EFFICIENT PLANNING FOR

FOOD GRAIN DISTRIBUTION

SHALLU BHASIN

DEPARTMENT OF MECHANICAL ENGINEERING

INDIAN INSTITUTE OF TECHNOLOGY DELHI

NEW DELHI-110016, INDIA

JUNE 2026

© Indian Institute of Technology Delhi (IITD), New Delhi, 2026

Efficient Planning for Food Grain Distribution

by

SHALLU BHASIN

Department of Mechanical Engineering

Submitted

In fulfilment of the requirements of the degree of

Doctor of Philosophy

to the



INDIAN INSTITUTE OF TECHNOLOGY DELHI

NEW DELHI-110016, INDIA

JUNE 2026

Dedicated to

My Parents

and

Siblings

CERTIFICATE

This is to certify that the thesis entitled **"Efficient Planning for Food Grain Distribution"** being submitted by **Ms. Shallu Bhasin** to the **Indian Institute of Technology Delhi** in fulfilment of the award of **Doctor of Philosophy** in Department of Mechanical Engineering is an authentic record of the investigations carried out by her under my guidance and supervision. The presented work has fulfilled the requirement for the submission of this thesis and has reached the required criterion to the best of my knowledge and belief.

The research reports and the results presented in this thesis have not been submitted in parts or in full previously for the award of any degree or diploma to any other University or Institute.

07/07/2026

Prof. Nomesh Bolia
Professor
Department of Mechanical Engineering
Indian Institute of Technology Delhi
New Delhi - 110016

ACKNOWLEDGEMENT

I would like to express my profound gratitude and heartfelt thanks to my esteemed supervisor, **Prof. Nomesh Bolia**, for providing me the opportunity to undertake this research under her expert guidance. Her mentorship has been the foundation of my academic and research journey. He consistently offered insightful advice, encouragement, and scholarly direction that have significantly enriched the depth and scope of this work.

I extend my heartfelt gratitude to the eminent members of my student research committee (SRC), **Prof.Sunil Jha, Prof. M.P Gupta,** and **Prof. Varun Ramamohan**. The thoughtful critiques, constructive feedback, and probing questions during various presentations have not only refined the contours of this thesis but have also broadened my scholarly perspective. Their collective expertise ensured the rigor and excellence of this research.

I express my heartfelt appreciation to the **United Nations World Food Programme (UNWFP)** and the **Department of Food & Public Distribution (DFPD), Government of India**, for extending their support, insights, and data access, without which the practical aspects of this research would not have been possible. I also thank officials across **31 States and Union Territories** for their cooperation during data collection, interactions, and validation exercises that helped refine the analysis.

I wish to express my sincere thanks to the senior research scholars of the Public Distribution Lab (PSL Lab) **Dr. Mansi Gupta, and Dr. Deepak Gautam**. Their association, intellectual engagement, and collective problem-solving have encouraged an environment that exceeds the challenges of research.

I express my gratitude toward my dear friends **Ms. Neha Alahwat, Mrs. Adya Pandey, Nishant Goswami and Nidhin BabuKuttan** due to their presence with me here in IIT, my whole journey was very inspiring & a memorable experience.

Lastly, I extend my gratitude to my parents and brother. Their unwavering love, encouragement, and belief in my capabilities have been a source of constant inspiration. Their enduring support has provided the foundation for my academic pursuits.

(SHALLU BHASIN)

ABSTRACT

India's Public Distribution System (PDS) plays a crucial role in ensuring national food security; however, inefficiencies in procurement, storage, and distribution persist, hindering its effectiveness. This thesis presents a comprehensive and systematic framework for optimizing the food grain supply chain through state-specific mathematical models and decision-support tools. The research begins with the development of mathematical models to optimize food grain movement under diverse operational constraints across states. These models aim to minimize transportation distances, streamline the distribution network, and enhance scalability.

To support practical implementation, the thesis introduces *Anna Chakra*, a route-optimization tool designed to automate data processing, execute optimization models, and facilitate data-driven decision-making for state governments. Built using Python, HTML/CSS/JavaScript, and MySQL, the tool incorporates robust error handling, validation checks, and flexibility to accommodate state-specific supply chain variations.

Building on the success of PDS movement optimization, the research extends to the procurement stage, modelling the movement of food grains from Procurement Centres (PCs) to mills and warehouses. Mathematical models have been developed for decentralised procurement states (DCP), such as Punjab and Haryana, resulting in a significant reduction in average transportation distance when implemented by state agencies. However, the location of procurement centres remains a persistent challenge, as current practices rely on annual grain arrival estimates. To address this gap, the thesis proposes a mathematical framework based facility location model to identify optimal PC locations, enhance accessibility, and mitigate regional imbalances in procurement infrastructure.

Overall, this research contributes a scalable, data-driven framework and a practical computational tool to strengthen India's food grain supply chain, from procurement to end-distribution, supporting more efficient, equitable, and resilient food security operations.

सारांश

भारत की सार्वजनिक वितरण प्रणाली (PDS) राष्ट्रीय खाद्य सुरक्षा सुनिश्चित करने में महत्वपूर्ण भूमिका निभाती है; हालाँकि, खरीद, भण्डारण और वितरण में कमियाँ बनी हुई हैं, जो इसकी प्रभावशीलता में बाधा डालती हैं। यह थीसिस राज्य के अनुरूप गणितीय मॉडल और निर्णय-सहायता उपकरणों के माध्यम से अनाज आपूर्ति श्रृंखला को बेहतर बनाने के लिए एक व्यापक और व्यवस्थित रूपरेखा प्रस्तुत करता है। शोध की शुरुआत राज्यों में विभिन्न परिचालन बाधाओं के अनाज की आवाजाही को बेहतर बनाने के लिए गणितीय मॉडल विकसित करने से होती है। इन मॉडलों का उद्देश्य परिवहन दूरी को कम करना, वितरण तंत्र को सुव्यवस्थित करना और व्यापकता को बढ़ाना है।

इसे वास्तविकता में लागू करने में मदद के लिए, यह थीसिस 'अन्ना चक्र' नाम का एक रूट-ऑप्टिमाइज़ेशन टूल पेश करती है। इसे डेटा प्रोसेसिंग को ऑटोमेट करने, ऑप्टिमाइज़ेशन मॉडल चलाने और राज्य सरकारों के लिए डेटा-आधारित फ़ैसले लेने में मदद करने के लिए बनाया गया है। Python, HTML/CSS/JavaScript और MySQL नामक तकनीकों का उपयोग करके बनाए गए इस टूल में मज़बूत त्रुटि निवारण, वैधता जाँच और राज्यों के अनुरूप आपूर्ति श्रृंखला में बदलावों को अपनाने की सुविधा है।

PDS मूवमेंट ऑप्टिमाइज़ेशन की सफलता को आगे बढ़ाते हुए, यह रिसर्च खरीद (procurement) के चरण तक फैली हुई है, जिसमें खरीद केंद्रों (PCs) से मिलों और गोदामों तक अनाज की आवाजाही की मॉडलिंग की गई है। पंजाब और हरियाणा जैसे विकेंद्रीकृत खरीद (DCP) प्रणाली वाले राज्यों के लिए गणितीय मॉडल विकसित किए गए हैं, जिन्हें राज्य एजेंसियों द्वारा लागू करने पर औसत परिवहन दूरी में काफ़ी कमी आई है। हालाँकि, खरीद केंद्रों की जगह तय करना एक लगातार बनी रहने वाली चुनौती है, क्योंकि मौजूदा तरीके अनाज की वार्षिक आवक के अनुमानों पर निर्भर करती हैं। इस कमी को दूर करने के लिए, थीसिस एक गणितीय फ़्रेमवर्क-आधारित सुविधा स्थान मॉडल (facility location model) का प्रस्ताव करती है ताकि मंडी के लिए सबसे सही जगह की पहचान की जा सके, पहुँच बढ़ाई जा सके और खरीद के बुनियादी ढाँचे में क्षेत्रीय असंतुलन को कम किया जा सके।

कुल मिलाकर, यह रिसर्च भारत की अनाज आपूर्ति श्रृंखला को मज़बूत करने के लिए एक स्केलेबल, डेटा आधारित फ़्रेमवर्क और एक व्यावहारिक कंप्यूटेशनल टूल देती है। यह खरीद से लेकर अंतिम वितरण तक की प्रक्रिया में मदद करती है, जिससे खाद्य सुरक्षा के काम ज़्यादा कुशल, निष्पक्ष और मज़बूत बनते हैं।

TABLE OF CONTENTS

CERTIFICATE ..... **i**

ACKNOWLEDGEMENT ..... **ii**

ABSTRACT ..... **iii**

सारांश ..... **iv**

TABLE OF CONTENTS ..... **v**

LIST OF FIGURES ..... **x**

LIST OF TABLES ..... **xii**

LIST OF ABBREVIATIONS ..... **xiii**

1. INTRODUCTION **1**

1.1 Food Security 1

1.1.1 Global Food Security System 2

1.1.2 Different Food Mechanisms in India 4

1.1.3 Public Distribution System of India 6

1.1.4 Motivation of the Present Work 7

1.2 Research Problem Studies 10

1.3 Outline of Thesis 11

1.4 Summary 13

2. LITERATURE REVIEW **14**

2.1 Introduction 14

2.2 Food Security 15

2.3 Components of Food Distribution 15

2.3.1 Procurement 15

2.3.2 Storage 16

2.3.3 Distribution 18

2.4 Public Distribution System 19

2.4.1 The Great Mountain Region 20

2.4.2 Plains of the Ganga and the Indus 21

2.4.3 The Western Desert 22

2.4.4 The Southern Peninsula 23

2.5 Optimization Techniques related to food distribution 24

2.6 Observations from Literature Review 26

2.7 Research Gaps 27

2.8 Summary 28

3. RESEARCH METHODOLOGY 29

3.1 Objectives of Research 29

3.1.1 Optimization of Food Grain Movement of the PDS 30

3.1.2 Anna Chakra- Movement optimization tool for PDS 31

3.1.3 Optimization of the Procurement System of India 31

3.1.4 Facility location models for identifying optimal locations for Procurement center's 32

3.2 Summary 32

4. FRAMEWORK FOR OPTIMIZATION OF PUBLIC DISTRIBUTION SYSTEM ..33

4.1 Introduction 33

4.2 Prioritization Analysis 36

4.3 Methodology 36

4.3.1 Data Collection 37

4.3.1.1 Distance Calculation 39

4.3.2 Mathematical Models 40

4.3.2.1 Assumptions 42

4.3.2.2 Notations and Parameters 42

4.3.2.3 Decision Variable 44

4.3.2.4 Mathematical formulation of a 2-tier supply chain network having a DCP system 44

4.3.2.5 Mathematical formulation of a 2-tier supply chain network having direct delivery 46

4.3.2.6 Mathematical formulation of a three-tier supply chain network 47

4.3.2.7 Mathematical formulation for the state of West Bengal 50

4.3.2.8 Mathematical formulation for the state of Maharashtra 53

4.3.2.9 Mathematical formulation for the state of Jammu, Kashmir, and Ladakh ..62

4.3.2.10 Mathematical formulation for the state of Meghalaya 68

4.3.2.11 Mathematical formulation for the state of Manipur 71

4.3.2.12 Mathematical formulation for the state of Odisha 74

4.3.2.13 Mathematical formulation for the state of Bihar 78

4.3.2.13.1. Model 1: Annual Model 79

4.3.2.13.2. Model 2: Sequential Optimisation 86

4.3.2.14 Algorithm Design 92

4.3.3 Plan Validation and Implementation 93

4.4 Results 100

4.4.1 QKM Reduction 100
4.4.2 Cost Saving 103
4.4.3 Reduction in Carbon Emissions 104
4.4.4 Qualitative Assessment of Pre and Post Optimization 106
4.4.5 Counterintuitive aspects of the research 107
4.5 Policy Implications 107
4.6 Key challenges, Mitigation strategies, and lessons learned 111
4.7 Summary 113
5. TOOL DEVELOPMENT FOR MOVEMENT OPTIMIZATION 115
5.1 Introduction 115
5.2 Structure and Architecture of the tool 116
5.3 Work Flow of the Intra Movement Optimization Tool 117
5.3.1 Login Module 121
5.3.2 Data Entry Module 122
5.3.2.1 Data Entry Module for Districts 123
5.3.2.2 Data Entry Module for Warehouse 123
5.3.2.3 Data Entry Module for FPSs 125
5.3.2.4 Data Entry Module for Mills 126
5.3.3 Optimization Module for the Movement between Nodes 132
5.3.4 Send Message Module 137
5.3.5 Validation Module 137
5.3.6 Edit Time Module 144
5.3.7 Implementation Module 148
5.3.8 Cost Module 148
5.3.9 Performance Module 152
5.3.10 Data Save and Result Save Module 152
5.3.11 Create/Block/Verify Username Module 155
5.3.12 Central Monitor Module 155
5.3.13 Issue Raise Module 158
5.4 Benefits of the Movement Optimization Tool 159
5.4.1 Re-Engineering of the supply chain process 159
5.4.2 Enhance Supply Chain Responsiveness and Resilience Through Analytics 160
5.4.3 Integration with PM Gati Shakti 160
5.4.4 Digital Modernization Through Cloud and Real-Time Data 160
5.4.5 Innovation, Scalability, and Alignment with National Priorities 161
5.4.6 Benefits to Stakeholders 162

5.5 Implementation strategies and Launch of "Anna Chakra" 163
5.6 Summary 166
6. OPTIMIZE THE PROCUREMENT SYSTEM OF INDIA 167
6.1 Introduction 167
6.2 Methodology 170
6.2.1 Data Acquisition 170
6.2.2 Mathematical Model 173
6.2.2.1 Model 1: Considering the Movement of Trucks from Procurement Centres to 175
6.2.2.2 Model 2: Considering the forward sequential optimization 177
6.2.2.3 Model 3: Determination of Minimum-Distance Routes via Weighbridge Proximity 178
6.2.3 Algorithm Design 180
6.2.3.1 Algorithm Design considering model 1 180
6.2.3.2 Algorithm Design considering model 2 181
6.2.3.3 Algorithm Design considering model 3 182
6.2.3.4 Comparative analysis of Model 1, Model 2, and Model 3 182
6.2.4 Results and Baseline Evaluation 184
6.3 Case Study 184
6.3.1 Results 186
6.3.1.1 Number of Weigh Bridges Used 187
6.3.1.2 Spatial Mapping of Different Nodes 189
6.3.1.3 Tag change between various Nodes 193
6.4 Policy Implication 194
6.5 Alignment of optimization of food distribution to sustainable development goals 196
6.6 Summary 200
7. OPTIMAL LOCATION OF PROCUREMENT CENTRES 201
7.1 Introduction 201
7.2 Literature Review 203
7.3 Methodology 203
7.3.1 Data Template 204
7.3.2 Mathematical Model Formulation 206
7.3.3 Result Presentation 211
7.4 Case Study 212
7.5 Summary 216

8. CONCLUSIONS AND DIRECTIONS FOR FUTURE RESEARCH 217

8.1 Totaled Summary 217
8.2 Utility of the Research Work 218
8.3 Policy Implications 220
8.4 Societal Implication 220
8.5 Summary and Features 221
8.6 Research Contribution 223
8.7 Limitation of the Research 227
8.8 Suggested Directions for Future Direction 227

9. REFERENCE 230

LIST OF FIGURES

Figure 1.1: Dimensions of Food Security 2
Figure 1.2: Supply Chain Structure of PDS 7
Figure 1.3: Scale of PDS Operations 8
Figure 1.4: Outline of Thesis 12
Figure 3.1: Research Methodology 30
Figure 4.1:Framework to optimize the PDS of India 37
Figure 4.2: Templates for data collection 38
Figure 4.3: Two-tier supply chain network from state warehouse to FPS 45
Figure 4.4: Two-tier direct delivery supply chain network from FCI warehouse to FPS 46
Figure 4.5: Three-tier supply chain network of the PDS 47
Figure 4.6: Supply chain of the PDS of West Bengal 50
Figure 4.7:Supply chain of Maharashtra PDS for surplus scenario 54
Figure 4.8: Supply chain of Maharashtra's PDS in deficit procurement 59
Figure 4.9: PDS supply chain of Kashmir and Ladakh 62
Figure 4.10: PDS supply chain for Jammu 65
Figure 4.11: Meghalaya supply chain for PDS 69
Figure 4.12: Supply chain of PDS in Manipur 72
Figure 4.13: Supply chain of PDS in Odisha 76
Figure 4.14: Supply chain of PDS in Bihar 79
Figure 4.15: Approach for the Algorithm Design 93
Figure 4.16: Steps followed for plan validation and implementation 97
Figure 4.17: Output sheet containing the network Plan 98
Figure 4.18: Monthly Performa of Cost Saving of Distribution of Grains under NFSA 99
Figure 4.19: Illustration for recommending tendering policy on average distance 109
Figure 4.20: Illustration for recommending boundary policy for inter-district movement 110
Figure 4.21: Illustration for recommending policy change in food distribution supply chain infrastructure 111
Figure 4.22: Key Challenges and Mitigations Strategies adopted at different phases of research 112
Figure 5.1: System architecture of the PDS movement optimization tool 116
Figure 5.2: Work flow of PDS Tool "Anna Chakra" 120
Figure 5.3: Common Platforms of user logins 121
Figure 5.4: Login Page for State officers 121
Figure 5.5: Login Page for District officers 122
Figure 5.6: Login Page for DFPD Officers 122
Figure 5.7: Data Entry module for District data 128
Figure 5.8: Data Entry Module for Warehouse Data 129
Figure 5.9: Data Entry Module for FPS data 130
Figure 5.10: Data Entry Module for Mill's data 131
Figure 5.11: Count of Nodes, Allocation, and Capacity in the optimization Module 134
Figure 5.12: State and district-wise total capacity vs total demand 135
Figure 5.13: Overall framework of the Optimization module 136

Figure 5.14: Result dashboard for review 140
Figure 5.15: Validation module for state officers showing the total number of tags, accepted tags, and changed tags by district officers 141
Figure 5.16: State-level validation in the validation module 142
Figure 5.17: District Level Validation Module 143
Figure 5.18: Send module for state officers 145
Figure 5.19: Send module for district officers 146
Figure 5.20: Edit Time Module for state officers 147
Figure 5.21: Implementation Module for state officers 149
Figure 5.22: Implementation Module for District officers 150
Figure 5.23: Cost module for state officer 151
Figure 5.24: Performance Module at state officer level 153
Figure 5.25: Data save and result save module 154
Figure 5.26: Login creation, block, and verification module 156
Figure 5.27: Central Monitoring Module 157
Figure 5.28: Issue-raise module for district officers 158
Figure 5.29: Issue-Raise Status Check 159
Figure 5.30: Training Session held for Anna Chakra in the state of " Telangana" 164
Figure 5.31: Training Session held to explain the results in the state of " Uttar Pradesh" 164
Figure 5.32: Launch of Anna Chakra, PDS Tool 166
Figure 6.1: Methodology developed for Optimizing the Procurement System of India 170
Figure 6.2: Sequences of Activities for Model 3 180
Figure 6.3: Supply chain of Punjab Procurement System 185
Figure 6.4: Number of weigh bridges in baseline and Model 1 188
Figure 6.5: Number of weigh bridges in Model 2 188
Figure 6.6: Number of weigh bridges used in Model 3 189
Figure 6.7: Spatial Mapping of PC → WB → Mill Across All Models 190
Figure 6.8: Spatial Mapping of PC → WB → Mill: Baseline vs. Model-1 (Full Optimization) 190
Figure 6.9: Spatial Mapping of PC → WB → Mill: Baseline vs. Model-2 (Sequential Optimization) 191
Figure 6.10: Spatial Mapping of PC → WB → Mill: Baseline vs. Model-3 (Nearest WB) 192
Figure 6.11: Mapping of optimization of the Procurement system to relevant Sustainable Development Goals (SDGs) 196
Figure 7.1: Methodology for optimizing the Procurement system of India 204
Figure 7.2: Villages to Procurement Centres tagging after optimization 214
Figure 7.3:Procurement Centres to mills tagging after optimization 214
Figure 7.4: Spatial illustration of Procurement centres in present and after optimization 216

LIST OF TABLES

Table 1:1. Different scheme under PDS adopted by the Government 5
Table 4:1: State-wise supply chain structures 40
Table 4:2: Relative scenarios and constraint relevant to leg1 optimization for Bihar State 92
Table 4:3: Variable and constraints comparison in the algorithm approach 93
Table 4:4: State-wise number of warehouses, FPS, and mills 100
Table 4:5: State-wise reduction in QKM before and after implementation of PDS movement optimization 102
Table 4:6: State-wise cost saving on implementation of movement optimization 103
Table 4:7: Reduction in CO_2 emission before and after PDS movement optimization 105
Table 5:1: Comparison showing before and after optimization in terms of facility count and average distance 133
Table 5:2: State-wise URL of PDS movement optimization tool "Anna Chakra" 165
Table 6:1: Comparison of algorithms using state as unit and district as unit 181
Table 6:2: Comparison of Algorithm design for models design 183
Table 6:3: Comparison of results obtained through the proposed methodology and the current on-field plan 187
Table 6:4: Utilization of Weigh Bridge for different scenarios 187
Table 6:5: Comparison of spatial characteristics of the baseline and three optimized models for PC–WB–Mill movement mapping. 192
Table 6:6: Number of tag change for different legs for different scenarios compared to baseline 193
Table 6:7: Sustainable Development Goal (SDG) linkages of the Procurement System Optimization, demonstrating its integrated contribution to economic efficiency, social equity, and environmental sustainability. 197
Table 7:1: Data Template for village data 205
Table 7:2: Data Template for Procurement data 205
Table 7:3: Data template for Mills data 206
Table 7:4: Fixed cost of establishing a PC 212
Table 7:5: Transportation Cost 213
Table 7:6: Summary table of total cost 213
Table 7:7: Number of Present Procurement centres and Procurement centres after optimization 215

LIST OF ABBREVIATIONS

PDS	Public Distribution System
NFSA	National Food Security Act
FPS	Fair Price Shop
DCP	Decentralised Procurement
NDCP	Non Decentralised Procurement
PC	Procurement Centres
FCI	Food Corporation of India
MILP	Mixed Integer Linear Programme
DFPD	Department of Food and Public Distribution
SDG	Sustainable Development Goal
Qtl/qtls	Quintals
Rs	Rupees
QKM	Quantity*Kilometre
WB	Weighbridge