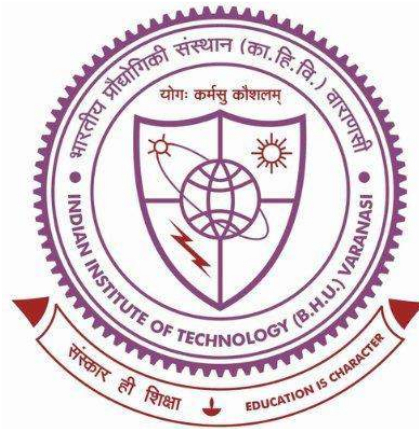


**Models and Algorithms to Facilitate the Logistics
Operations of Caregivers for Home Healthcare Services
in India**



**Thesis submitted towards the partial fulfillment
for the Award of Degree
*Doctor of Philosophy***

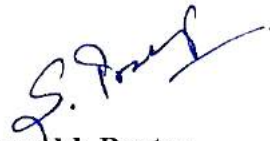
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CERTIFICATE

It is certified that the work contained in the thesis titled “**Models and Algorithms to Facilitate the Logistics Operations of Caregivers for Home Healthcare Services in India**” has been carried out by **Mr. Niteesh Yadav** and that this thesis has not been submitted elsewhere for a degree or a research proposal.

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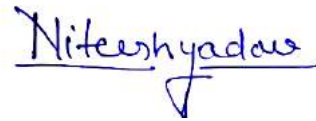
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TABLE OF CONTENTS

ACKNOWLEDGEMENT	iv
TABLE OF CONTENTS	vi
LIST OF FIGURES	ix
LIST OF TABLES	xi
LIST OF ABBREVIATIONS	xiv
PREFACE	xvi
1. Introduction.....	1
1.1. About the Home healthcare delivery.....	2
1.2. Research Motivation	4
1.3. Research issues.....	6
1.4. Research objectives and scope of the thesis.....	8
1.5. Outline of the thesis	12
2. Literature Review	15
2.1. Home healthcare delivery problem	15
2.1.1. Objective functions.....	20
2.1.2. Constraints	23
2.2. Literature on logistics and transportation.....	27
2.3. Solution methodologies.....	29
2.4. Gaps identified in the literature	32
2.5. Conclusions	34
3. A Generalized Single-Period Home Healthcare Delivery Problem.....	36
3.1. Introduction	36
3.2. Problem description	38
3.3. Mathematical model.....	41
3.4. An Illustrative Example	52
3.5. Solution approach.....	58

3.5.1. MIP-based Decomposition Heuristic	59
3.5.1.1 Single-Stage Decomposition.....	61
3.5.1.2. Multi-Stage Decomposition.....	65
3.5.1.3. Local Search	68
3.5.2. Rank-Based Decomposition Heuristic	70
3.5.3. p -Genetic Algorithm (p -GA).....	73
3.5.3.1. Chromosome Design.....	74
3.5.3.2. Fitness Evaluation.....	76
3.5.3.3. Parallelism	77
3.6. Computational Experiment	78
3.6.1. Experimental Settings.....	79
3.6.2. Algorithm selection	83
3.7. Experimentation on benchmark problem instances	88
3.8. Comparison of patient accommodation policies	93
3.9. Conclusions	104
4. A Multi-Objective Home Healthcare Delivery Problem	106
4.1. Introduction	106
4.2. Problem description	109
4.3. Mathematical model [M].....	113
4.4. An illustrative example	134
4.5. Solution methodology	140
4.5.1. NSGA-III.....	141
4.5.1.1. Chromosome design and fitness evaluation.....	141
4.5.1.2. NSGA operations and selection of the reference directions	145
4.5.2 Multi-objective Particle Swarm Optimization.....	147
4.5.2.1 Distance and Velocity	147
4.5.2.2 Elite repository.....	151

4.5.3 Multi-objective Grey Wolf Optimizer	152
4.6. Computational Experiments and Results	154
4.6.1. Experimental Settings.....	154
4.6.2. Quality Indicators	157
4.6.2.1. Mean Ideal Distance	158
4.6.2.2. Spread of Non-Dominated Solution	158
4.6.2.3. Max-Spread.....	158
4.6.3. Parameters tuning using the Taguchi method	159
4.6.5. Discussion on Pareto front and extreme solutions	170
4.6.6. Calculating the cost of patient convenience	177
4.6.7. Robustness testing	181
4.7. Conclusions	183
5. Conclusion and Future Scope	185
5.1. Introduction	185
5.2. Chapter-wise summary and conclusions	185
5.3. Contribution of the thesis	189
5.4. Managerial insights and recommendations	192
5.5. Scope of future research.....	194
References.....	196
Appendix A	
Appendix B	
Appendix C	
List of papers published	

LIST OF FIGURES

Figure 1.1: Diagram of a home healthcare delivery setup.	3
Figure 3.1: 3-D representation of feasible solution.	55
Figure 3.2: Framework for MIP-based decomposition strategies.	60
Figure 3.3: Flowchart – Single Stage decomposition.	64
Figure 3.4: Flowchart – Multi-Stage decomposition.	66
Figure 3.5: Flowchart – Local search algorithm.	69
Figure 3.6: Framework – Ranked-based decomposition.	71
Figure 3.7: GA operators. (a) Representation of parent solutions with crossover point. (b) Crossover operator. (c) Repair operator.	75
Figure 3.8: Box and whisker plot comparing the solution quality of the algorithms.	86
Figure 3.9: Comparison with benchmark instances.	91
Figure 3.10: Comparison of utility score under different objective functions.	96
Figure 3.11: Comparison of objective function values under different accommodation policies.	98
Figure 4.1: Objective functions considered in the proposed model.	112
Figure 4.2: Workload assignment for healthcare workers.	126
Figure 4.3: Possible schedules for various cases of multiple visits to a single patient.	129
Figure 4.4: Classification of time segments in relation to the ITW.	131
Figure 4.5: Values of decision variables related to the ITW constraints.	132
Figure 4.6: NSGA operators. (a) An example of the selection and crossover operation (b) Recombination step (c) repair operator	144
Figure 4.7: Calculating the point-of-difference matrix.	148

Figure 4.8: Calculating the next position of a particle using the vector sum method.	149
Figure 4.9: Method for estimating the location of the prey in GWO.	152
Figure 4.10: S/N ratio plots (a) NSGA-III with Single-point crossover (b) NSGA-III with Uniform crossover (c) MOPSO	162
Figure 4.11: Performance comparison based on the quality indicators.	167
Figure 4.12: Pareto front obtained by NSGA-III for HHI 25_50_40.	170
Figure 4.13: Box and whisker plot comparing the runs of NSGA-III.	173
Figure 4.14: Non-dominated solutions while only considering Objective-1 and Objective-5.	178
Figure 4.15: Relative gain in patient convenience with a reduction in profit.	180
Figure 4.16: Changes in the quality indicator values during robustness analysis.	182

LIST OF TABLES

Table 2.1: Classification of research papers based on the selection of objectives.	18
Table 2.2: Classification of research papers based on the selection of constraints.	25
Table 3.1: Hub information.	52
Table 3.2: Caregiver information.	52
Table 3.3: Patient information.	52
Table 3.4: Procedure information.	53
Table 3.5: Travel distances between nodes.	54
Table 3.6: Selected procedures under partial accommodation policy (Objective-3.1).	57
Table 3.7: Selected procedures under complete accommodation policy (Objective-3.3).	57
Table 3.8: Result comparison between the two accommodation policies.	57
Table 3.9: Description of the range and values of various input parameters.	80
Table 3.10: Size of the problem instances from Set_1.	81
Table 3.11: Limitations of commercial solver.	83
Table 3.12: Summary of the result obtained from different algorithms for set_1 instance	84
Table 3.13: Result of paired samples <i>t</i> -test.	87
Table 3.14: Modification needed to adapt our work to a benchmark instance set from the existing literature.	89
Table 3.15: Parameter values to incorporate the skill level in presented mathematical models.	90

Table 3.16: Result obtained for the benchmark instances using p-GA.	92
Table 3.17: Summary of results under complete accommodation restriction for set_1 instance.	94
Table 3.18: Summary of the results under partial accommodation relaxation for set_1 instance.	95
Table 3.19: Analysis of staff utilization.	101
Table 3.20: Financial analysis.	102
Table 4.1: Hub information.	134
Table 4.2: Healthcare staff information.	134
Table 4.3: Patient information.	134
Table 4.4: Procedure information.	135
Table 4.5: Travel distances between nodes.	135
Table 4.6: Assignment decision for Solution 1.	137
Table 4.7: Job sequence and schedule for Solution 1.	137
Table 4.8: Assignment decision for Solution 2.	138
Table 4.9: Job sequence and schedule for Solution 2.	138
Table 4.10: Comparison of the objective function values.	140
Table 4.11: Coordinates of the reference points in the normalized objective space.	146
Table 4.12: Description of the range and values of various input parameters.	155
Table 4.13: Characteristics of the generated problem instances.	156
Table 4.14: Considered parameter values for the three metaheuristics.	160
Table 4.15: L9 orthogonal array for the Taguchi trials.	161
Table 4.16: Quality indicator values obtained using NSGA-III variants for the Taguchi trials.	161

Table 4.17: Quality indicator values of the Pareto fronts obtained by MOPSO.	163
Table 4.18: Quality indicator values of the Pareto fronts obtained by MOGWO.	163
Table 4.19: Comparison of the NSGA-III crossover operators using the Pareto front quality indicators.	164
Table 4.20: Result of paired sample <i>t</i> -test for the two crossover operators of NSGA-III.	165
Table 4.21: Average values of the results obtained by five independent runs.	169
Table 4.22: Extreme solutions obtained by NSGA-III for problem instance HHI 25_50_40.	172
Table 4.23: Result of one-way repeated measures ANOVA for 5 independent runs of NSGA-III.	174
Table 4.24: Result of paired sample <i>t</i> -test for independent runs of NSGA-III using MID indicator.	175
Table 4.25: Quality indicator values for the five independent runs of NSGA-III using HHI 25_50_40.	175
Table 4.26: Pareto front obtained by run-5 of NSGA-III for problem instance HHI 25_50_40.	176
Table 4.27: Trade-off analysis between Patients' inconvenience and Net profit.	179

LIST OF ABBREVIATIONS

WHO	World Health Organization
OECD	Organisation for Economic Co-operation and Development
NCIRD	National Center for Immunization and Respiratory Diseases
HHC	Home HealthCare
GVR	Grand View Research
CAGR	Compound Annual Growth Rate
USD	United States Dollar
ITW	Inconvenient Time Window
MIP	Mixed Integer Program
NSGA	Non-dominated Sorting Genetic Algorithm
HHCRSP	Home HealthCare Routing and Scheduling Problem
VRP	Vehicle Routing Problem
TOP	Team Orienteering Problem
VRPTW	Vehicle Routing Problem with Time Window
MOWFA	Multi-Objective Water Flow-like Algorithm
MOSA	Multi-Objective Simulated Annealing
MOICA	Multi-Objective Imperialist Competitive Algorithm
GPU	Graphics Processing Unit
p-GA	Parallel-processed Genetic Algorithm
MD-HVRPTW	Multi-Depot Heterogeneous Fleet Vehicle Routing Problem with Time Windows
SSD	Single Stage Decomposition
MSD	Multi-Stage Decomposition

LS	Local Search
GA	Genetic Algorithm
QS	Quality Score
MAL	Maximum Assignment Limit
RDH	Rank-based Decomposition Heuristic
CV	Capability Value
AV	Accessibility Value
TFLOPS	Trillion Floating Point Operations Per Second
ANOVA	Analysis of Variance
MOPSO	Multi-Objective Particle Swarm Optimization
MOGWO	Multi-Objective Grey Wolf Optimizer
PSO	Particle Swarm Optimization
POD	Point-of-difference
PFA	Pareto Front Approximation
MID	Mean Ideal Distance
SNS	Spread of Non-dominated Solution
MS	Max-spread
DOE	Design of experiment

PREFACE

In an era characterized by rapid advancements in healthcare and an aging population, the need for efficient and accessible healthcare solutions has never been more apparent. This fact was laid bare during the recent COVID-19 pandemic. On the one hand, where we were able to successfully develop the vaccines in record time, almost seven million people died due to the pandemic. In the case of India, with half a million COVID-19-related deaths, it was clear that a rapid improvement in the healthcare infrastructure was required. In response, the Healthcare Federation of India produced a white paper titled '*Indian Home Healthcare 2.0: Redefining the Modern Care Continuum*'. The document highlighted the benefits of a sufficiently developed home healthcare sector in providing a viable alternative to traditional healthcare services. Hence, in the current work, we aim to design and develop OR techniques to facilitate the logistics operations of home healthcare delivery, an essential part of home healthcare services. Simultaneously, we intend to provide robust solution methodologies that can be used for a wide variety of home healthcare delivery setups.

In this thesis, we consider a single-period home healthcare delivery problem, where a heterogeneous set of caregivers are to be deployed from multiple hubs to fulfill the demands of multiple patients. The thesis focuses on developing methodologies that can be useful for as many home healthcare delivery services as possible without much friction. This translates into the development of generalized home healthcare delivery models alongside efficient and robust solution approaches. Further, the selection of the objective function needs to be done very carefully. With the competitive goals of the different stakeholders and the varying

maturity levels of various home healthcare delivery organizations, any generalized model should be designed to accommodate obscure combinations of objective functions. Finally, the gaps in the existing literature on the home healthcare delivery problem regarding the more refined scheduling, multiple time windows, and contact restriction methods need to be filled. To capture these research themes, three broad sets of objectives are defined.

In the first objective, a mathematical model that can be used to represent a wide variety of home healthcare delivery setups is developed. Patients' demands are modeled in a general fashion, with as many attributes as possible. The mathematical model also incorporates the most commonly appearing constraints from the home healthcare delivery literature. Developed models can be reduced to represent more obscure scenarios by strategically omitting certain constraints or altering parameter values. The resulting monolithic home healthcare delivery model is tested on a benchmark problem set, and a method for adapting the mathematical model to the benchmark problem is provided. The modified model is found to be capable of solving the benchmark problem for 26 out of 30 instances. Two MIP-based metaheuristic, namely single-stage decomposition (SSD) and multi-stage decomposition, alongside the parallelly processed version of the genetic algorithm (p -GA), are developed. Statistical analysis is carried out to establish the appropriate niche for each algorithm. Finally, p -GA was used to find the favorable combination of objective function and 'demand satisfaction policy' for an overburdened healthcare system. In the second objective, we extend the monolithic mixed integer programming model to a multi-objective setup. The multi-objective variant of the model is developed to accommodate the competitive goals of the different stakeholders from a home healthcare delivery setup. Twelve criteria are initially

identified for optimization. These criteria are eventually categorized into five objective functions based on the requirements of three stakeholders (patient, caregivers, and management). Multi-objective metaheuristics like NSGA-III, MOPSO, and MOGWO are used to produce diverse Pareto solutions. NSGA-III with single point crossover operator is found to be the most efficient for solving the multi-objective home healthcare delivery problem. The Pareto set obtained from the same is also tested for the 50% variation in service time and travel time. Approximate Pareto front is found to be robust, with only 11% to 17% maximum degradation in key quality indicators.

Further, as the third objective, the thesis adds novelties to the home healthcare delivery problem. First, an extensive literature review identifies some gaps in the existing literature. Constraints to restrict unnecessary contact between patients and staff have been added to the monolithic mathematical model. 'Contact restriction' constraints use a prescribed maximum number of allowed contacts as a hard limit for each entity. Similarly, models incorporate the 'inconvenient time window' as an example of multiple favorable time windows where a visit can only be scheduled into one of the time slots. The thesis also presents a soft implementation of the 'inconvenient time window' constraints by allowing visits to be scheduled inside it. The extent of violation of the 'inconvenient time window' is subsequently minimized as a part of a novel objective function - The patient's inconvenience due to improper scheduling. Another aspect of the same objective function focuses on improving the quality of schedules when scheduling multiple visits to a single patient by clubbing the scattered visits into the minimum possible number of sessions.