
Research Study on Food Banks in India: Barriers, Distribution Planning and Network Design

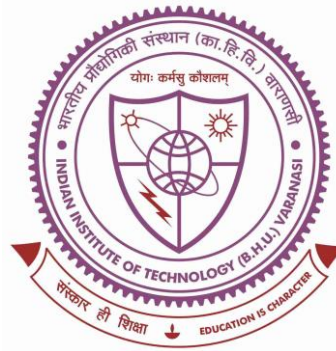
Thesis submitted in partial fulfillment

for the Award of Degree

DOCTOR OF PHILOSOPHY

by

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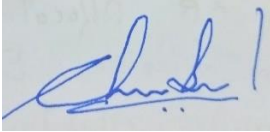
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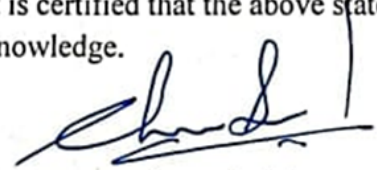
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LIST OF FIGURES

Figure 1.1.	Import vs. Export of food grains (rice and wheat)	3
Figure 1.2.	A typical Food banking system	5
Figure 2.1.	Various research dimensions for study of food banks	27
Figure 2.2.	Food banks and its associated timeframe in literature	28
Figure 2.3.	Various research dimension for barriers of food banks	30
Figure 2.4.	Network visualization of food bank’s literature	48
Figure 3.1.	Flowchart of hybridized DEMATEL-based ANP	60
Figure 3.2.	Format distributed to experts	69
Figure 3.3.	Impact Relation Map of barriers and sub-barriers	70
Figure 4.1.	Problem description of MDVRP-TW-SP-SD	90
Figure 4.2.	Encoding and Decoding of chromosomes	99
Figure 4.3.	Single point crossover for generating offspring	103
Figure 4.4.	Flowchart of elitist GA hybridized with local search	108
Figure 4.5.	Convergence diagram of GA, GA_LS1, and GA_LS_2 algorithms	117
Figure 4.6.	Location of depots, pickup, delivery sites on Lucknow Map	120
Figure 4.7.	Plot of the first route from depot 3 using vehicle number 16.....	125
Figure 4.8.	Multiple objectives of food banks	133
Figure 4.9.	Flowchart for NSGA-II algorithm	140
Figure 4.10.	Non-dominated solutions obtained by exact method.....	150
Figure 4.11.	Pareto-front obtained for the multi-objective model.....	151
Figure 4.12.	Pareto efficient solution in 3-D space.....	153
Figure 4.13.	Heat-map for correlation among different objectives.....	154
Figure 5.1.	Schematic diagram of food bank network operating in India.....	167
Figure 5.2.	Nomenclature of tier-1 and tier-2 food banks	182
Figure 5.3.	Location of donors, beneficiaries and food banks	183
Figure 5.4.	Total strategic budget expenditure distribution in all models	194
Figure 5.5.	Percent available donation undertaken in all models	195
Figure 5.6.	Food donation and purchase behavior in all models	196
Figure 5.7.	Variation in the shortage value with variation in donation	199
Figure 5.8.	Food purchase cost and unused operational budget with variation in donation.....	200

Figure 5.9.	Strategic budget expenditure with varying donation	201
Figure 5.10.	Workforce hired at tier-1 and tier-2 food banks with variation in donation....	202
Figure 5.11.	Variation in the shortage value with variation in demand	203
Figure 5.12.	Variation in total purchase cost and food transferred from tier-1 to tier-2.....	204
Figure 5.13.	Strategic budget expenditure with varying demand	205
Figure 5.14.	Workforce hired at tier-1 and tier-2 food banks with variation in demand....	206
Figure 5.15.	Shortage vs variation in initial volunteers at each existing food banks	207
Figure 5.16.	Manpower hired with variation in volunteers at existing food banks.....	208
Figure 5.17.	Total shortage with variation in strategic budget.....	209
Figure 5.18.	Manpower hired with variation in strategic budget	210
Figure 5.19.	Total shortage with variation in operational budget	211
Figure 5.20.	Total cost and Total shortage with variation in penalty value on shortage...	212

LIST OF TABLES

Table 2.1.	Identified Barriers for adoption and growth of food banks in India	35
Table 2.2.	Detailed description of problem setting for VRP and food banks literature	41
Table 3.1.	Encodings of identified barriers	54
Table 3.2.	Prominence, cause-degree, local and global weights and local & global ranks ...	70
Table 3.3.	The limit supermatrix, W^α for sub-barriers.....	74
Table 4.1.	Description of sets, indices and parameters used in the model formulation	90
Table 4.2.	Specification of instances in the proposed dataset	111
Table 4.3.	Specifications of generated instances	111
Table 4.4.	Parameter values used in experimentation	113
Table 4.5.	The results of elitist GA, GA_LS_1, GA_LS_2 on sub-class ID-1	115
Table 4.6.	Aggregated values of the objective function on sub-classes.....	116
Table 4.7.	Results of ANOVA	118
Table 4.8.	Description of supply and demand donation of base scenario.....	122
Table 4.9.	Results of the proposed algorithm on base-case scenario.....	122
Table 4.10.	The routes formed by GA_LS_2 on current existing scenario S-1.....	124
Table 4.11.	Description of variation on generated scenarios	126
Table 4.12.	Results of elitist GA on the generated scenarios.....	127
Table 4.13.	Results of GA_LS_1 on the generated scenarios.....	127
Table 4.14.	Results of GA_LS_2 on the generated scenarios.....	128
Table 4.15.	Description of the smaller size problem.....	143
Table 4.16.	Different weights used for weighted sum method.....	144
Table 4.17.	Non-dominated solution using weighted sum approach	145
Table 4.18.	Payoff table.....	146
Table 4.19.	Value of parameters e_2 and e_3 for Augmecon method.....	146
Table 4.20.	Non-dominated solution using Augmecon method.....	147
Table 4.21.	Non-dominated solution using Augmented weighted Tchebycheff method....	148
Table 5.1.	Characteristic of Tier-1 and Tier-2 food banks operating in India	164
Table 5.2.	Dataset related to existing food bank network	182
Table 5.3.	Summarized results of all the 11 models	189
Table 5.4.	Manpower hiring distribution in the operating food banks	192

Table 5.5. Comparison of different objective values recorded for each model197

ABBREVIATIONS

Abbreviation	Definition
ACO	Ant Colony Optimization
ANP	Analytic Network Process
CVRP	Capacitated Vehicle Routing Problem
DEMATEL	Decision Making Trial and Evaluation Laboratory
DSS	Decision Support System
GA	Genetic Algorithm
IFSA	Indian Food Sharing Alliance
IRM	Impact Relation Map
MCDM	Multi-Criteria Decision Making
MDVRP	Multi-Depot Vehicle Routing Problem
MDVRP-TW-SP-SD	VRP with time windows, split-pickup, and split delivery
MILP	Mixed Integer Linear Programming
MO	Multi-Objective
NGO	Non-Government Organizations
NSGA	Non-dominated Sorting Genetic Algorithm
PDP	Pickup and Delivery Problem
PDS	Public Distribution System
PSO	Particle Swarm Optimization
SDVRP	Split Delivery Vehicle Routing Problem
VRDAP	VRP with Demand Allocation Problem
VRP	Vehicle Routing Problem
VRPTW	Vehicle Routing Problem with Time Windows

TABLE OF CONTENTS

CERTIFICATE	ii
COPYRIGHT TRANSFER CERTIFICATE.....	iv
ACKNOWLEDGEMENT	v
TABLE OF CONTENTS.....	vii
LIST OF FIGURES	xi
LIST OF TABLES	xiii
ABBREVIATIONS	xv
Chapter 1: Introduction	1
1.1. Food banks: Global Overview and Local Snapshot.....	5
1.2. Barriers to the adoption of food banks in India.....	7
1.3. Optimal distribution of food.....	9
1.4. Network design of food banks in India	12
1.5. Motivation	15
1.6. Problem Statement	17
1.7. Research Contributions	21
1.8. Thesis Outline	23
Chapter 2: Literature review	27
2.1. Introduction	27
2.2. Barriers	29
2.3. MDVRP.....	37
2.3.1. Single Objective.....	37
2.3.2. Multi-objective.....	44
2.4. Integrated Food bank network	46
2.5. Conclusion.....	51
Chapter 3: Barriers to the Adoption and Growth of Food Banks in India.....	53
3.1. Introduction	53
3.2. Methodology	61
3.2.1. Procedure for constructing Impact relation map [IRM] using DEMATEL.....	61
3.2.2. Obtaining priority weights of barriers and sub-barriers using Analytic Network Process	65
3.3. Results	68
3.4. Discussion	75
3.5. Conclusion.....	80
Chapter 4: Multi-Depot Vehicle Routing Problem.....	85

4.1. A Multi-Depot Vehicle Routing Problem for Surplus Food Recovery and Redistribution.....	85
4.1.1. Introduction.....	85
4.1.2. Model Formulation	89
4.1.3. Solution Approach	95
4.1.4. Computational Experiments.....	109
4.1.5. Conclusion	129
4.2. Multi-Objective Optimisation for Surplus Food Recovery and Redistribution	131
4.2.1. Introduction.....	131
4.2.2. Model Formulation	134
4.2.3. Methodology	137
4.2.4. Computational Experiments.....	142
4.2.5. Conclusion	155
Chapter 5: Optimal Design of an Integrated Food Bank Network Considering Nutritional Requirements: Modeling and Case Study.....	159
5.1. Introduction	159
5.2. Model formulation.....	163
5.2.1. Problem description	163
5.2.2. Notation.....	168
5.2.2.1. Sets and indices	168
5.2.3. Decision variables.....	170
5.2.4. Formulation.....	171
5.2.5. Variations in the model.....	175
5.3. Case Study.....	181
5.4. Computational Experiments.....	186
5.4.1 Results.....	187
5.5. Sensitivity Analysis.....	197
5.5.1. Sensitivity analysis on shortage model (P)	198
5.5.2. Sensitivity analysis on food donation	198
5.5.3. Sensitivity analysis on demand.....	202
5.5.4. Sensitivity analysis on workforce	206
5.5.5. Sensitivity analysis on strategic budget and operational budget	209
5.5.6. Sensitivity analysis on Total Cost minimization model (P5).....	211
5.6. Conclusion.....	212
Chapter 6: Conclusions and Future Research Directions	217

6.1. Conclusion.....	217
6.2. Limitations and Future Research direction	221
References.....	223
Appendix A.....	257
Table A-1: Direct influence matrix and Normalized direct influence matrix of barriers .	257
Table A-2: Total relation matrix of barriers	258
Table A-3: Total relation matrix of sub-barriers.....	259
Table A-4: Unweighted supermatrix Zs for sub-barriers	261
Table A-5: The normalized matrix U_B and weight matrix W_B for barriers	263
Table A-6: Weighted supermatrix, W for sub-barriers.....	264
Appendix B	266
Table B-1: The results of GA, GA_LS_1, GA_LS_ 2 and effectiveness score of sub-class ID-2 to sub-class ID-9.....	266
Table B-2: The latitude, longitude, service time and demand of pickup and delivery locations	273
Appendix C	275
Excerpts from interview with Food Bank executive on configuration details of Food Banks	275
List of Publications	281

Extended Abstract

Food banks are non-for profit organizations that play a significant role to ensure food security, reduce food wastage and alleviate hunger. Their primary role concerns recovery and redistribution of surplus or leftover food to economically deprived and marginalized people. Food banks acts as a bridge between the food insecure and food surplus population. The primary goal of food banks to alleviate hunger aligns with the second goal – zero hunger of United Nations Sustainable Development Goals (SDGs). In addition, food banks agenda of reducing food wastage aligns with goal -12 of SDGs encompassing responsible consumption and production. Food banks are gaining momentum globally but still it is in a preliminary stage in several developing countries including India. Food banks faces several challenges ranging from strategic to operational aspect. These challenges typically concern with identifying critical challenges, addressing the daily operational problem of collection and distribution and designing integrated food banks network model encompassing underlying characteristics of Indian food banks. These challenges have significant impact on the daily operation and overall effectiveness of food bank. These challenges have paramount impact especially on food banks that are in nascent stage in developing countries like India. Therefore, these critical challenges need to addressed to increase the overall effectiveness of food banks.

The study aims identify challenges and barriers that impede the growth and adoption of food banks in the Indian context and to evaluate critical barriers by prioritizing them. A total of 14 barriers have been identified through literature survey, qualitative interviews with different stakeholders of food banks in India and expert's inputs. These barriers have been clustered into 7 categories - Policy and regulation, financial resources, infrastructure and human resources, planning and coordination, knowledge, uncertainty, and characteristics of food, of main barriers. Then, DEMATEL is used to find the cause-effect relationship among the identified barriers. A network of inter-relationship among the identified barriers is devised using Analytic

Network Process (ANP) using the output from DEMATEL. Results of DEMATEL indicates that lack of planning and coordination is the most significant barrier that hinders the growth and sustenance of food banks in India. Also, lack of infrastructure and human resources are the major effect of the other barriers. Further, the financial barrier attains maximum weight in the ANP process and came out to be the most critical barrier. This study can be help food banks and policy makers to devise the plans for sustenance of the food banks. To the best of our knowledge, this is the first attempt ever to identify and prioritize the barriers for the food banks.

Collection and distribution of donated food is the core of food bank operations. The problem faced by the food banks operating on the front-end model is the collection of surplus food from donation points and re-distribution of it to the demand points. These operation is carried out using a fleet of vehicles available at different volunteer locations/depots within specified time windows. Sometimes, the quantity of supply donation and demand exceeds the available vehicle capacity leading to multiple visits to those supply (pickup) and demand points. Thus, demand splitting is allowed at the pickup as well and delivery points. Therefore, this problem can be seen as a rich variant of the vehicle routing problem (VRP) and named as a multi-depot VRP with time windows, split pickup and split delivery (MDVRP-TW-SP-SD). The problem is to determine the optimal number of vehicles from each depot to be hired and their optimal routes (sequence for visiting pickup and demand nodes) such that the total cost of hiring the vehicles, routing cost and penalty for unmet demand are minimized and it is formulated as a mixed-integer programming problem. We have used single composite objective of total transportation cost and penalty minimization to model this problem. To the best of our knowledge, this is the first attempt to formulate the MDVRP-TW-SP-SD. We have endeavored both exact techniques and metaheuristics to solve the problem. To efficiently and effectively solve the single-composite objective problem, an elitist GA and a GA hybridized with the local search are proposed. The performance of the proposed algorithms is tested through extensive

computational experiments carried out on 180 modified benchmark problem instances from the literature. The overall computational experiments are carried out on PARAM SHIVAY super computer. The results of computational experiments show the superiority of the GA hybridized with 3-opt local search. In addition, our proposed algorithms outperform state-of-the-art solver Gurobi both in terms of solution quality and efficiency. A case of the Robin Hood Army operating in the Lucknow city of India is also presented to demonstrate the applicability of the proposed model to practice and several insights were outlined. The result of case study demonstrates higher utilization of bigger vehicles, average 28% and 17% multiple visits to pickup and delivery nodes, respectively. Additionally, the analysis indicates a higher utilization of four-wheeler vehicles as opposed to two-wheeler vehicles, attributed to the latter's limited capacity.

Unlike commercial institutions, food banks operate in non-profit model and aims to achieve social goals along with cost minimization. We endeavor three primary objectives of food banks - efficiency, effectiveness, and equity. The measure for efficiency is minimum total transportation cost, minimum total shortage for effectiveness, and minimum of the maximum shortage of network is taken for equity. These objectives have underlying trade-offs and therefore we need a multi-objective model to analyze these conflicting objective using pareto-front. This paper proposes a MILP model for multi-objective optimization of surplus food recovery and redistribution in India. Specifically, the problem is formulated MO-MDVRP-TW-SP-SD (Multi - Objective MDVRP-TW-SP-SD) problem. To the best of our knowledge, our study is the first to evaluate Indian food banks from a multi-objective perspective. To solve the proposed problem, state-of-the-art-solver Gurobi is used for weighted sum method, augmented ϵ -constraint method, and augmented weighted Tchebycheff methods. Non-dominated Sorting Genetic Algorithm (NSGA-II) is developed to solve the larger size problems. The results of the computational experiments show significant trade-off behavior

between efficiency and effectiveness. The outcomes demonstrate that the weighted sum method, augmented ϵ -constraint method, and augmented weighted Tchebycheff method yield 5%, 19%, and 15% distinct non-dominated solutions, respectively. It is noteworthy that even with extensive computational capabilities of the supercomputer, the exact methods failed to provide optimal solutions for specific combinations within a one-hour runtime. NSGA-II remarkably produces near-optimal solutions within 76 seconds for the larger network.

Despite of non-profit nature, these food banks incurs cost for storage, transportation and food purchase. The architecture of Indian food banks differs widely from other food banks in terms of hierarchical framework of food banks on the basis of their scale of operation and type of food donors. Specifically, food banks operate in two different tiers based on the types of donor, beneficiaries, food and scale of operation. Food banks operate in resource scarce environment and this hierarchical framework of Indian food banks brings additional challenges to food bank supply chain network design. This study is motivated from Indian food banks and it presents a mixed – integer linear programming model and its variation for integrated network design of food banks with different objectives concerning efficiency, effectiveness and equity. The novelty corresponds to the inclusion of aspects related to nutritious meal in our work. To the best of our knowledge, food bank network design model has not been investigated for ensuring the nutritional requirements of the beneficiaries according to their age-group profile. We endeavor to fill this research gap in our proposed study. We conducted a realistic data based case study to design integrated food bank network encompassing nutritional aspect, in Delhi, the capital of India, with an aim to provide some insights for their better functioning. The computational experiment is carried out on the case problem and proposed mathematical model and its variation is solved using state-of-the-art solver Gurobi. An extensive sensitive analysis is performed on the mathematical model to assess the performance of the proposed model and generate insights for the food banks. The results indicate that considerable portion (around 77

to 79%) of strategic budget has been used for manpower hiring. The findings indicate that achieving a zero total shortage in the system necessitates a significant strategic budget and, on average, a 37.5% increase in the number of volunteers is required. Based on the work proposed in this study, we presented some promising avenues for future research directions to further enhance the proposed models.