Models and Algorithms to Facilitate the Logistics Operations of Caregivers for Home Healthcare Services in India

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By

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Chapter 5
Conclusion and Future Scope

5.1. Introduction

In today's world, operation research tools have become indispensable in designing and managing any logistic operation. This is also true for the quick and wider adoption of home healthcare delivery services in India. This thesis highlights this fact and addresses the issue of assignment, routing, and scheduling for a generic home healthcare delivery setup by providing highly capable mathematical models and robust solution approaches. A thorough review of existing literature is carried out to establish state-of-the-art in the field of HHC problems. Keeping the culture and necessity of Indian healthcare sector in mind, the gap in the existing literature is identified. Subsequently, immense effort has been made to incorporate almost all the existing requirements from the literature in a single monolithic home healthcare delivery model while also introducing some major enhancements. Further, statistical rigor has been applied in order to produce efficient and robust algorithms for solving developed MIP models. Additional experiments are further designed to generate some important managerial insights. The remaining part of this chapter presents these insights, novel contributions to the existing literature, and the direction of future research alongside a brief summary of all the chapters.

5.2. Chapter-wise summary and conclusions

Chapter 1 - Introduction: This chapter introduces home healthcare delivery and presents the challenges in modeling a specific HHC operation due to its unique consideration of goals and restrictions. The chapter also highlights the scope and necessity of quick and wider adoption of operation research techniques in the Indian HHC industry. Motivated by this, we undertake the present research work and subsequently present the specific research objectives and issues relating to the proposed work.

Chapter 2 - Literature review: The chapter presents the relevant literature necessary to achieve the stated research goal. In addition to placing the home healthcare delivery problem in the wider vehicle routing and scheduling field, the chapter mainly focuses on the existing variation in the selection of objectives and constraints while modeling HHC delivery. Further, a review of solution techniques is provided for single as well as multi-objective setups. Finally, the research gap in the existing literature is underlined, which provides a suitable base for the present thesis.

Chapter 3 - A generalized single-period home healthcare delivery problem: A generalized model for home healthcare delivery is developed in this chapter. The model is shown to be capable of routing heterogeneously skilled staff from multiple hubs in multiple shifts while considering several patient-staff compatibility criteria. More importantly, the model is capable of scheduling and routing jobs that may require more than one visit and more than one staff simultaneously. The chapter also includes the successful implementation of the "inconvenient time window" and "limited contact restriction" constraints, which are the novel contributions of this thesis to the existing literature. The generalized mathematical model for the home healthcare delivery problem accomplishes the first objective of the thesis, as described in Section 1.4. Similarly, introducing novel concepts to the HHC problem partially fulfills the third thesis objective. First, the developed model is validated using a small problem instance. In order to solve the monolithic model for real-world instances, efficient implementation for two matheuristics and a novel version of GA (p-GA) are developed. While none of the algorithms was found to be categorically dominating the others, clear use cases (based on the problem size) for each were established by experiments. Further, the generality of the proposed model was demonstrated by successfully adopting it for the benchmark instance set from the literature.

Further experiments on the two candidate policies found that the imposition of a "complete accommodation" restriction will severely reduce the total number of visits and the resulting revenue without any significant increment to the number of completely served patients. Hence, the model corresponding to the "partial accommodation" policy is recommended for both cases under limited staff availability. Additionally, when allowing for the overtime workload and the part-time staff, experiments show that the investment made in the acquisition of additional capability will lead to higher revenue and higher profit. However, it consistently results in a lower profit-to-investment ratio, signifying a lower return on a dollar.

Chapter 4 - A multi-objective home healthcare delivery problem: Chapter 4 primarily focuses on the second and third objectives from Section 1.4. The generalized home healthcare delivery model is extended to a multi-objective setup. Similar to the previous model, the resulting formulation is found to be capable of handling a wide variety of restrictions in relation to the number of staff requirements, number of visit requirements, procedural dependencies, etc. In addition to this, the model was enhanced to incorporate the caregiver's proficiency level alongside the minimum required proficiency for each procedure request. Further, modifications to the implementation of 'workload balance' restrictions as well as 'patient's time window' were also proposed as a novelty to the existing literature. The model was found to be capable of handling the complications relating to the implementation of inconvenient time windows as the soft constraint. It can successfully calculate the overlap of the scheduled visits with ITW regardless of their lengths. Finally, the definition and method to calculate patient inconvenience due to unnecessarily scattered visits are presented and incorporated into the mathematical model. The model identifies the correct number of sessions required to generate a ‘proper schedule’ for the selected visits and minimizes the total inconvenience due to improper schedules. This marks the successful completion of all three objectives as laid out in Chapter 1.

On the solution approach front, three metaheuristics are designed and compared. Out of these three, NSGA-III was found to be the best-performing algorithm for the net quality indicator (Y). While utilizing single-point crossover, NSGA-III was found to be consistent in producing a set of good-quality Pareto solutions in each run. Similarly, the produced Pareto front was concluded to be robust for a 50% increment in the service and travel time. In the worst-case scenario, more than 50% of solutions remain non-dominated, with only around a 15% reduction in quality. Hence, the proposed implementation of NSGA-III was found to be robust and consistent in finding a diverse set of non-dominated solutions for a generalized multi-objective home healthcare routing and scheduling problem. Further experiment establishes the relation between patient convenience and the net profit. The experiment finds that the relation between inconvenience caused due to improper scheduling and net profit closely resembles an exponential curve, and a significant improvement in patient convenience can be achieved with only a minuscule reduction in profits. The thesis provides some guidelines for incorporating this aspect of home healthcare delivery into the industry.

5.3. Contribution of the thesis

The thesis has addressed the issue of assignment, routing, and scheduling in a generalized home healthcare delivery setup. Mixed integer programming models and efficient metaheuristics are designed to solve the HHC problem for practical instances. Hence, the novelty and key contribution of this thesis with regard to the model complexity and improved solution techniques in the field of home healthcare delivery can be summarized as follows.

i. A major criticism of existing literature on HHC delivery is that models are highly specific and are not easily modifiable to be used in practice. We bridge this gap by presenting a generalized models that can easily be reduced to serve a wide variety of cases. Our work does not restrict any key procedure attributes like staff and visit requirements or limit the number of requests a patient can make, simultaneously incorporating most of the commonly used constraints presented in the literature in a single monolith model. Two variations of this model covering single and multi-objective setup have been provided.

ii. The thesis presents the first-ever implementation of the inconvenient time slot (an example of multiple time windows). Implementation for both the soft and hard versions of the inconvenient time windows is developed, and the arising complexity is successfully modeled in the proposed mixed-integer program. For the soft ITW, violation of the provided time window has been minimized as a part of patients' inconvenience in multi-objective healthcare setup.

iii. We incorporate the constraints to limit the contact between caregivers and patients in the model to adhere to the COVID-19 guidelines. It takes separate inputs for the maximum allowed contacts for patient and caregiver and can easily be modified to take separate values for different patients, which will cover the possibility of different immunity levels of patients depending on their diagnosis.

iv. Two ‘hardware first’ MIP-based decomposition algorithms, enhanced with local search, are developed to divide the single-objective HHC problems into hardware-manageable smaller subproblems.

v. A modified Genetic algorithm with a novel 3-phase fitness evaluation function is developed to accommodate the complexity of constraints. Inherent parallelism in the evolutionary process is used to utilize the multi-core architecture of commonly available computational hardware. To the best of our knowledge, ours is the first study to incorporate this.

vi. The multi-objective mixed-integer programming model for the home healthcare delivery problem is designed to accommodate the competitive goals of different stakeholders to ensure the long-term sustainability of the system. The model is further enhanced by introducing the ‘Loss of employed labor’ as a novel objective to existing HHC literature. In this case, the loss is measured on the basis of the caregiver’s skill, wage, and working time and their actual utilization. Additionally, while implementing the ‘balance workload’ requirement, we propose an additional cap on the minimum assigned workload to further remove the possibility of assigning an unfair workload.

vii. The thesis also introduces the concept of a ‘convenient schedule’ to the HHC literature and provides a detailed qualification for the ‘quality of schedule’ in relation to the patient’s convenience. Unnecessary interruptions to the patient's daily life are calculated and minimized as a part of the objective - the 'cost of improper scheduling' in a multi-objective setup. In order to reduce unnecessarily scattered visits, the model tries to group patient's multiple visits in the minimum possible number of sessions and minimizes the total session time.

viii. In regards to the solution approach for the multi-objective formulation, an efficient implementation of reference-point-based non-dominated sorting genetic algorithm (NSGA-III) for generating a good quality set of non-dominated solutions is successfully achieved.

In summary, the thesis advances the adoption of OR-based methods in India's home healthcare sector in two significant ways. Firstly, it enhances the usability of existing models and algorithms. The proposed models and algorithms can improve the logistics of caregivers across various home healthcare setups. This also allows the simplification of the models to represent a more obscure home healthcare delivery problem. Moreover, the models' effectiveness is further boosted by implementing contact restrictions and measures to minimize patient inconvenience. These improvements should be broadly applied, particularly when they can meaningfully enhance service quality with only minimal profit reductions. Secondly, the thesis makes several efforts to increase the acceptance of the proposed methods. It incorporates a variety of objective functions to suit home healthcare delivery setups at different maturity levels. The thesis also addresses the conflicting goals of different stakeholders when setting objectives, enabling the selection of the most appropriate solution based on current needs, thus ensuring the social sustainability of the organization. Furthermore, the solution methods are designed to involve decision-makers in key stages of the decision-making process. The developed algorithm generates a set of Pareto optimal solutions for managers, reducing their reluctance to implement solutions derived from a black-box approach.

5.4. Managerial insights and recommendations

After a careful study of the home healthcare delivery problem and analyzing the results obtained by the various experiments, the following key insights and recommendations for the considered problem are generated.

i. It has been observed that explicit implementation of a "complete accommodation" restriction, where a patient can only be selected when all his procedure requests can be met, does not provide any significant benefit in increasing the number of completely served patients. On the other hand, it leads to a drastic reduction in number of visits made and the total revenue. Hence, under the complex patient-caregiver compatibility, the implementation of a complete accommodation policy is ill-advised.

ii. In this thesis, problem instances are designed to represent an overburdened healthcare setup where available capacity (number of full-time caregivers) is severely insufficient for the requested tasks. Experiments show that investment made in order to meet this additional demand will lead to a substantial increase in total revenue. However, a clear trend showing a diminishing return is observed, where every additional dollar put as an investment will provide a lesser and lesser return. Hence, it will not be wise for a for-profit organization to make this investment decision in a vacuum without considering other investment opportunities.

iii. While experiments show an adverse relationship between patient convenience and the net profit, it has also been observed that a significant improvement in patient convenience can be achieved without almost any compromise in profit. Additionally, based on the requirements of an organization, decision-makers can achieve higher gains in patient convenience with a relatively low loss of profit. The use of the graph presented in **Figure 4.15** is recommended to find the best solution for an approximate improvement goal. Hence, we highly recommend the incorporation of patient convenience as a worthwhile goal for a home healthcare delivery organization.

iv. By observing the solutions presented in Section 4.4, it can be said that efficient use of the hired resources (reduction in the value of 'loss of employed labor') corresponds to higher profits. Higher profit was achieved by efficiently utilizing the hired staff rather than serving a greater number of requests. Hence, an integrated model that can provide a more compatible set of staff based on the requirement of the day in addition to the routing and scheduling decisions is highly recommended.

v. Finally, it has been observed that sometimes it is impossible to serve some of the procedure requests by only utilizing the existing set of caregivers when considering a complex patient-caregiver compatibility requirement. We recommend a preprocessing step for identifying and removing such procedure requests before using the proposed solution methods. This will ease the computation requirement of the metaheuristic and can lead to a better-quality solution under the same computational budget.

5.5. Scope of future research

This thesis has provided capable mathematical models and a robust solution approach in order to remove some hurdles in the adoption of OR techniques in the home healthcare delivery sector. Additionally, improvements to the existing HHC practices have been proposed and verified with rigorous experiments. However, some aspects of a real-life home healthcare delivery operation have not been considered in this work. We provide the following suggestion as the possible future direction for the work presented in this thesis.

i. To further develop the presented work, the MIP models can be modified to incorporate multi-period decision-making. The procedure's weekly frequency, minimum guaranteed employment for part-time caregivers, and patient-caregiver loyalty should be a part of multi-period decisions for HHC delivery.

ii. With consideration of a longer planning horizon, the element of uncertainty should also be incorporated into the advanced model (Bowers et al., 2015).

iii. The "limited person-to-person contact" constraints can also be implemented as a soft restriction in case the strict limit for the number of allowed individual contacts is not available.

iv. Some attention can also be provided to the nature of overtime. With a higher pay rate for overtime in comparison to regular work, it can be perceived as a positive by some employees. Workload definition should be suitably modified to fairly reflect the perceived workload in 'workload balance' constraints.

v. Addition decisions like caregivers' shift assignment, multi-tier routing decisions when using a common transportation solution, and horizontal collaboration between multiple service providers where they pool their resources and perform joint logistic operations can be incorporated into the existing models.

vi. At the algorithm front, additional study can also be done on the effect of other selection operators on the performance of p-GA. In the current work, “roulette wheel selection” was used to facilitate easy implementation of parallel processing, but methods of implementing other selection strategies and their effect on the performance of the algorithm can be studied further.

vii. Finally, in addition to the metaheuristics considered in this work, other intelligence algorithms should also be tested to find the most efficient metaheuristics for the proposed problem. With a good chance that no one algorithm will dominate the search procedure on all the quality indicators in a multi-objective setting, the effort can be put toward developing a hyper-heuristic (Zhao et al., 2021), where a high-level algorithm will be used to utilize the unique capabilities of several low-level algorithms (metaheuristics) more effectively.