Chapter 23
Primary Health Care Facility Location and Telemedicine

Kaushal Kumar

Abstract A major challenge for achieving universal health care is to sustain balanced primary care access in society. In highly populated developing countries like India, a low-cost approach is inevitable. Telemedicine can be highly beneficial to address this concern. Moreover, the growing demand for health care in epidemics like COVID-19 has also promoted the usage of teleconsultation. This article presents a framework for incorporating telemedicine services to strengthen the existing primary health care network. An integer linear programming-based optimization model has been developed for locating primary care facilities in the presence of functioning telemedicine services. The objective would be to find a trade-off between the location of new primary health care facilities and the usage of telemedicine services for primary health care. Numerical experiments and a case study have been carried out to explain the working of the model and to derive policy directions. While performing sensitivity analysis concerning budget, it was observed that teleconsultation services outweigh new primary care facilities. Moreover, increasing the levels of capacity by 50% over existing capacity levels resulted in complete coverage. By conducting a case study in the northeast district of Delhi, it was found that complete coverage could not be achieved and therefore, new sites for primary care centers along with new teleconsultation services are required to be identified.

Keywords Primary health care · Location-allocation · Telemedicine · Teleconsultation · Maximal covering location model · COVID-19

Introduction

Universal health coverage requires a robust health care system in place. The role of primary health care is immeasurable in ensuring satisfactory functioning of a health care system [26]. Reinforcing primary health care is the most efficient and cost-

K. Kumar (✉)
Department of Operational Research, University of Delhi, Delhi, India
e-mail: kkumar@or.du.ac.in

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effective approach to strengthen overall health system [4]. Success of primary health care depends on accessibility of primary health care services [25]. If the access to primary health care services is not convenient and comfortable, it tends to scale down the effectiveness of primary health care. A useful approach to address this concern is to consider patient preferences while designing a primary health care system.

The demand for primary health care services becomes manifold during pandemics like COVID-19. Moreover, the closing of health facilities in many countries has resulted in primary care services cutback [15]. As a result, delivery of primary care services becomes an enormous challenge [17]. Expansion of existing primary care services is therefore needed to meet the increased demand [3]. Virtual health care practices like teleconsultation can be highly beneficial in these situations [18, 28].

Teleconsultation services assist in the smooth delivery of primary care and become highly significant during epidemics [23]. Virtual health practices like teleconsultation have the potential to regulate congestion at health facilities and thereby improve their utilization [30]. Moreover, teleconsultation is not only a cost-effective approach, but it can also cater to a higher population in comparison with traditional health systems [12]. Therefore, in addition to improving access to care, teleconsultation also lifts the quality of health care delivery [22]. Kadir [17] discussed the importance of teleconsultation services for primary care during the COVID-19 outbreak. Jnr [16] presented a discussion on the role of digital health care practices like telemedicine in handling pandemic situations like COVID-19.

Leventer-Roberts et al. [20] conducted a cross-sectional study in Israel and found teleconsultation feasible for pediatrician after-hours services. Vosburg and Robinson [28] in their study reported higher patient and provider satisfaction levels associated with teleconsultation services in comparison with in-person visits. Bressman et al. [5] through their findings established the ability of teleconsultation services to improve post-discharge primary care access. Gomez et al. [11] performed a qualitative study on physicians and found teleconsultation services convenient for patients and helpful in improving access to primary care.

Extensive research is available on location-allocation problems in health care. The majority of the location-allocation literature caters to an emergency-free environment [12]. Emergencies like pandemics result in a sudden increase in health care demand, and prompt location-allocation decision-making of health services is required in such situations [29]. Moreover, location-allocation decision-making is inevitable for establishing an emergency response system [21]. In recent times, the outburst of COVID-19 calls for making teleconsultation an inherent part of a health system to deal with emergencies [24].

Gulzari and Tarakci [12] presented a location-allocation framework involving teleconsultation for assisting relief activities during an earthquake emergency. Gao et al. [9] presented a location-allocation model for locating temporary health centers to handle earthquake-emergency operations. This study presents a location-allocation model that incorporates teleconsultation services in addition to finding the location of new health centers. Demirbas and Ertem [8] presented a mixed-integer programming-based location-reallocation model for disaster relief operations. Geng et al. [10] introduced a location-allocation emergency relief model based on victims' pain perception cost.

Maximal covering location model given by Church and ReVelle [7] is concerned with maximizing the coverage of the target population. Due to this important objective, it finds applications in various service domains, viz. health care, banking, retail, hotel, restaurant, etc. [6]. Moreover, the significance of coverage maximization becomes immense in emergencies for health care. Many contributions illustrate the utilization of the maximal covering model in health emergencies. Zhang et al. [31] utilized maximal covering location model to develop an optimization framework to deal with uncertainty during emergencies. Alizadeh et al. [1] presented a multi-period version of the maximal covering location model for the location of relief centers for calamities. Hassan et al. [13] suggested a nonlinear version of the maximal coverage model for locating field hospitals to tackle the COVID-19 pandemic. Taiwo [27] used maximal covering location model for locating supplementary COVID-19 testing laboratories in Nigeria. This study presents a novel expansion of the maximal covering location model that considers engagement of teleconsultation services and locating new facilities simultaneously for the first time.

This study extends the maximal covering location model to incorporate teleconsultation services in the health care optimization modeling framework with a view to achieving universal basic health care. The proposed model tries to find a trade-off between locating new primary care centers and using teleconsultation services for primary care. The objective is the maximization of overall patient coverage. The model considers patient choice for locating new primary care facilities and also ensures equitable distribution of these facilities by means of anti-covering restrictions. Moreover, the model also takes care of congestion and places capacity restrictions for both primary care centers and teleconsultation services.

In the next section, the optimization model is presented. Numerical illustrations of the model are provided in Section "Numerical Experiment". A real-life case, where the model is implemented is given in Section "Case Study". Section "Conclusion" presents conclusion.

Optimization Model

The success of public health care programs depends on the effectiveness of strategic decision-making, e.g., location-allocation problems in health care. For effective application of location-allocation problems in health care, the preference of patients holds very high importance. Moreover, the inclusion of teleconsultation services in the location-allocation modeling framework will make it more practical and robust. This study presents next a discrete choice framework-based expansion of the maximal covering location model that incorporates teleconsultation services. Assumptions of the proposed optimization model are listed below:

1. Patients depend on primary care centers and teleconsultation services for their primary care needs.
2. The model is based on a discrete choice framework.
3. Physical facilities are separated by *minimum separation distance* to ensure their equitable distribution.
4. Policy maker has limited budget for location-allocation decision-making.
5. Primary care facilities and teleconsultation-based facilities have limited capacities.

Teleconsultation-Based Maximal Coverage Model

Consider a territory where teleconsultation program is required to be setup alongside locating new primary care centers. The objective is to satisfy the primary care demand of the target population concentrated in various neighborhoods. Consider, D_i be the demand for primary health care in locality $i \in I$; $j_1 \in J_1$ represents a likely location for a new primary care facility and $j_2 \in J_2$ represents a health care facility providing primary care services through teleconsultation.

Consider $a_{ij}, i \in I, j \in J_1$, be a binary parameter capturing the preference of patients in locality i for new primary care facility at $j \in J_1$. When patients at i make use of primary care facility $j \in J_1$, a_{ij} is 1, otherwise it is 0. Further, assume $b_{ij}, i \in I, j \in J_2$, be a binary parameter capturing the choice of patients in locality i for teleconsultation service provided by $j \in J_2$. The objective of providing primary health care services to maximum population in the territory jointly by new facilities and teleconsultation can be achieved by extending the *maximal covering location model* [7] as given below.

Mathematical model

$$\textbf{Maximize} \sum_{i \in I} \sum_{j \in J_1} D_i \, X_{ij} + \sum_{i \in I} \sum_{j \in J_2} D_i \, Y_{ij} \tag{23.1}$$

subject to

$$\sum_{j \in J_1} a_{ij} X_{ij} + \sum_{j \in J_2} b_{ij} Y_{ij} = 1 \qquad \forall i \in I \tag{23.2}$$

$$\sum_{j \in J_1} C_{1j} W_j + \sum_{j \in J_2} C_{2j} Z_j \leq B \tag{23.3}$$

$$\sum_{i \in I} D_i X_{ij} \leq \text{Cap}_j^1 \qquad \forall j \in J_1 \tag{23.4}$$

$$\sum_{i \in I} D_i Y_{ij} \leq \text{Cap}_j^2 \qquad \forall j \in J_2 \tag{23.5}$$

$$\alpha(1 - W_j) \geq \sum_{k \in S_j} W_k \qquad \forall j \in J_1 \tag{23.6}$$

$$X_{ij} \leq W_j \qquad \forall i \in I, j \in J_1 \tag{23.7}$$

$$Y_{ij} \leq Z_j \qquad \forall i \in I, j \in J_2 \tag{23.8}$$

$$X_{ij} \in [0, 1] \qquad \forall i \in I, j \in J_1$$

$$Y_{ij} \in [0, 1] \qquad \forall i \in I, j \in J_2$$

$$W_j \in \{0, 1\} \qquad \forall j \in J_1$$

$$Z_j \in \{0, 1\} \qquad \forall j \in J_2$$

In this model, C_{1j} is cost of locating new primary care facility at $j \in J_1$; C_{2j} is cost to the government for bringing health facility $j \in J_2$ into teleconsultation network; W_j represents a binary variable taking value 1 if a new primary care facility gets established at $j \in J_1$; Z_j also represents a binary variable taking value 1 if health care facility $j \in J_2$ gets included in teleconsultation network; X_{ij} represents the proportion of primary care demand at locality i serviced by primary care facility at $j \in J_1$, and Y_{ij} represents the proportion of primary care demand at locality i served by the facility $j \in J_2$ through teleconsultation; Cap_j^1 represents capacity of new primary care facility at $j \in J_1$, and Cap_j^2 represents capacity of facility $j \in J_2$ for teleconsultation services; B represents available budget; $S_j = \{k \in J_1\text{: for } k \neq j, d_{kj} \leq D\}$; D is radius of exclusion zone for new primary care facilities and d_{kj} is distance between "k" and "j"; α represents a large number.

The objective function (23.1) is maximizing population coverage through new primary care centers and teleconsultation services. Constraint (23.2) represents the covering constraint and ensures that demand at locality i is covered either through new primary care centers or teleconsultation. (23.3) represents the budget limitation. (23.4) and (23.5) are capacity constraints. Constraint (23.6) is the anti-covering restriction for new primary care facilities to ensure equitable distribution of these facilities. (23.7) and (23.8) represent contingency conditions.

Numerical Experiment

In this section, we explain the working of the model discussed in Section "Optimization Model" through a small example. Consider a territory with 15 localities, named L1, L2, . . ., L15. There are five sites identified for locating new primary care facilities (H1, H2, . . ., H5), and five health care facilities identified for teleconsultation services (H6, H7, . . ., H10). Tables 23.1, 23.2 and 23.3 provide the parameter values required for the model. For each locality, preferences for new primary care facilities and teleconsultation services are listed in Table 23.1. For each site for a physical primary care facility, the primary care facilities lying at sites in the anti-covering exclusion zone are provided in Table 23.2.

Table 23.1 Population characteristics

Locality	Demand for primary care	Choice for primary care	
		New facility	Teleconsultation
L1	72	H1 H3 H5	H6 H7 ⋯ H10
L2	65	H1 H3 H4	H6 H7 ⋯ H10
L3	56	H1 H3 H4 H5	H6 H7 ⋯ H10
L4	69	H1 H2 H4	H6 H7 ⋯ H10
L5	84	H1 H4 H5	H6 H7 ⋯ H10
L6	92	H1 H4	H6 H7 ⋯ H10
L7	75	H1 H3 H5	H6 H7 ⋯ H10
L8	54	H2 H5	H6 H7 ⋯ H10
L9	45	H2 H5	H6 H7 ⋯ H10
L10	52	H2 H3	H6 H7 ⋯ H10
L11	68	H2 H3 H5	H6 H7 ⋯ H10
L12	64	H2 H3	H6 H7 ⋯ H10
L13	77	H2 H4 H5	H6 H7 ⋯ H10
L14	66	H2 H3 H4	H6 H7 ⋯ H10
L15	57	H2 H3 H5	H6 H7 ⋯ H10

Table 23.2 New facility-site characteristics

Site	H1	H2	H3	H4	H5
Capacity	150	150	150	150	150
Cost of setting up	45	40	54	62	65
Sites in exclusion zone	H2	H1	H4 H5	H3	H3

Table 23.3 Teleconsultation facility characteristics

Facility	H6	H7	H8	H9	H10
Capacity	50	50	50	50	50
Cost of teleconsultation contracts	20	20	20	20	20

The model presented in section "Optimization Model" was applied on the data given in Tables 23.1, 23.2 and 23.3. Initially, the solution was observed at different levels of budget. Table 23.4 presents the experimental results. With increase in budget, coverage increases as expected (Fig. 23.1). A change in combinations of new sites and teleconsultation is observed, and no definite trend was detected (Fig. 23.2). For higher budget levels, number of teleconsultation contracts outweigh the number of new primary care centers. It might be happening due to anti-covering restrictions for new primary care centers. As seen in Table 23.4, a maximum coverage of 70.28% could be

Table 23.4 Sensitivity analysis_budget variations

Budget	Coverage (%)	Teleconsultation	Tele coverage (%)	New facilities	New facilities coverage (%)
20	5.02	H6	5.02	–	0
40	15.06	–	0	H2	15.06
50	15.06	–	0	H1	15.06
60	20.08	H10	5.02	H2	15.06
80	25.10	H7 H8	10.04	H2	15.06
100	30.12	H8 H9 H10	15.06	H2	15.06
120	35.14	H10	5.02	H2 H3	30.12
140	40.16	H6 H7 H8 H9 H10	25.10	H2	15.06
150	40.16	H6 H7 H8 H9 H10	25.10	H2	15.06
200	55.22	H6 H7 H8 H9 H10	25.10	H2 H3	30.12
250	65.26	H6 H7 H9 H10	20.08	H2 H4 H5	45.18
300	70.28	H6 H7 H8 H9 H10	25.10	H1 H4 H5	45.18
350	70.28	H6 H7 H8 H9 H10	25.10	H1 H4 H5	45.18

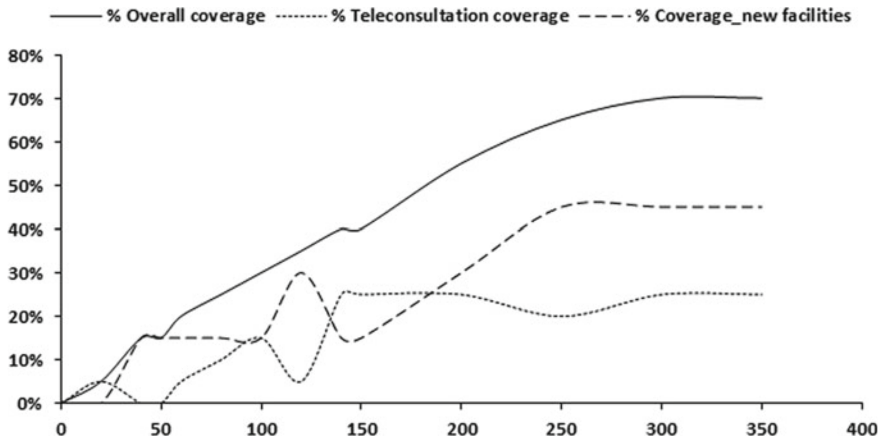

Fig. 23.1 Experiment_budget versus coverage

achieved in the existing setup. To increase the coverage further, either additional sites for new primary care facilities or new facilities providing teleconsultation services are to identified.

The model was further observed at different capacity levels. Capacities of both new primary care centers and teleconsultation services were increased simultane-

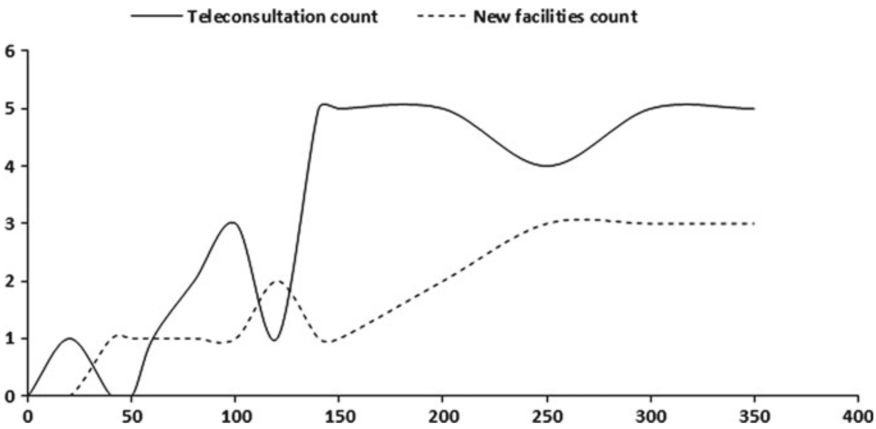

Fig. 23.2 Experiment_budget versus teleconsultation and new facilities count

Table 23.5 Sensitivity analysis_capacity variations

Capacity new facility	Capacity teleconsultation	Overall coverage (%)	Teleconsultation coverage (%)	New facilities coverage (%)
90	30	42.17	15.06	27.11
105	35	49.20	17.57	31.63
120	40	56.22	20.08	36.14
135	45	63.25	22.59	40.66
150	50	70.28	25.10	45.18
165	55	77.31	27.61	49.70
180	60	84.34	30.12	54.22
195	65	91.37	32.63	58.73
210	70	98.39	35.14	63.25
225	75	100.00	37.65	62.35

ously in the same proportion. Budget was fixed at 300 for this experiment. Table 23.5 shows the results of the experiment. Again, overall coverage increased with increase in the levels of capacity. Increasing trend is observed in the coverage through teleconsultation and new facilities. At capacity level (225, 75), the entire population gets covered, and teleconsultation services are utilized to their full capacity and remaining coverage corresponds to new primary care centers. This complete coverage is achieved by making a 50% increase in existing capacity levels, viz. (150, 50).

Later, a combined experiment was performed to see the effect of changing budget and capacity simultaneously. Results are presented in Table 23.6. At low budget and capacity levels, the coverage was attributed equally to teleconsultation and new primary care centers, while at intermediary budget levels, coverage by new facilities exceeds teleconsultation coverage slightly. When capacity levels are very large, cov-

Table 23.6 Sensitivity analysis_budget and capacity variations

Budget	Capacity new facility	Capacity telecon-sultation	Overall coverage (%)	Tele count	Tele coverage (%)	New facilities count	New facilities coverage (%)
100	90	30	18.08	3	9.04	1	9.04
100	150	50	30.12	3	15.06	1	15.06
100	210	70	42.17	0	0	2	42.17
200	90	30	33.13	5	15.06	2	18.07
200	150	50	55.22	5	25.10	2	30.12
200	210	70	77.31	5	35.14	2	42.17
350	90	30	42.17	5	15.06	3	27.11
350	150	50	70.28	5	25.10	3	45.18
350	210	70	98.39	5	35.14	3	63.25

erage by new primary care centers exceeds teleconsultation coverage by a significant amount.

Case Study

A case study was conducted to comprehend the usefulness of proposed optimization model. The model was applied on a data set pertaining to economically weaker people[1] residing in northeast district of Delhi. The analysis was performed on twenty nine localities of disadvantaged population. Locations of twenty-one *Mohalla clinics* (viz. M1, M2, ..., M21) have been considered as potential candidates for locating new primary care centers, while ten big hospitals have been considered for teleconsultation.[2] Table 23.7 presents the population of twenty nine neighborhoods considered for the study and number of *Mohalla clinics* located within a radius of 300 m, 500 m and 1 km of these twenty nine neighborhoods. Spatial distribution of twenty nine population centers and twenty-one *Mohalla clinics* can be found in Fig. 23.3.

The proposed optimization model is aimed at maximizing the coverage of the population seeking primary care. In this study, coverage of 19,828 households residing in twenty nine localities is to be maximized through new primary care centers and teleconsultation services. For locating new primary care facilities, choice of population is considered. It was assumed that a patient visits a new primary care center if it is located within 500 m from the residence. Moreover, it is also assumed that every patient prefers to use teleconsultation-based primary care services through

[1] https://delhishelterboard.in/main/.

[2] http://health.delhigovt.nic.in/wps/wcm/connect/doit_health/Health/Home/Directorate+General+of+Health+Services/Aam+Aadmi+Mohalla+Clinics/.

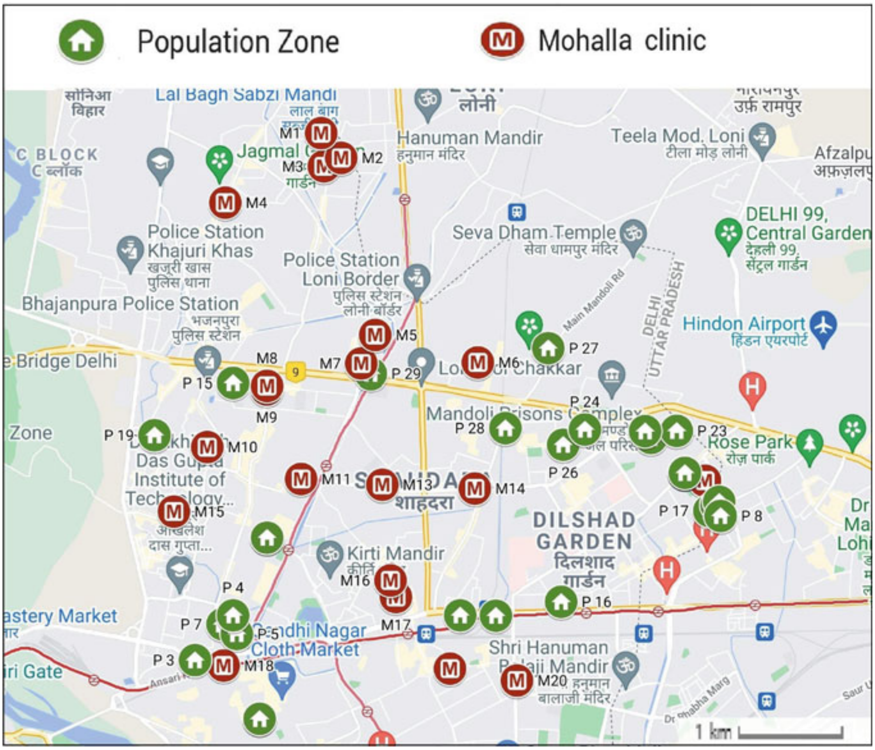

Fig. 23.3 Spatial distribution of localities and Mohalla clinics

any available facility. The anti-covering distance was assumed to be 1.5 km for primary care facilities. Cost of locating a new primary care center was assumed to be INR 2,000,000, whereas cost incurred on establishing teleconsultation services in a hospital is considered to be INR 500,000. Capacity of a new primary care center is assumed to be 2000 households, while capacity of a single teleconsultation platform is considered to be 500 households. Table 23.8 presents the implementation of the proposed model at different levels of budget. It was observed that teleconsultation services are prevalent at low budget levels. With increase in budget, new primary care facilities are located. As seen in Fig. 23.4, patient coverage increases with increase in budget and a maximum coverage of 67.35% could be achieved through existing setup of primary care centers and teleconsultation services (Table 23.8). It implies that there is a need to consider new set of sites for primary care centers, and additional hospitals should be included into teleconsultation network.

Table 23.7 Target localities and Mohalla clinics in northeast Delhi

Zone	Population size	Mohalla clinics within		
		300 m	500 m	1 km
p1	3943	0	0	1
p2	5000	0	0	1
p3	151	0	1	1
p4	348	0	0	1
p5	254	0	1	1
p6	1000	1	1	2
p7	107	0	0	1
p8	175	0	1	1
p9	313	0	1	1
p10	157	0	1	1
p11	129	1	1	1
p12	110	1	1	1
p13	320	0	1	1
p14	444	1	1	1
p15	488	0	2	3
p16	841	0	0	0
p17	1107	0	1	1
p18	123	0	0	3
p19	223	0	0	2
p20	557	0	0	2
p21	1073	1	1	1
p22	999	0	1	1
p23	188	0	0	1
p24	93	0	0	0
p25	290	0	0	1
p26	69	0	0	0
p27	99	0	0	1
p28	492	0	0	2
p29	735	0	0	1

Conclusion

To achieve universal health care, standards of primary care require improvement. Moreover, pandemics like COVID-19 increase the demand for primary health care by an immense amount. To meet the rising demand in these situations, finding locations of new primary care facilities is helpful but not sufficient. Teleconsultation services can help to a great extent in these situations. Therefore, policymakers should consider

Table 23.8 Case study

Budget	Coverage (%)	Teleconsultation	Tele coverage (%)	New facilities	New facilities coverage (%)
1,000,000	5.04	2	5.04	–	0
2,000,000	10.09	4	10.09	–	0
4,000,000	20.18	4	10.09	1	10.09
5,000,000	25.22	6	15.13	1	10.09
6,000,000	30.26	8	20.17	1	10.09
8,000,000	40.34	8	20.17	2	20.17
10,000,000	49.72	8	20.17	3	29.55
15,000,000	65.72	10	25.22	5	40.50
20,000,000	67.35	10	25.22	7	42.13
25,000,000	67.35	10	25.22	7	42.13

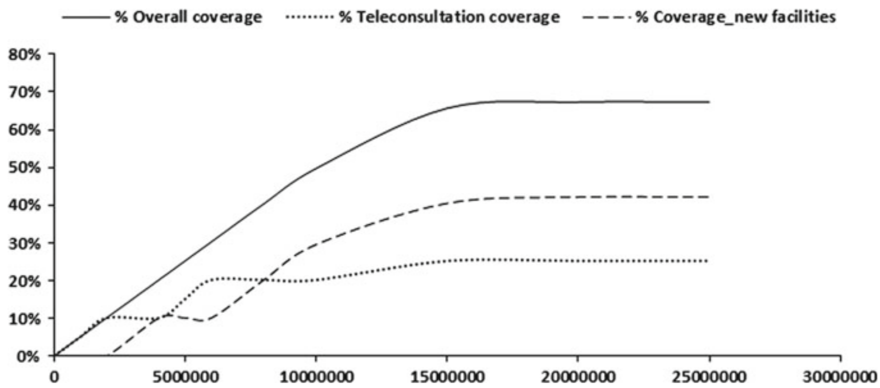

Fig. 23.4 Case study_budget versus coverage

the possibility of starting teleconsultation services along with locating new primary care facilities.

In this article, a location optimization model is proposed that incorporates teleconsultation services in the location-allocation optimization framework. Numerical experiments along with a case study were carried out to explain the working of the model. The proposed optimization model was solved by varying model parameters. Teleconsultation services surpassed new primary care facilities at a higher budget level. Moreover, increasing the levels of capacity by 50% over existing capacity levels resulted in complete coverage. A case study in the northeast district of Delhi has discovered the need to identify new sites for primary care centers and additional teleconsultation services.

Pandemics like COVID-19 enforce the need for extensive health care services instantly. Giving due consideration to primary health care is required to meet rising health care demand in such situations. Locating new makeshift primary health care centers will be helpful but not sufficient. Therefore, telemedicine services should be inherent to the primary health care system as a future medical practice. Keeping this motivation in mind, this article presents a location-allocation-based decision-making framework for incorporating telemedicine services in the existing primary health care network. Implementation of the model will help in strengthening the existing primary health care network.

Parameters involved in proposed optimization model are assumed to be known and deterministic. However, status of health changes dynamically in real life. Zhang and Atkins [32] presented probabilistic choice models to design a network of medical care facilities. Bagherinejad and Shoeib [2] considered dynamic capacities in maximal covering location problem and described a dynamic maximal coverage model. The proposed model can be more practical if it involves dynamic parameters.

Integer linear programming (ILP) problems are generally very complex and hard to solve, and therefore, efficient solution algorithms should be developed for these problems. The model proposed in this paper is an integer programming formulation and requires a solution algorithm for dealing with larger instances of the problem. There are many contributions illustrating the importance and utilization of solution algorithms in facility location problems. Some of the recent contributions are given as follows: [2, 14, 19, 32]. We are also currently working on designing a solution algorithm for solving larger dimensions of the problem more quickly and efficiently.

The proposed model considers locating facilities of same type that can be extended to location of facilities of multiple types. Heyns and van Vuuren [14] proposed a location model for locating multiple types of facilities in multiple areas. Kumar and Bardhan [19] proposed an optimization model for locating two types of primary health care centers. A more general location modeling approach would be to develop a hierarchical facility network. A three-tier health care system may be developed to satisfy health care needs of the population.

This paper also presents a case study concentrated on the northeast district of Delhi. The study has brought some interesting and important insights useful for policymaking. This study can be extended to other regions of the city to draw more general policy directives. The implementation of the proposed model in rural areas is expected to produce more useful results and observations.

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