PREFACE

The present work seeks to establish a structured approach for proper planning of the maternal healthcare facilities to address the availability and accessibility issues that mothers-to-be (MTBs) had to face mostly in developing and underdeveloped countries. These issues also concern India. The Indian Government has been moving its resources for better maternal healthcare through its schemes, such as, Janani Suraksha Yojana–2005, National Rural Health Mission–2005, Pradhan Mantri Surakshit Matritva Abhiyan–2016, etc.

Planning for the required maternal healthcare facilities, from basic ones to neonatal ones, while considering population growth is a tedious task for the Governments. In the present work, this planning problem has been addressed by proposing several mixed-integer linear programming (MILP) formulations for determining the optimal number and locations of varied and capacitated maternal healthcare facilities for different planning scenarios. These formulations also help in optimal allocation of MTBs to these facilities while minimizing the overall cost. The facilities are hierarchical (i.e., a system of different types of interacting facilities) and successively inclusive (i.e., a higher level will also provide all lower-level services). All these models are equally applicable in the Indian context.

In the first variation, the planning framework does not compromise on service quality. Considering accessibility issues in terms of coverage distance and availability issues in terms of establishing required facility types, the mathematical model has been developed. The proposed model is NP-hard and is thus computationally inefficient in solving the planning problem. To reduce the computational time requirement, three additional valid inequalities are proposed. Computational experiments and statistical test confirm the usefulness of these valid inequalities. Additionally, a sequential approach is also proposed to cut down the computational requirements sizably without

practically compromising the solution quality. Sensitivity analyses have been carried out with respect to coverage distance, capacity, referral proportion and fixed cost to provide important and practical insights related to the mix of the facilities to be established.

The healthcare facilities are generally overburdened due to large demand in excess of capacity of the facilities and is mainly because of lack of funds for creating the right number and mix of facilities. Under such a scenario, overburdening may be unavoidable but is certainly undesirable. To acknowledge this practical reality, the earlier proposed planning framework was modified to accommodate the possibility of overburdening but at a penalty cost. The level of penalty cost controls the amount of overburdening and the number of maternal healthcare facilities to be established. The small penalty cost causes huge overburdening but establishment of a few facilities. A very high penalty has the opposite effect. The amount of overburdening in comparison to the capacity of the facilities defining the service quality is naturally is the best in the case of high penalty costs. Understandably, the mathematical model encompassing the features of this planning problem is also NP-hard. For solving the large-size real-world problem in a reasonable time, suitable frameworks of Particle Swarm Optimization (PSO), Artificial Bee Colony (ABC), and JAYA metaheuristics have been developed. Extensive computational experiments have been performed to analyze their comparative efficiency and usefulness. PSO was found to be the best. The proposed mathematical model assumed the demand for various maternal healthcare services to be deterministic. In real life, the demand for these services may vary day-to-day and these variations may be random. For this reason, the robustness of the solutions for deterministic demand case has been analysed for application in stochastic demand case by performing computational experiments on several problems of varying size and variability in the demand. It was found that

the solutions obtained are practically quite robust. The sensitivity strengthened our belief in increasing the penalty cost for achieving high service quality.

The maternal healthcare planning frameworks presented above, and also in the available literature, did not address the multiperiod maternal healthcare planning problem. Simultaneous planning over the whole planning horizon, as compared to period-wise planning, results in a better plan for establishing and upgrading the facilities in various periods of the planning horizon. The upgradation of healthcare facilities is a common phenomenon and has been encountered, at least in the Indian context. This aspect considered in the present research work has not been viewed by any other researcher so far, at least for the planning of maternal healthcare facilities. Besides, the planning framework considers the possibility of referrals from all the lower level facilities to their higher level facilities. This generalized feature of referral, which is practically common in India, has not been considered in the available researches. The framework of the mathematical model is general. One has to simply change the number of periods in the planning horizon to comp up with mid-term planning or long-term planning decisions. Incorporating all these realities of the planning framework, the proposed mathematical model proposed also considers inflationary pressure on the cost parameters and growth in the demand of services from MTBs owing to population growth. To solve the developed multi-period planning problem effectively and efficiently, an accelerated Benders Decomposition algorithm (a Benders Decomposition Algorithm with several acceleration strategies such as valid inequalities, disaggregated Benders cuts, rolling horizon heuristic and parallelism) has been developed. A Benders type heuristic is also tested by solving the master problem heuristically. Additionally, Particle Swarm Optimization (PSO) with local search and hybridized Simulated Annealing (SA) approaches have also been developed to obtain good quality solutions in a reasonable time, particularly for large-size planning problems. The results of the

computational experiments find the accelerated Benders Decomposition algorithm and Benders-type heuristic to outperform the Gurobi solver for medium and large-size problems in terms of solution quality. The proposed PSO heuristic performed worst, whereas hybrid SA was found to be the best in yielding better solutions in lesser CPU time. Computational experiments prove the premise of integrated planning being economically better than year-to-year based planning.

The application of the proposed models has been demonstrated by taking the problem of maternal healthcare planning for a region in India. The case study shows a lot of work to be done to significantly improve the existing maternal healthcare infrastructure in order to meet the Strategic Development Goals (SDGs).