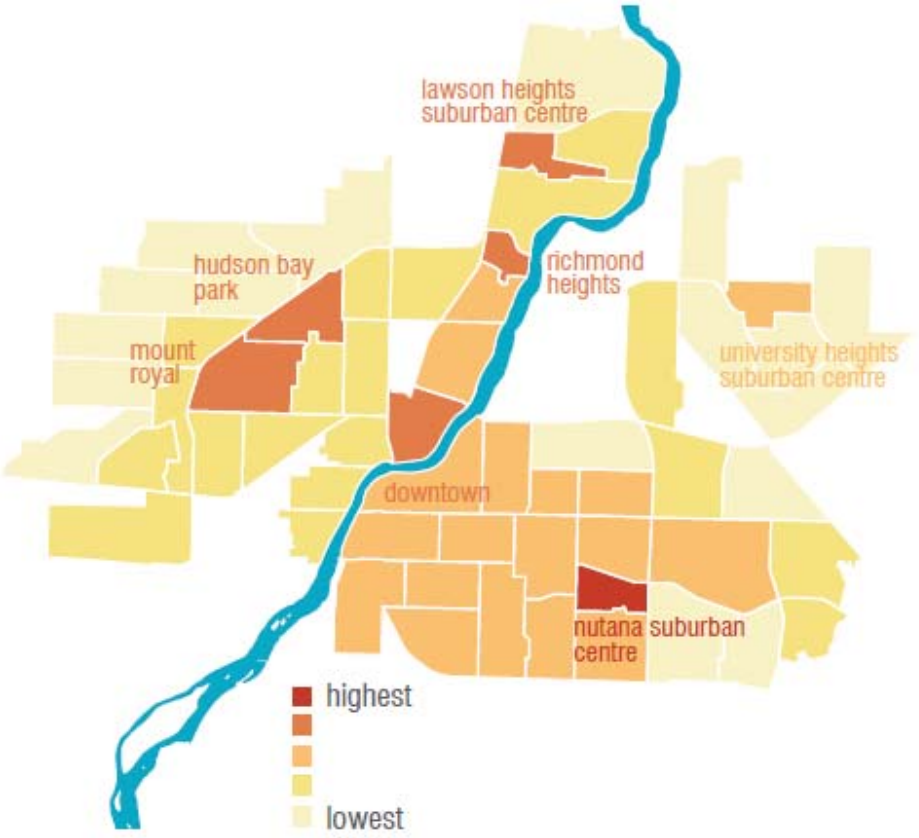
Number of HHAs allocated to each location:

	number of facilities to open				
proposed locations	**1**	**2**	**3**	**4**	**5**
Ave H south	128	107	73	52	30
University Heights Square		21	21	21	21
Confederation Mall			34	32	22
Lawson Heights Mall				23	21
Market Mall					34

Appendix T: Pareto chart



Appendix U: Senior population in City of Saskatoon



Senior Population
(source: City of Saskatoon Implementation of Accessibility Action Plan)