APPLYING ANALYTICAL MODELING TO THE DECENTRALIZATION OF HOMECARE SERVICES

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ABSTRACT

The Saskatoon Health Region's homecare program is responsible for providing in-home respite, meal preparation, security calls, home management, wound care and medication assistance to elderly persons and patients recently discharged from acute care facilities. This health jurisdiction currently includes a sole office located at the Idylwyld Centre, close to the city's downtown core. Homecare management has observed that staff members are incurring lengthy travel distances in driving from this office to client homes scattered throughout the city. We develop an optimization model to prioritize candidate facilities.

Keywords: Health Care Systems, Location, Mathematical Programming/ Optimization

INTRODUCTION

The Saskatoon Health Region (SHR) is the largest health jurisdiction in the Canadian province of Saskatchewan. As described on its website (www.saskatoonhealthregion.ca), it serves roughly 300,000 individuals in more than 100 cities, towns, villages and First Nation communities spread over 34,000 square kilometers. The principal city within this region is Saskatoon, a municipality with over 250,000 residents. The health region operates more than 75 facilities and delivers a vast array of programs and services, including hospital and long term care, public health and homecare, and mental health and addiction services. With nearly 900 physicians and over 13,000 nurses and other health care workers, it is the province's largest employer.

The health region's homecare program is responsible for providing a variety of services within Saskatoon, such as in-home respite, meal preparation, security calls, home management, wound care and medication assistance. These services employ home health aides (HHA) and nurses to deliver important assistance to elderly persons as well as patients ("clients") recently discharged from acute care facilities. Generally, nurses provide more medically complex homecare services than those offered by HHAs.

In order to more effectively manage homecare demand within Saskatoon, the city is divided into four quadrants. Quadrant managers are tasked with the challenging assignment of ensuring that limited homecare staff resources are efficiently deployed to meet client care needs. To accomplish this, these managers scrutinize care plans to determine the prioritization of clients receiving homecare services. Further, the managers build a more detailed care plan for each individual that includes, among other features, client preferences for caregiver gender, preferred times for homecare visits, required equipment for client services, and so forth.

At the beginning of their 8-hour shifts, each HHA or nurse reports to the Idylwyld Centre, a two-story facility located close to Saskatoon's downtown core. This facility serves as the city's homecare base. Upon reporting to the Idylwyld Centre, staff members are provided with their assigned daily schedules. At the conclusion of their daily list of visits and service calls, each HHA or nurse reports back to the Idylwyld Centre to complete required reports and return various medical supplies and equipment.

Despite the best intentions of quadrant managers (who attempt to provide health care workers with daily assignments that reduce travel burden), it is not entirely uncommon for staff members to repeatedly travel across the city to fulfill their health care obligations. These occurrences could arise due to staff unavailability (e.g. calling in sick), surges in homecare demand, last-minute client cancellations, or particular services taking longer than anticipated. With a city that spans an area roughly 25 kilometres (east to west) and about 20 kilometres (north to south), inefficient travelling intensifies staff anxiety, reduces available time for providing homecare services, frustrates clients, and increases total system costs. Current contractual agreements govern health care worker reimbursements for travel between consecutive homecare appointments. For example, a HHA is paid a fixed amount of $3.50 for any distance traveled up to 9.1 kilometres and $0.38 per kilometre for any trips beyond this distance. Nurses are paid a fixed amount of $4.50 for trips up to 11.4 kilometres and $0.40 per kilometre for distances above this threshold.

Health region management has recognized that requiring each homecare worker to report to the Idylwyld Centre at the beginning and conclusion of their shifts may engender system inefficiencies. For example, it may be preferable for SHR to consider a network of homecare offices distributed throughout the Saskatoon metropolitan area. Under such a configuration, homecare workers could report to an office closer to the residence. Although homecare workers are not reimbursed for travel prior to or after their shifts, such a move would most likely increase staff satisfaction. Further, having multiple offices located within Saskatoon may provide greater opportunity for homecare professionals to be associated with and provide service for specific city zones, thereby reducing total distance travelled and decreasing system expenditures. The determination of a cost-effective decentralized network of homecare offices is the focus of this paper.

Management's motivation to analytically explore this location problem stems from a variety of reasons. First, an optimal configuration would lead to travel distance and cost savings. Currently, these homecare workers are annually travelling in excess of 800,000 kilometres. Since the government reimburses homecare travel through taxation revenues, cost savings would reduce the burden on the public purse.

Secondly, reducing travel times would lead to more time for direct care. Within the current system, homecare workers provide actual client care for roughly 50% of their typical working day. The remaining 50% is absorbed with driving to client homes, finding parking spots, and negotiating travel through congested urban streets. Moreover, the demand for nurse and HHA services increased by nearly 20% and 15%, respectively, between 2008 and 2010. This augmentation of homecare demand – accompanied by the ubiquitous problem of staff recruitment - fuels the need to identify a solution in which medical professionals devote less of their day to traveling.

An additional impetus for a location analysis involves the city of Saskatoon's plan to expand the roadway near the Idylwyld Centre. This would curtail the available office space in this building, thereby reducing the amount of medical equipment and supplies that could be stored. Further, it would limit the number of staff members that could report there for duty at the beginning and end of their shifts.

Our paper proceeds as follows. The next section provides a brief literature summary. We then explain the development of our analytical optimization model, after which we describe various homecare office location results. We conclude the paper with some summary remarks.

LITERATURE SUMMARY

The determination of the optimal number, size and location of facilities to serve a base of customers is one of a well-studied class of problems known as location/allocation analysis. These problems have been studied by researchers from several academic disciplines including economics, engineering, mathematics and operations research. Cooper (1963) was an early contributor. Love, Morris and Wesolowsky (1988) provided a seminal treatment. Daskin and Dean (2004) discussed facility location analysis solely within a health care context. These authors illustrated that that healthcare facilities should be situated in locations that optimize accessibility, adaptability and availability of required services.

Rather than devoting coverage to the myriad of location analyses described in the literature, this summary will instead illustrate particular health care applications. This ought to provide the reader a sense of the various health care areas explored by researchers. Gu, Wang and McGregor

(2010) investigated the best location for breast cancer screening programs in the Canadian province of Alberta. Increasing patients' participation in this program was imperative since it promoted enhanced quality of life. Therefore, the authors sought to increase the accessibility of these preventive healthcare services.

Malczewski and Ogryczak (1990) employed an interactive approach to find best locations for a pediatric hospital in Warsaw. They deployed a multi-objective analysis to minimize such factors as travel cost, investment cost, operating cost and the hospital's environmental pollution. Further, they maximized users' satisfaction. Rahman and Smith (2000) used quantitative models to find the best locations of hospitals in developing countries such as Bangladesh.

Rajagopalan, Saydam and Xiao (2008) explored the dynamic redeployment of ambulances. In this case, ambulance demand fluctuated during the week and throughout the day. The authors determined the minimum number of ambulances and their concomitant locations. Investigating a situation in which demands were stochastic, Chan, Carter and Burnes (2001) formulated a stochastic location-routing problem for a medical-evacuation case study of the U.S. Air Force.

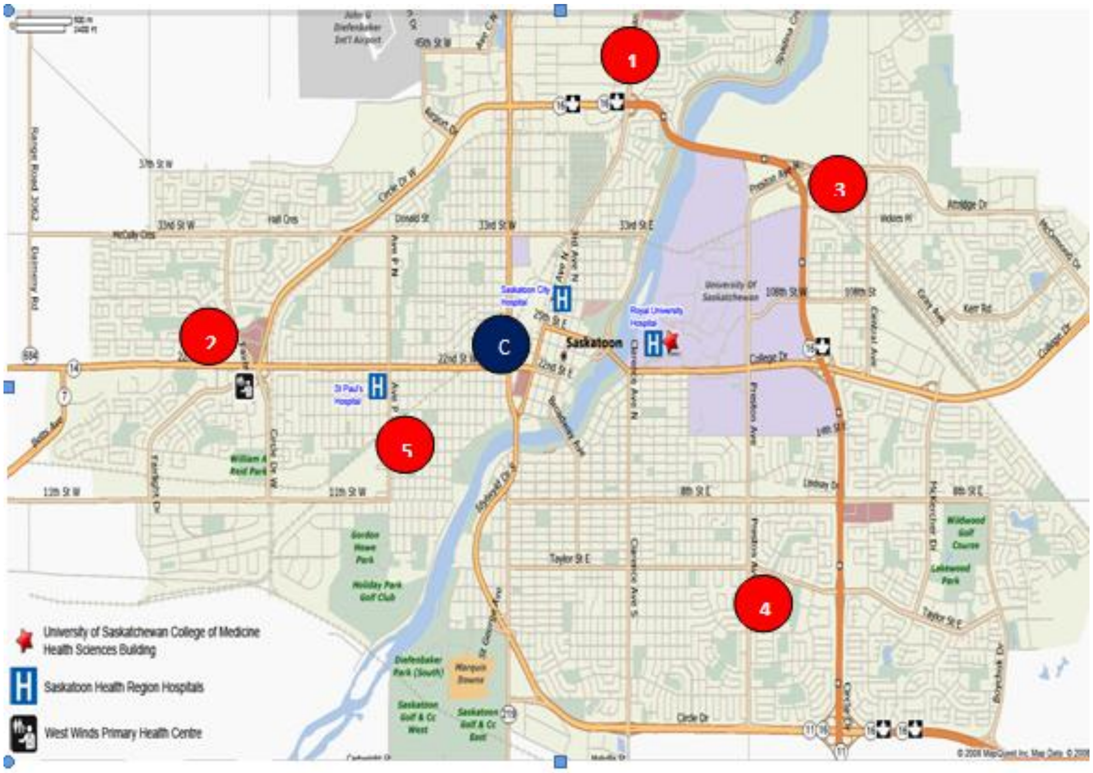
Verter and Lapierre (2002) analyzed the location of preventive healthcare facilities. The main objective of their research was to maximize participation, defined as the probability that a patient requiring preventive healthcare services would select the closest facility location. Exploring an actual Quebec City case, Price, Turcotte and Hebert (1986) studied the relocation of a blood bank. Due to population increases, blood demand was expected to rise. The authors gathered data related to mobile clinics, blood deliveries and donors who travel to clinic centres, and performed a series of gravity models to optimize location options.

Jia et al (2007) used different facility location models to plan the location of emergency medical services for large-scale crises such as terrorist attacks, hurricanes and earthquakes in the Los Angeles area. Since these events rarely occur but have huge influence on medical service demand, the authors adopted an objective of minimizing the loss of life. They determined that facilitating access to multiple highways and being safe from crisis damage are important criteria in selecting locations.

MODEL

Recall that the Idylwyld Centre is the health region's current homecare office. SHR management has identified five potential office locations distributed throughout the city of Saskatoon. Each of the proposed locations is situated near a major thoroughfare or a commercial real estate area. The Idylwyld Centre and candidate locations are illustrated in Figure 1.

FIGURE 1:
Current and potential homecare office locations



The candidate facilities involve office space in the following areas (numbers represent particular circles in Figure 1):

- Lawson Heights Mall (1)
- Confederation Park Mall (2)
- University Heights Square (3)
- Market Mall (4)
- Avenue H South (5)

The Idylwyld Centre is denoted by the letter "C".

Our analytical facility location model determines the optimal set of sites that leads to overall cost minimization. We consider factors such as new facility lease costs, as well as the travel expenditures associated with meeting homecare demand. Using information from Saskatoon commercial real estate data, we obtained the total lease cost for office space of suitable capacity at or near each proposed site. Besides determining the best number and location of homecare offices, it is desirable to establish the size of each facility in terms of the number of healthcare professionals assigned to each site.

In order to proceed with finding the best set of locations, we segmented the city of Saskatoon into 64 residential neighborhoods. Using Google map, we computed the distance travelled between the set of locations (either current facility or proposed sites) and the centre of each neighborhood. This assumes, of course, that each area's demand originates at each neighborhood's hub. However, we felt that such an aggregated approach would still provide realistic travel distances. Moreover, this method was deemed preferable to calculating travel distances from all locations to individual homecare clients. Since the set of clients displays some variation over time (some folks may no longer require service, with new clients being routinely added to the homecare roster), it would be an extremely challenging task to calculate actual distances at the level of the individual client.

We also required each neighborhood's demand for homecare services. Homecare managers provided this information in terms of the annual number of visits for either HHAs or nurses. Further, we note that there are currently 128 HHAs and 88 nurses available for delivering homecare services.

For the most recent fiscal year, annual homecare travel was 820,155 kilometres. This travel distance necessitated a reimbursement of $377,883. Therefore, we can evaluate performance of our analytical model in terms of reducing this overall cost amount.

We will use the p-median model as described in Daskin and Dean (2004) to determine optimal facility location. Using the subscript *i* to represent neighborhoods and *j* to denote locations, our model is as follows:

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

Subject to:

$$\sum_j {S_{ij}}^{HHA} \geq {d_i}^{HHA} \qquad \forall\, i \in I \tag{2}$$

$$\sum_j {S_{ij}}^{RN} \geq {d_i}^{RN} \qquad \forall\, i \in I \tag{3}$$

$$15X_j \leq \sum_i {S_{ij}}^{HHA} \leq 128\, X_j \qquad \forall\, j \in J \tag{4}$$

$$10X_j \leq \sum_i {S_{ij}}^{RN} \leq 88\, X_j \qquad \forall\, j \in J \tag{5}$$

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

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

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

$${S_{ij}}^{HHA} \in \mathbb{N}^0 \forall\, j \in J,\ \forall\, i \in I \tag{9}$$

$${S_{ij}}^{RN} \in \mathbb{N}^0 \forall\, j \in J,\ \forall\, i \in I \tag{10}$$

$$X_j \in \{0, 1\} \qquad \forall\, j \in J \tag{11}$$

We adopted the following variable definitions:

${C_{ij}}^{HHA}$: Cost of travelling from facility *j* to neighborhood *i* for a HHA

${C_{ij}}^{RN}$: Cost of travelling from facility *j* to neighborhood *i* for a registered nurse

${S_{ij}}^{HHA}$: Number of HHAs sent from facility *j* to neighborhood *i* each day

${S_{ij}}^{RN}$: Number of registered nurses sent from facility *j* to neighborhood *i* each day

$X_j = 1$ *:* 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 facilities required to be open

The objective function tabulates the annual travel cost as well as lease costs for new facilities. Constraints (2) and (3) ensure that the number of homecare professionals assigned from all open locations to each neighborhood is such that the demand of that neighborhood is fully covered.

In constraints (4) and (5), we prevent assigning a neighborhood's demand to an unopened site. The maximum amount corresponds to the number of available HHAs or nurses. Officials were careful to consider candidate locations that had sufficient office space to house, if needed, the entire allotment of homecare workers. The minimum number refers to the lowest possible assignment of staff that would still make a location suitable. Obviously, it would be rather inefficient to open an office location within the city and only assign one or two homecare professionals to it. Homecare management felt that the minimum values of 15 (HHA) and 10 (nurses) were reasonably appropriate minima. Constraints (6) and (7) limit the total number of HHAs and nurses sent from all open locations to all neighborhoods.

The variable P represents the number of facilities required to be open. We use constraint (8) to ensure that our model results meet this condition. Constraints (9) through (11) feature numerical bounds on various variables.

RESULTS

We used Premium Solver to minimize the objective function. This software package determined the best set of locations, as well as the number of HHAs and nurses that should be dispatched from any site to each neighborhood. Generally, the model solved to optimality within a few seconds.

Table 1 reports our model results for different numbers of open facilities. It lists the annual travelling and lease costs associated with each solution. As per constraint (8) in our model, we ran versions for values of p from 1 through 6 but only report the first five instances in this table. When p = 6, the model simply retains the current Idylwyld Centre and opens each new candidate location.

According to our expectations, the annual transportation costs drop and the overall lease costs climb as we increase the number of open facilities. As more facilities are in operation, homecare professionals are located closer to each neighborhood thus reducing travel distances. However, additional open facilities necessitate greater total lease costs. It is interesting to note that total costs increase monotonically as we escalate the number of open facilities. If healthcare planners wanted to minimize overall costs, the best system configuration would be a one-facility (Idylwyld Centre) network. The reduced transportation costs associated with facility expansions are outweighed by the resulting lease costs.

TABLE 1:
Optimization model results

Number of open facilities	Annual transportation cost	Annual lease cost	Total annual cost
1	$377,883	$0	$377,883
2	$373,517	$122,429	$495,945
3	$324,905	$242,827	$567,732
4	$319,450	$271,680	$591,130
5	$317,863	$330,387	$648,250

Of particular interest to homecare planners is the relative ranking of the candidate locations. This can be understood by observing the order in which each location entered the optimal network configuration. We provide these details in Table 2. The letter or number after each location refers to its symbol provided in the map in Figure 1. Since the health region owns Idylwyld Centre, they do not incur any lease costs for its operation. Thus, no matter the number of facilities that are required to be open, this location is always one of the best sites to use. After the Idylwyld Centre, the Avenue H South location is the second best choice. This outcome was influenced by this particular location's relatively low lease costs. The third best place for a new facility is the Market Mall location due to the high demand for homecare services in that neighborhood. This facility is situated near a conglomeration of senior-citizen apartment buildings. The Confederation Mall and Lawson Heights Mall locations are the next to enter the optimal solution. The University Heights Square location is the least preferred site, since it did not become part of an optimal solution until we forced the model to open all locations. Tables 3 and 4 provide the number of nurses and HHAs, respectively, assigned to each office location.

TABLE 2:
Optimal locations

Proposed locations	Number of facilities to open				
	1	2	3	4	5
Idylwyld Centre (C)	✓	✓	✓	✓	✓
Avenue H South (5)		✓	✓	✓	✓
Market Mall (4)			✓	✓	✓
Confederation Mall (2)				✓	✓
Lawson Heights Mall (1)					✓

TABLE 3:
Nurse assignments

Proposed locations	Number of facilities to open				
	1	2	3	4	5
Idylwyld Centre (C)	83	30	14	14	14
Avenue H South (5)		53	42	28	18
Market Mall (4)			27	27	23
Confederation Mall (2)				14	14
Lawson Heights Mall (1)					14

TABLE 4:
HHA assignments

Proposed locations	Number of facilities to open				
	1	2	3	4	5
Idylwyld Centre (C)	128	73	35	28	21
Avenue H South (5)		55	44	30	21
Market Mall (4)			49	49	44
Confederation Mall (2)				21	21
Lawson Heights Mall (1)					21

To provide additional insight to homecare management, we analyzed various scenarios and their impact on model solutions. We report on a few of them in this paper. For instance, we explored a scenario to determine the best set of locations if one assumed there were no lease costs. In this particular situation, the only relevant costs are the travel expenditures. This is akin to a "Greenfield" situation in which planners would have the luxury of starting afresh with a brand-new location configuration. If one could start all over again, where would the homecare offices be located in the city of Saskatoon?

We offer these results in Table 5. This analysis demonstrates that Idylwyld Centre is again the best location for a one-facility homecare system. In fact, except for P = 2 or 3, the best set locations remained the same as those discovered earlier. However, when only two facilities are required to be open, the best locations are Idylwyld Centre and University Heights Square. For three facility locations, we found that Market Mall, Confederation Mall and Lawson Heights Mall are chosen as the best sites. This analysis reinforces the cost-effectiveness of the Idylwyld Centre location, since it was featured in all but one of the Table 5 model versions. This facility's attractiveness is influenced by its central location within the city.

TABLE 5:
"Greenfield" locations

Proposed locations	**Number of facilities to open**				
	1	**2**	**3**	**4**	**5**
Idylwyld Centre (C)	✓	✓		✓	✓
Avenue H South (5)				✓	✓
Market Mall (4)			✓	✓	✓
Confederation Mall (2)			✓	✓	✓
Lawson Heights Mall (1)			✓		✓
University Heights Square (3)		✓			

We also modeled a scenario in which homecare management forced the closure of the Idylwyld Centre. If one were to do this and restrict the number of open facilities to one, the best location would be the Avenue H South site. However, we found that the annual transportation cost would rise to $414,389, an increase of over $36,000 from the one-site transportation costs reported in Table 1. This solution also incurred lease costs of $122,429, meaning that the total system costs would definitely increase by using Avenue H South as the one-facility alternative instead of Idylwyld Centre.

CONCLUSIONS

In this paper, we have explored the application of analytical modeling to the decentralization of homecare offices for the Saskatoon Health Region. This health jurisdiction currently includes a sole facility located at the Idylwyld Centre, close to the city's downtown core. Challenging circumstances involve lengthy travel distances for its highly-trained homecare staff which precipitates a reduction in the amount of client care time these professionals can provide throughout the day. The city is experiencing growth in homecare demand. Further, a roadway expansion near the present location may reduce available office space, thereby forcing the health region to consider an alternative location scheme

We used a model that minimized total annual costs subject to a set of constraints. Based on homecare management suggestions, we studied five possible candidate locations. Our model results reported the optimal number, location and size of homecare offices under a variety of particular scenarios. The preferred locations are (in descending order) Idylwyld Centre, Avenue H South, Market Mall, Confederation Mall, Lawson Heights Mall and University Heights Square.

We did assume that homecare staff would pick the shortest route (the ones we computed with Google map) when travelling between consecutive appointments. In reality, it is conceivable that staff would select a different (longer) route according to individual preferences, or on days involving high traffic or construction along the pre-determined shortest route. Notwithstanding this assumption, we feel that our model results can inform homecare management decision-making. It analytically demonstrates the impact of various cost factors on location planning and prioritizes a list of candidate facilities.

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