GSJ: Volume 9, Issue 10, October 2021, Online: ISSN 2320-9186
www.globalscientificjournal.com

A PATIENT-BASED SET COVERING FACILITY LOCATION MODEL

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ABSTRACT

Facility location decisions are taken at almost all areas of life. These decisions are usually a strategic issue. Industries and government agencies must decide the location of facilities to maximise utility. The focal point of most facility location studies is the owner of the system. In this research, we looked at location of health care access points for patients with Chronic health conditions, from the perspective of the patient. We noted that this category of patients most likely to have social, cultural, and political considerations in their associations including choice of points of healthcare access. We introduced a few modifications to the classical set covering facility location model to achieve this. We considered each chronic challenge as a scenario. We introduced a quality threshold for each patient location below which a service provider is not considered a candidate facility. The study thereby recommended the modified model for application in the location of counselling centres, location of screening centres for illnesses that could attract stigmatization e.g. HIV Aids or other viral infections, location of collection centres for volunteer information to security organizations, location of feedback systems in military settings, among others.

Key Words:

Facility, Location, Chronic Diseases, Set Covering, Decisions, Health Care, Modelling

BACKGROUND

Without doubts, analysis of the effectiveness of locational decisions is as old as human history. Facility location decisions are taken at almost all areas of human endeavour. The term “facility” here is mostly used in its broadest sense. That is, it is meant to include entities such as air and maritime ports, factories, warehouses, retail outlets, schools, hospitals, day-care centres, bus stops, subway stations, electronic switching centres, computer concentrators and terminals, rain gages, emergency warning sirens, and satellites, to name but a few that have been analysed in research literature. The ubiquity of locational decision-making has led to a strong interest in location analysis and modelling within the Operations Research and Management Science community. The long and large history of location research results from a number of factors some of which are:

1. That location decisions are frequently made at all levels of human organization from individuals and households to firms, government agencies and even international agencies.
2. That those decisions are often strategic in nature. That is, they involve large sums of capital resources and their economic effects are long term. In the private sector they have a major influence on the competitive capability of the firm in the market place. In the public sector they influence the efficiency by which jurisdictions provide public services and the ability of these jurisdictions to attract households and other economic activity.
3. That they frequently impose economic externalities. Such externalities include pollution, congestion, and economic development, among others.
4. That location models are often extremely difficult to solve, at least optimally. Even the most basic models are computationally intractable for large problem instances. In fact, the computational complexity of location models is

a major reason that the widespread interest in formulating and implementing such models did not occur until the advent of high-speed digital computers.

5. That location models are application specific. That is, their structural form (the objectives, constraints and variables) is determined by the particular location problem under study. Consequently, there does not exist a general location model that is appropriate for all potential or existing applications [3].

Decisions about facility location are a strategic issue for almost every organisation. The problem of locating facilities and allocating customers covers the core components of distribution system design. Industries must locate their factories, warehouses, distribution/sales outlets etc. properly to take advantage of raw materials and the market as applicable. Similarly, government agencies have to decide about the location of offices, schools, hospitals, fire stations, etc. In every case, the quality of the services depends on the location of the facilities in relation to other facilities.
Location theory and modelling has its roots in the pioneering work of Weber [9] who considered the problem of locating a single facility to minimize the total travel distance between the site and a set of customers. Later, [5] studied the location of two facilities on a line. In his simple model, customers patronize the closer of the two facilities and the vendors locate to maximize their market share.
Not much of the literature on facility location modelling has been directed to specific applications (i.e., case studies). Rather, it has been directed to formulating new models and modifications to existing models which have many potential applications, and to developing efficient solution techniques for existing or newly formulated models.

THE PROBLEM

Chronic Disease conditions represent more than 60 percent of the global disease burden and account for 70 percent of deaths, yet receives less than two percent of development assistance for health [11].
About 41 million people die of Chronic Disease conditions each year, accounting for 71% of all global deaths [10]. The high prevalence of Chronic Disease conditions is particularly problematic for Sub-Saharan Africa since Chronic Disease conditions are already a major cause of mortality in the sub-region. While the case fatality rate of COVID-19 is quite low (6% as of June 3 2020) [10], it is worth noting that people with underlying Chronic Disease conditions constitute the majority of those who die from the virus [7]. The Sustainable Development Goal (SDG) 3.4 seeks to reduce by one third, premature mortality from Chronic Disease conditions through effective prevention and management by the year 2030 and the NHIS is one of the approaches the government is deploying to help manage the burden of chronic disease challenge in the country. For the NHIS to manage this burden of chronic disease challenge, it requires the efficient utilization of the health resources which are limited, owing to a large extent, to the devastation caused by the recent crises. Despite the limited health resources however, the patients with chronic diseases must be attended to. The inputs that can guide the efficient utilization of the limited health resources in meeting up with service delivery to the patients can be derived from models, in particular facility location models.
The most common class of facility Location models employed over the years for locating medical infrastructure is the set covering location models. These group of models guarantee a given measurable level of reach (coverage) for any given target population.
Attempts have been made in this area resulting in such models as: the covering models which aim to minimize the number of facilities located while providing coverage to all demand nodes or maximize the coverage provided the facility quantity is pre-specified [2]; the P-Centre models which have an objective to minimize the maximum distance (or travel time) between the demand nodes and the facilities [1] are often used to optimize the location of facilities in the public sector such as hospitals, post-offices and fire stations; the P-median models which attempt to minimize the sum of distances (or average distance) between the demand nodes and their nearest facilities [8], often used by Companies in the private sector to make facility distribution plans so as to improve their competitive edge; probabilistic and non-probabilistic models were also developed including congestion models; etc.
These models made extensive coverage of researches made by researchers in healthcare location problems. These models are developed with bias towards service providers (facility owners) Their main objectives were mostly to minimise either the number of facilities sited or minimise the total cost of siting the facilities, or maximizing the total coverage when a given fixed number of facilities are to be sited, or minimising the total distance travelled by patients of the facilities, under the assumption that the health conditions of the patients are the same. Ideally, patients with chronic health conditions are supposed to be given preferences while providing health care services. If these preferences are ignored, the patients with chronic diseases are likely to suffer and may resort to finding alternatives that may further complicate the management of their situation. Thus, the need to develop a model that will focus on the needs of these patients in facility location is desirous. It is in the light of this need that the study developed a patient-based location model.

The purpose of this research is to develop a patient-model by modifying the Set Covering Facility Location Model such that the model addresses adequately, the problem of locating a point of access for a patient with chronic health conditions from the patient's point of view. The proposed model accommodates the peculiarities of these category of patients who have other factors that cannot easily be quantified but which affects their choice of the point of access.

Significance of this research: Any research that could lead to an enhanced management of Chronic Health conditions is very needful because chronic disease is an important contemporary health issue, and is growing in importance, because:

i. A person's social circumstances affect the chance of him/her having a chronic disease greatly. So the chances are right that more people will come down with one chronic health condition or the other.
ii. Some patients have multiple chronic diseases, which make their care particularly complex.
iii. Chronic diseases usually have a mild beginning, a simple social habit, or what appears to be a normal life, but gradually grow into a life-threatening monster.
iv. There is evidence that chronic disease can be better managed through increased ease of access to special medical help.

Most existing studies on facility location are focused only on the point of view of the owners of the system.

Methodology

The classical Set Covering Facility Location model (SCFL) as presented by [4] is:

$$Minimze\ Z = \sum_{j \in J} x_j$$

$$Subject\ to\text{:} \sum_{j \in N_i} x_j \geq 1, \ \forall i \in I$$

$$x_j = 0{,}1, \forall j \in J$$

Where:

Z = the Objective Function
J = the set of eligible facility sites
I = the set of Customer Points
$x_j = \begin{cases} 1, & if\ a\ facility\ is\ located\ at\ j \\ 0, & otherwise \end{cases}$
N_i (the Number of candidate facilities) = $\{j/d_{ij} \leq s\}$; $with\ d_{ij} = \begin{Bmatrix} the\ shortest\ distance\ from\ potential \\ facility\ location\ j\ to\ Customer\ Point\ i \end{Bmatrix}$

s = distance standard for coverage.

Constraint (1) above forces the model to assign a patient's location to at least a service facility.

Considering the combined effects of the objective function and constraint (1) above, if this model attains it's best, a patient's location should be assigned to only one service facility. In this case, the Patient has no choice than attend that service facility. But these patients are healthy looking, so they do have social, political, religious or cultural considerations which may have strong influence on their decisions. [6] corroborated this and maintained that humans have a mind of their own and so will always have other considerations in the choices they make, which cannot be mechanically pre-determined.
Therefore, we modified this classical model to accommodate the peculiarity of the customer's situation discussed above by making room for larger number of choices to the patient. This was done by modifying the first constraint in the model.

It was also found to be necessary to streamline the sample space of candidate service points from where the model can make selection. This was achieved through the introduction of a threshold of quality for the service points.

The scenario analysis was also incorporated into the set covering model where each chronic condition was considered a scenario. This improves the coverage capability of the model.

RESULTS AND DISCUSSION

The Proposed Model Development

The proposed modified model uses the classical Set Covering Facility Location Model as a framework.

The classical set covering facility location model is given as:

$$\left.\begin{aligned} &Minimze\ Z = \sum_{j \in J} x_j \\ &Subject\ to: \sum_{j \in N_i} x_j \ \geq 1, \ \ \forall i \in I \\ &\qquad\qquad\qquad\qquad x_j = 0{,}1, \forall j \in J \end{aligned}\right\} \quad (1)$$

Where:

Z - Minimum no of facilities that covers all demand points

J - the set of eligible facility sites

I - the set of demand Centres

$x_j = \begin{cases} 1, & if\ a\ facility\ is\ located\ at\ j \\ 0, & otherwise \end{cases}$

N_i (the Number of candidate facilities) -- $\{j \backslash d_{ij} \leq s\}$;

------------------------ (2)

$with\ d_{ij} - \begin{Bmatrix} the\ shortest\ distance\ from\ demand\ node\ i\ to\ potential \\ facility\ location\ j \end{Bmatrix}$

s - distance standard for coverage.
Constraint (1) above forces the model to assign a demand centre to at least one service facility.
The classical set covering facility location model makes among others, the following assumptions:

i. That there are patrons who need a particular service that can be provided.
ii. That the location of these patrons is known.
iii. That the cost of providing this service is considerably large.
iv. That the cost of not providing this service is even larger.
v. That considerable savings/profits are desired by the service provider.
vi. That a patron is considered adequately served if at least one service point is placed within a specified distance from his location.

This model was modified by relaxing assumption (vi) and emphasizing assumption (iv).

The proposed model, henceforth referred to as: Modified Set Covering Facility Location Model (MSCFL) is hereby presented as follows:

$$\left.\begin{aligned} &Minimze \quad Z_s = \sum_{j \in J} x_j \\ &\text{Subject to: } \frac{1}{d_{ij}} \left(E_{js} + E_{js}\right) \geq T_s \\ &\qquad \sum_{j \in J} x_{js} \ \geq 2, \ \ \forall i \in I \\ &\qquad x_j = 0{,}1, \qquad \forall j \in J \end{aligned}\right\} \quad (3)$$

Where:
J - the set of eligible facilities (Indexed by j)

I - the set of patients' locations (Indexed by i)

$x_j = \begin{cases} 1, & if\ a\ Service\ point\ is\ located\ at\ j \\ & 0, \ otherwise \end{cases}$

E_{js} - Rating of equipment at service point j for management of scenario s.

F_{js} - Rating of Specialists at service point j for management of scenario s.

T_s - quality threshold for scenario s.

If we consider each of the six (6) chronic disease conditions under study as a scenario (*s = 1, 2, … 6*),

Given a set of service points

$N_i = \{J \backslash Q_{jis} \geq T_s\}, \ \forall j \in J, \ \forall i \in I$ and for each scenario s, $s = 1,2, \ldots 6$

i.e. N_i is a set of facilities capable of offering service to patients in location i at a quality level of at least T_s

Where:

T_s - Quality threshold for scenario s.

$$Q_{jis} = \frac{1}{d_{ij}}\{F_{js} + E_{js}\} \quad (4)$$

F_{js} –Rating of Specialists at service point j for management of scenario s.

E_{js} –Rating of equipment at service point j for management of scenario s.

Q_{jis} - Quality of service facility j can provide to patient location i with scenario s.

And d_{ij} - Distance from patient location i to hospital j

Then the Modified Set Covering Facility Location Model (MSCFL) becomes:

$$\left.\begin{aligned} &Minimze\ Z_s = \sum_{j \in J} x_j \\ &Subject\ to\!: \sum_{j \in N_i} x_j \geq 2, \ \forall i \in I \\ &\qquad\qquad x_j = 0,1, \qquad \forall j \in J \end{aligned}\right\} \quad (5)$$

Where:

Z_s - minimum number of facilities required to offer complete coverage to all patients with scenario *s* in all patient locations

J - the set of eligible NHIS facilities (Indexed by *j*)

I - the set of patients' locations (Indexed by i)

$$x_j = \begin{cases} 1, & if\ a\ facility\ is\ located\ at\ j \\ 0, & otherwise \end{cases}$$

From the formulation above, the objective function minimizes the total number of facilities used. The first constraint ensures that the selection of a service provider is made from a set of facilities whose capacity to provide service to the particular scenario exceeds a certain quality level called the quality threshold T_s. This constraint also relaxes the restriction on the number of service providers for each patient location to at least two (2). This ensures that a given patient location has at least two facilities that can provide quality coverage to that point. The second constraint declares the variable x_j as a binary variable.

CONCLUSION

From the reviews and analyses made so far, it has been explained that the classical set covering facility location model is inadequate in handling optimization cases where the direct beneficiaries of that system are people most especially patients suffering from Chronic health conditions. It was shown that human customers have a number of factors they take into consideration in the choices they make including choices of points to access health care.

Having studied the systems above with their peculiarities, particularly that the customers are humans, this study believes that the scenario set covering facility location model proposed in this study makes considerable accommodation of the additional factors that frequently influence the choices made by patients with Chronic health conditions in the choices they make of access points to health care and hereby recommends it.

This model is recommended for use in the location of counselling units, screening centres for illnesses that could attract stigmatization e.g. HIV Aids or other viral infections, location of collection centres for volunteer information to security organizations, feedback systems in military settings or any such systems similar to that of the patients with Chronic health conditions.

ACKNOWLEDGEMENT

We wish to acknowledge the support and guidance of Prof. H. G. Muazu of the Modibbo Adama University, Nigeria.

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