CHAPTER 5

CONCLUSIONS AND SCOPE FOR FURTHER WORK

5.1 Conclusions

The present thesis addresses accessibility, availability and service quality issues related to maternal healthcare. In India, the mortality rate of the mother and child is quite significant. Looking into the urgent need to reduce this number, State and Central Governments in India are giving a lot of importance to maternal healthcare through their various governmental schemes. Based on this fact, it is necessary to establish, upgrade and adequately locate the Community Health Centres (CHCs), Primary Healthcare Centres (PHCs) and Sub-centers (SCs) in the right mix to meet the present and the future demand of various related services of the mothers-to-be (MTBs). Determination of the right location of these facilities in a wide geographical area in India is a big and challenging task. It is because the maternal healthcare facilities are to be provided at the least cost, even from the perspective of its users. This thesis endeavours to handle such a problem by developing various mixed integer linear programming (MILP) based facility location-allocation models. In the proposed models, besides determining the number and location of maternal healthcare facilities, the models allocate MTBs to these facilities for their varied service requirements, including referrals. In this work, various computationally efficient approaches have also been proposed to solve large size real-world problems.

The accessibility and availability issues are mathematically modelled first to minimize the total cost of establishing various maternal healthcare facilities and the travel cost of MTBs to these facilities, including referrals, without compromising on the service quality. The accessibility issue is addressed by considering coverage distance limitation both for referral and non-referral cases. The issue of the availability of the healthcare facilities is addressed by ensuring the establishment of required facility types to meet the complete demand of MTBs. Through the computational experiments, it gets revealed that the developed model is computationally inefficient in solving large size real-world problems due to the combinatorial nature of the problem. The number of binary variables increases linearly as the problem size increases, and so as the computational complexity. To reduce the computational complexity, a set of three additional valid inequalities were added to the model. The addition of valid inequalities is found to be quite useful. The upper bound (UB) obtained by adding valid inequalities is found to be better than the UB obtained through the Gurobi solver for solving large-size problems. The statistical analyses also confirm the usefulness of the proposed valid inequalities. This concept can be applied to other similar combinatorial problems in solving them efficiently. Another strategy for reducing the computational effort has been developed for solving the problem sequentially and each time of much smaller size. This sequential approach produces much better solutions in lesser computational time. The effectiveness and computational efficiency of the sequential approach were also established by the statistical analysis. Further, sensitivity analysis was carried out by varying the coverage distance, referral proportion, capacity of the facilities, and fixed cost on establishing the facilities. During the sensitivity analyses, it was found that the coverage distance and the capacity of the facilities play an important role in minimizing the overall cost but up to a certain extent. The change in the referral proportion impacts not only the number of higher-level facilities but also of lower-level facilities. The fixed cost was found to impact the mix of numbers of SCs, PHCs, and

CHCs to be established. Even when the same becomes very high as compared to the travel cost (beyond a limit), it does not cause any such impact.

The large demand coming from a huge population and lack of funds for creating the right number and mix of facilities leads to overburdening of the healthcare facilities. Overburdening is undoubtedly undesirable, but it cannot be avoided. To model this reality, a penalty on allocations of MTBs beyond the facility's limited capacity is imposed. The overburdening beyond the capacity of the facilities leads to poor service quality. The service quality issue, along with the availability and accessibility issues, is addressed further in the developed model. The objective considered is the minimization of the total cost, which includes the cost of establishing a new facility, transportation costs and the penalty cost due to overburdening. Similar to the previous model, this model is also computationally inefficient in solving large-size problems. For this purpose, a framework of three metaheuristics, namely Particle Swarm Optimization (PSO), Artificial Bee Colony (ABC) and JAYA algorithm, is proposed and developed to solve large-size problems. Statistical analyses show that the PSO approach is the most effective and efficient, even over the Gurobi Solver and ABC approach. ABC approach which performed better than the JAYA approach in terms of solution quality and computational time.

The analyses with respect to the on change in penalty cost revealed that a high penalty cost leads to huge overburdening on facilities by establishing lesser number of facilities. Conversely, if the penalty cost is very high, then a large number of facilities are to be established and overburdening will be zero, resulting in high service quality. The planner must choose the penalty cost depending on the desired service quality. Further, Monte-Carlo simulation is performed to observe the effect of randomly varying demand on service quality.

The simulation results show that the service level declines linearly as the coefficient of variation increases. If the mean demand for a service type is high, this fall is more severe. These results can be used to make a decision about the capacity of various service types available at various facility types to maintain the desired service level.

The issue of population growth is addressed by developing the multi-period planning model, which considers the up gradation of existing healthcare facilities and the establishment of new facilities to respond to the demand in various time periods of the planning horizon. To solve large-size problems such as for 20 years of the planning horizon, Benders decomposition approach is used. Through the experimentation, it is observed that classical Benders decomposition approach does not perform well as compared to the Gurobi solver and struggles to converge. To accelerate the classical Benders decomposition approach, various acceleration strategies such as valid inequalities, disaggregated Benders cuts, rolling horizon heuristic and parallelism are used. During the experimentation, it is observed that the Benders decomposition algorithm struggles to converge largely because of the master problem. To solve the master problem with less computational effort and in timely manner Benders type heuristic is proposed. Additionally, PSO with local search and hybridized Simulated Annealing (SA) have also been proposed. Through the extensive computational experiments, it is observed that both of the accelerated Benders decomposition approach and Benders type heuristic surpassed the Gurobi solver, PSO showed worst performance, and hybridized SA was found to be the best in terms of producing high-quality solutions in a lesser amount of time. Further, analyses suggested that integrated multi-period planning is economically more beneficial compared to year-to-year basis planning. The proposed mathematical model was also utilized for developing the maternal healthcare facility network for the District of

Chandauli in Uttar Pradesh, India, for the next 20 years. The planning suggests a lot of significant improvement required in the Indian healthcare system, and specifically for maternal healthcare.

5.2 Managerial Implications of the Study

Some key insights which can be drawn from the present study, from the managerial point of view are listed below.

- The accessibility issue is taken care in the present work by considering coverage distance restriction, to ensures that the maternal healthcare facility is available within the reach of MTBs. This will encourage MTBs to visit healthcare facilities for regular consultation during their pregnancy. This will also result in more deliveries taking place in the maternal healthcare facilities.
- By establishing required number of new facilities or upgrading the existing ones, the overcrowding of the facilities can be prevented. It will support medical professionals in carrying out their duties properly and efficiently. The end result will be high-quality maternal care.
- The healthcare planner can plan the facilities in advance to meet the rising demand due to population growth in the future. The advance planning will help Governments to plan the financial outlay accordingly. This integrated planning will be more economical compared to adhoc yearly plan. The proposed planning framework considers inflationary pressure and is going to yield more realistic and economic plan.
- The planning framework also provides opportunity for seeking a plan while compromising service quality due to shortage of funds for upgrading the existing facilities establishing the new facilities.

5.3 Scope for Future Research

The work presented in the thesis can be extended in several directions. Some of these are as follows.

- The present work focuses on the strategic planning of healthcare facilities for maternal healthcare. The work can further be extended to address the tactical and operational challenges.
- The proposed hierarchical maternal healthcare facilities can also include essential services required by MTBs during delivery and complication, such as blood bank and mothers-milk bank.
- The presented mathematical model can be extended to a scenario-based robust optimization model to address the uncertainty in demand.
- The models presented in the thesis considered a single objective function which includes various costs. The various costs in the objective function can be modelled as a multi-objective optimization model to obtain the Pareto solutions for the considered objectives.
- The metaheuristics proposed in the thesis can be hybridized with other heuristics such as Tabu search and neighbourhood search for exploring the possibility for enhancing the computational efficiency.