Optimization of Maximum Food Supply to Impoverished Countries with Cost-efficiency

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Abstract

Addressing the critical issue of food insecurity, this initiative tackles challenges in aid distribution faced by organizations like the World Food Programme. Despite sufficient donations, distribution inefficiencies persist due to authorization system discrepancies. The project focuses on optimizing aid distribution in impoverished countries by evaluating factors like annual food requirements, World Food Programme contributions, preservation periods, cost-effectiveness, transportation efficiency, and storage capacity. The objectives include maximizing aid distribution efficiency, considering specific needs, and refining resource distribution using credible information. What sets this project apart is its holistic consideration of multiple factors related to impoverished countries, contributing significantly to sustainability initiatives. The approach introduces novel considerations through a multi-objective framework, enhancing the methodology's complexity and comprehensiveness.

1 Introduction

In the intricate tapestry of a global panorama marked by profound imbalances in the accessibility of essential resources and sustenance, "The United Nations World Food Programme (WFP)" manifests as a beacon and a catalyst for humanitarian pursuits and emerges as an immensely consequential institution dedicated to confronting one of the world's most pressing predicaments: pervasive hunger. The central mission revolves around transcending racial and geographic barriers to seamlessly integrate into nations teetering on the precipice of poverty, to address the highly debated issue of hunger. To facilitate the optimal distribution of food donations, particularly to the most economically challenged nations globally, we have devised an optimization model. The primary aim of this model is to maximize the allocation of food donations to impoverished countries while concurrently minimizing the associated costs related to transportation mediums.

2 Motivation

The challenges faced by organizations like WFP revolve around a lack of comprehensive data concerning aid requirements, particularly in countries teetering on the brink of poverty. In instances like Burundi, where approximately 1.4 million people grapple with food insecurity, and Somalia, where an estimated 6.5 million individuals face similar challenges, the deficiency in accurate data hinders the organization's ability to optimize resource allocation with precision [4] [1]. Moreover, the constraints imposed by predetermined budget allocations contribute to the suboptimal nature of the distribution methodology. In response to these exigencies, diligently fashioned by our team from the ground up, this endeavor is informed by real-time global conditions.

In this comprehensive study aimed at optimizing food distribution in impoverished countries, we meticulously evaluate key factors. These include annual food requirements, the World Food Programme's annual contribution, preservation periods in country-specific storage, cost-effectiveness in distribution processes, transportation medium efficiency, storage capacity of local hubs, and the critical role of accurate and current data. The study seeks to maximize aid distribution efficiently, considering the specific needs and conditions of each location. Two fundamental objectives will be aimed for - firstly, it seeks to ensure maximum distribution of food donations and enhance, endowing the mission set upon with cost-effectiveness. Secondly, it endeavors to refine the resource distribution process by harnessing the wealth of credible information already at its disposal. At the culmination of our meticulously tailored research endeavor, our team aspires to attain the objectives of making substantial contributions to sustainability initiatives by meticulously preserving the environment. The distinctive feature that sets this project apart is the methodical progression we have employed. We introduce novel considerations that significantly contribute to the logical development of our optimization model. Our approach involves a multi-objective framework, allowing us to account for various factors concurrently, enhancing the complexity and comprehensiveness of our methodology. This deliberate integration of multiple objectives ensures a nuanced and robust optimization process, aligning with the intricate dynamics of food distribution in impoverished regions. Additionally, we endeavor to serve as a pivotal decision support entity for the World Food Programme (WFP), assisting in its mission to optimize food distribution while upholding optimal cost-effectiveness and long-term sustainability at the pinnacle of excellence.

3 Related Works

In the realm of global hunger, the imperative to address the multifaceted challenges of malnutrition and health issues has prompted a surge in scholarly research utilizing advanced mathematical modeling. A prime example is the case study "Food Aid Supply and Distribution in Insecure Regions: World Food Programme Operation Analysis in Ethiopia," aligning with Sustainable Development Goals related to hunger eradication, food security, nutritional well-being, and sustainable agriculture. The study elucidates challenges such as demand volatility, data deficiencies, and diverse costs faced by humanitarian organizations. Addressing these challenges, the study proposes a "two-stage stochastic linear program model" to minimize expenditures in aid supply and distribution, factoring in uncertainties like fluctuating demand and environmental disruptions. The model, applied to World Food Programme data, suggests significant cost savings and provides recommendations for operational efficiency.

This illustrative case study demonstrates the potential benefits of sustainable optimization modeling, offering cost savings, improved efficiency, and strategic recommendations. As the project evolves, additional data will be sourced from the World Food Programme's official website. The envisioned trajectory aims to simulate complex food crisis scenarios in diverse countries, converging toward a realistic and nuanced sustainable solution. [2]

4 Problem Statement

The imperative lies in the meticulous collection of precise food requirements from each country, coupled with the judicious allocation of resources based on historical data, thereby optimizing the distribution of food donations. To gain a comprehensive understanding of the prevailing circumstances, we shall leverage annual data about food requisites and resource allocations for countries situated below the poverty [5]).

The optimization model comprises three fundamental steps: identifying decision variables related to the quantity of required and distributed food, defining an objective function aimed at maximizing food supply in impoverished nations with cost-effectiveness and establishing constraints based on finite resources or donated food availability. Addressing challenges in food allocation, including cost-effectiveness, transportation logistics, data accuracy, and maintaining a streamlined supply chain management system, is crucial for enhancing distribution efficiency. Therefore, the pivotal considerations include- Data Accuracy Challenge: Gathering precise data on food requirements in underdeveloped countries is hindered by inefficiencies in fieldworker performance, impacting the efficacy of data collection.

5 Preliminary Concepts and Model Formulation

5.1 Multiobjective Optimization

Aligned with the conventions of optimization methodologies, our project is structured as a multiobjective program, representing a paradigm where more than one objective is harmoniously integrated to articulate the comprehensive goals of the optimization initiative. [3]. In our specific context, the objective function is a synthesized amalgamation of diverse goals, prominently featuring the maximization of food distribution and the concurrent minimization of associated costs. Of particular significance is the meticulous attention dedicated to the transportation cost, a pivotal factor influencing the overall efficiency and economic viability of the distribution process.

Within this intricate framework, we contend with an additional layer of complexity introduced by an uncertain parameter known as the transportation time cost. This dynamic element injects an element of uncertainty into the optimization model, demanding its careful consideration and minimization. In essence, our approach to this multiobjective optimization problem encompasses a holistic consideration of various dimensions, aiming to strike an optimal balance between the conflicting goals of maximizing distribution reach and minimizing the financial outlay associated with the intricate logistics of food distribution.

5.2 Sets, Indices, and Parameters

In the context of our optimization model, the delineation of sets, indices, and key parameters is presented as follows:

Sets and Indices:

- Let i denote the index corresponding to countries situated below the poverty line.
- Let j denote the index signifying various transportation modes.

Parameters:

- FR_i: Annual food requirements for country i.
- DA_i: Annual donation of the World Food Programme (WFP) for country i.
- PD_i: Preservation period for food in country i.
- SC_i: Storage capacity of the local hub for country i.
- MC_j: Maximum capacity for transportation mode j.
- WCM: Expenses related to weather conditions are classified based on seasons, including winter, summer, and the rainy season.
- WTM: Duration linked to weather conditions is classified according to seasons: winter, summer, and the rainy season.
- TCM: Cost per unit linked with transportation medium.
- TTM: Time per unit linked with individual transportation medium.
- D: Distance between local hub and distribution area
- $\alpha, \beta, \gamma, \delta$: Weight factors contributing to the objective function.

Uncertain Parameters

- CT_{ij}: Nominal transportation cost per unit of food for country i using mode j.
- TT_{ij}: Nominal transportation time for country i using mode j.

These specified sets, indices, and parameters lay the foundational framework for our optimization model, providing a structured representation of the pertinent elements within the optimization problem.

5.3 Decision Variables

In the realm of our optimization model, Q_{ij} stands as a pivotal variable signifying the quantity of food aid allocated to the country i through the utilization of the designated transportation mode j. This variable assumes a central role as a decision variable within our computational framework, encapsulating the intricacies of the distribution process. The optimization of Q_{ij} aligns with our overarching goals of enhancing food distribution efficiency while concurrently minimizing associated costs. This representation facilitates a detailed and nuanced examination of distribution dynamics, offering valuable insights into the allocation of food aid across various countries and transportation modes within the optimization paradigm.

Q_{ij}: Quantity of food aid distributed to country i using transportation mode j.

5.4 Objective Function

Objective functions constitute indispensable elements in the landscape of optimization methodologies, functioning as computational metrics systematically applied to decision variables for the meticulous evaluation of solution quality. In our contextual framework, the nuanced objective function encompasses three pivotal facets. The inaugural segment is dedicated to the optimization objective of maximizing food distribution. Subsequently, the second component scrutinizes the intricacies of transportation cost, pivoting on our paramount objective of cost minimization, thereby directing efforts toward its minimization. Finally, the third facet introduces the dimension of transportation time cost, meticulously accounting for uncertainties and associated costs inherent in the transportation process to the designated area. The holistic articulation of this multifaceted objective function is meticulously delineated below.

$$\alpha \sum_i \sum_j Q_{ij} - \beta \sum_i \sum_j (WCM+TCM) \cdot CT_{ij} \cdot Q_{ij} - \gamma \sum_i \sum_j (WTM+TTM) \cdot TT_{ij} \cdot Q_{ij} - \delta \sum_i \sum_j distance_{ij} \cdot Q_{ij} \tag{1}$$

5.5 Constraints

a. Budget Constraint

This constraint ensures that the cumulative transportation cost, represented by the product of unit transportation cost CT_{ij} and quantity Q_{ij}, does not exceed the predefined budget PC. It functions as a vital financial control mechanism in our optimization framework.

$$\sum_i \sum_j CT_{ij}.Q_{ij} \leq PC$$

b. Preservation Constraint

Dictating that the quantity of distributed food aid Q_{ij} should not surpass the product of the annual donation DA_i and the preservation period PD_i, this constraint reflects practical constraints on the preservation of food aid in country-specific storage.

$$Q_{ij} \leq DA_i.PD_i$$

c. Demand Constraint

This constraint ensures that the quantity of distributed food aid Q_{ij} does not exceed the annual food requirement FR_i for the respective country i, aligning distribution with local demand.

$$Q_{ij} \leq FR_i$$

d. Storage Capacity Constraint

Imposing an upper limit on the quantity of food aid Q_{ij} based on the storage capacity SC_i of the local storage hub in country i, this constraint prevents overutilization of storage resources.

$$Q_{ij} \leq SC_i$$

e. Transportation Capacity Constraint

This constraint optimizes transportation efficiency by ensuring that the total quantity of food aid transported using mode j does not surpass the maximum capacity MC_j of that transportation mode.

$$\sum_i Q_{ij} \leq MC_j$$

f. Non-Negativity Constraint

Serving as a foundational constraint, it dictates that the quantity of food aid (Q_{ij}) must be non-negative, as negative quantities are not practical in this context.

$$Q_{ij} \geq 0$$

These constraints collectively form a comprehensive and technically sophisticated optimization model, addressing various facets of logistical challenges in food distribution.

5.6 Assumptions

Within the framework of this project, numerous assumptions have been deliberated to streamline the intricacies of the modeling and optimization processes. The following assumptions encapsulate key considerations:

a. Homogeneous Storage Conditions: Uniform storage conditions are assumed across countries for computational simplicity, acknowledging the potential for regional variations.

b. Consistent Transportation Infrastructure: The transportation infrastructure is considered consistent annually, yet acknowledging potential fluctuations contingent upon dynamic factors such as weather conditions, geopolitical landscapes, or political situations.

c. Static Demand and Preservation Factors: Static values are assumed for annual food requirements (FR_i), preservation periods (PD_i), and annual donations (DA_i), simplifying the model by temporarily disregarding potential yearly fluctuations.

d. Fixed Transportation Time and Costs: Fixed transportation time and costs are assumed, devoid of real-time adjustments based on dynamic factors like traffic conditions, road closures, or unforeseen events.

e. Uniform Weather Conditions: Uniform weather conditions within each season across all countries are assumed, excluding the potential impact of extreme weather events, complementing seasonal considerations.

f. Constant Transportation Medium Conditions: Consistent transportation medium conditions (Excellent, Moderate, Poor) are considered, without accounting for dynamic changes in road conditions, port availability, or disruptions in air traffic.

g. Country-Specific Transportation Infrastructure: While recognizing three transportation mediums (road, air, water), the potential for country-specific transportation conditions is acknowledged, subject to alterations due to the socio-political state of a country.

h. Linear Relationship Between Transportation Cost and Distance: A linear relationship between transportation cost and distance is assumed, omitting potential non-linear cost variations arising from factors like terrain or geopolitical considerations.

i. Stable Exchange Rates: Stable exchange rates between countries are assumed, simplifying the financial aspects of international transactions within the model.

j. Reliable Data Accuracy: A high level of accuracy in the gathered data is assumed, without significant errors or discrepancies that might compromise the reliability of the optimization model.

It is imperative to recognize these assumptions as instrumental in simplifying the model for computational feasibility. However, a conscientious awareness of their potential ramifications on the real-world applicability of the optimization results is equally crucial. Sensitivity analyses can be conducted to assess the model's robustness to variations in these assumptions.

5.7 Data Structure and Elements

We leveraged synthetic data, drawing inspiration from real-life scenarios observed in the top five most impoverished countries globally—Burundi, Central African Republic, South Sudan, Congo, and Somalia. The primary dataset involved a meticulous quantification of each nation's food requirements, derived from the prevalence of food insecurity within their populations. This method entailed estimating the requisite food quantities based on the extent of individuals facing food insecurity. Considering the pivotal role of transportation modes in determining overall costs, we systematically gathered specific data on the transportation infrastructure coverage encompassing road, air, and water for these five nations. This dataset furnished a foundational insight into the potential transportation mediums available in each country, along with corresponding cost metrics. Subsequently, we synthesized this information to construct a dummy dataset, laying the groundwork for our optimization program modeling within a technical framework. It is noteworthy that the data presented are in relevant units, selected as dummy data to align with our current model requirements.

Table 1: Country-Specific Data

Country	**Food Demand**	**Allocated Donation**	**Storage Capacity**
Burundi	1400000	20000000	140000000
Central African Republic	2000000	20000000	200000000
South Sudan	7800000	30000000	780000000
Congo	25800000	500000000	2580000000
Somalia	6600000	70000000	660000000

Table 1 provides crucial country-specific data integral to our model's parameters. This data encompasses a detailed breakdown of annual food requirements, annual donations of WFP, preservation periods, storage capacities of local hubs, and maximum transportation capacities for each respective country in our study. This comprehensive dataset serves as the foundational input, enabling our optimization model to intricately analyze and formulate strategies for maximizing food aid distribution while considering specific conditions and constraints unique to each country.

Table 2: Country-Specific Transportation Capacity

Country	**Cargo Truck**	**Cargo Ship**	**Cargo Plane**
Burundi	700000	7800000	78000
Central African Republic	600000	8000000	88000
South Sudan	500000	8200000	98000
Congo	400000	9000000	58000
Somalia	300000	8500000	68000

Table 2 provides a detailed overview of the transportation capacity specific to each country for various transportation mediums, including road, air, and water. The data presented in this table is crucial for our optimization model, as it outlines the maximum capacity of each transportation mode in every country under consideration. This comprehensive dataset serves as a cornerstone for our analysis, allowing us to tailor our distribution strategies based on the transportation infrastructure and capabilities of each nation. By incorporating this specific information into our model, we aim to optimize the food distribution process by selecting the most efficient and feasible transportation mode for each country, thereby enhancing the overall effectiveness of aid delivery.

Table 3: Weather Condition

Season	Summer	Winter	Rainy Season

Table 3 illustrates the various weather conditions that have been taken into account in our optimization model. Recognizing the significant impact of weather on transportation infrastructure, time, and cost, this table provides a comprehensive overview of the potential weather scenarios considered during our analysis. By incorporating this crucial information, our model can adapt to different weather conditions, allowing us to optimize food distribution strategies based on the specific challenges posed by each season. This meticulous consideration of weather conditions contributes to the robustness of our model, ensuring that it can effectively navigate the complexities of real-world scenarios and provide resilient solutions for food distribution in diverse environmental contexts.

Table 4: Transportation Infrastructure Condition

Condition	Excellent	Moderate	Poor

Table 4 delineates the conceivable transportation infrastructure scenarios, recognizing the fluctuating costs and availability contingent on the prevailing conditions. This table serves as a crucial reference point in our optimization model, capturing the diverse transportation possibilities that may influence the overall cost and efficiency of food distribution. By accounting for these varying infrastructure conditions, our model can adeptly navigate the dynamic landscape of transportation, contributing to a more nuanced and accurate representation of the challenges and opportunities associated with each scenario. This comprehensive consideration of transportation infrastructure enhances the adaptability and effectiveness of our optimization approach, ensuring that it remains attuned to the intricacies of real-world logistics in different regions.

6 Design Optimization

6.1 Strategic Workflow

In tackling the challenge at hand, we will employ advanced optimization methodologies, specifically leveraging linear programming and mixed-integer programming. This strategic approach aims to construct a comprehensive mathematical model that accounts for factors such as cost-effectiveness, unit distribution time, transportation capacities, and sustainability criteria.

The optimization model is meticulously formulated with the primary objective of maximizing the distribution of food aid within low-income countries. This formulation is underpinned by the imperative to ensure that the obtained solution adheres to stringent cost-effectiveness and sustainability constraints.

The procedural workflow commences with the aggregation of donated goods at a central donation hub, a pivotal point in the logistical chain. The optimization initiation point is strategically chosen at this juncture to prioritize attention to the distribution countries and their corresponding transportation routes. Consequently, the transportation routes assume a paramount role in the optimization process.

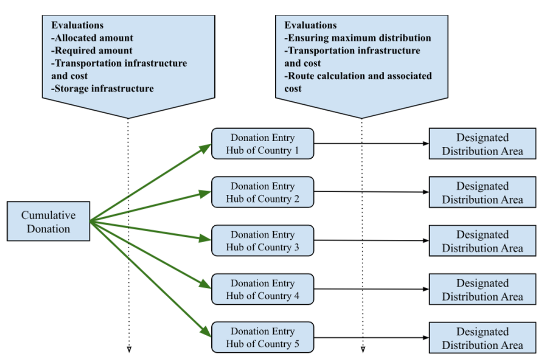

Figure 1: Strategic Workflow of the Model

Upon establishing the transportation roots, the focus shifts decisively toward the distribution hub or country. In the scrutiny of countries, a detailed examination is undertaken encompassing their transportation infrastructure, prevailing weather conditions, and the availability of ports capable of accommodating resources and facilitating transportation logistics. This meticulous approach ensures a holistic optimization model that takes into account the intricacies of the distribution process from donation to the ultimate recipients.

6.2 Methodology

In our ongoing research, our methodology centers on the implementation of a robust optimization framework, a methodological paradigm that surpasses conventional optimization approaches. This approach deliberately refrains from assigning explicit probabilities to a range of potential scenarios, opting instead to navigate the intricacies of uncertainty by seeking solutions resilient to the most formidable, adverse scenarios or a curated ensemble of adversarial conditions. This strategic system has enabled the identification of optimal solutions that showcase exceptional efficacy under conditions of heightened uncertainty.

Within the specified model, the treatment of uncertainty takes a precise and systematic form, seamlessly integrated through the meticulous imposition of robust constraints on pivotal variables such as transportation costs and times. Importantly, this approach avoids explicit specification of probabilities associated with diverse scenarios, opting for a more nuanced and versatile framework. This innovative methodology ensures that the optimization model is adept at navigating the intricacies of real-world uncertainty, presenting a dynamic and adaptive solution capable of addressing a myriad of potential challenges inherent in the complex landscape of food distribution.

We utilized the Gurobi Optimization modeling method to implement and execute the optimization process. By employing the Gurobi Optimization modeling method in our project, we harnessed the capabilities of a cutting-edge solver to address the multi-objective optimization inherent in our food distribution model. The methodological prowess of Gurobi allowed us to navigate the complexities of decision variables, constraints, and the intricate objective function, enabling the derivation of optimal solutions for maximizing food distribution while minimizing associated costs. The Gurobi framework, with its robust mathematical optimization capabilities, played a pivotal role in achieving precision and efficiency in our modeling process.

Rooted in robust optimization principles, this methodological choice enriches the research by providing a resilient and adaptable framework for tackling the inherent uncertainties in the distribution process.

6.3 System Logic Flow

The program unfolds with an initial scenario where all components of the objective share equal priority, constituting the foundational projection of our system. Subsequently, we introduce greater intricacies by incorporating weights to prioritize specific sub-parts of the objective. It is imperative to underscore that, across all scenarios, the paramount importance of prioritizing food supply remains unwavering. In Scenario 1, our focus accentuates transportation costs, while maintaining constant food distribution, and assigning comparatively lower priorities to the remaining sub-objectives. This deliberate emphasis seeks to explore the impact of transportation cost prioritization on the overall objective.

Moving to Scenario 2, the emphasis shifts to transportation time costs, with food distribution remaining constant and other sub-objectives receiving diminished priorities. This targeted approach aims to evaluate the implications of prioritizing transportation time costs within the optimization model.

In Scenario 3, the spotlight turns to the maximum transportation capacity, holding food distribution constant while relegating other sub-objectives to lesser priorities. This scenario probes the consequences of emphasizing transportation maximum capacity in the optimization process.

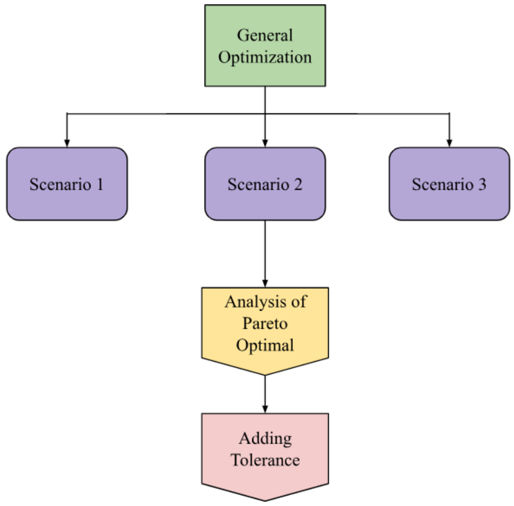

Figure 2: Logical Flow of the Model

Following these scenarios, we assign optimal values to the weights based on their priorities, thereby implementing the Pareto optimal front to systematically explore all potential optimal outcomes. This comprehensive exploration ensures a nuanced understanding of the trade-offs and synergies associated with different weightings. To introduce further complexity and assess project sustainability, we scrutinize the tolerance level of the entire system. This critical evaluation serves to gauge the robustness of the system under varying conditions, adding a layer of analysis to ensure the viability and resilience of the optimization model.

7 Result Analysis

7.1 General Optimization

In the initial stages of our optimization exploration, we laid the foundation by working with fundamental data and adopting a baseline scenario that uniformly prioritized all sub-objectives. This foundational approach aimed to provide an equitable starting point for our analysis. To effectively communicate the outcomes of our optimization model, we harnessed the power of visualization through a bar chart. This graphical representation intricately captures the interplay between geographical distance and the optimal transportation mode recommended by the model. By visually articulating the relationship between these variables, our objective was to unravel insights into the transportation medium that could yield maximal food distribution while concurrently achieving cost efficiency.

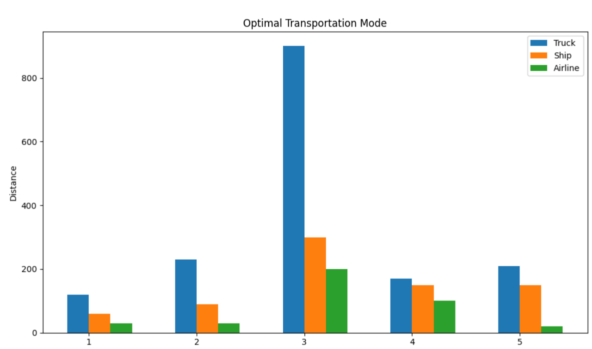

Figure 3: Distance vs Optimal Transportation Mode for General Scenario

The essence of this visual representation transcends mere illustration; it serves as a critical component in substantiating the depth and efficacy of our research methodology. As we delve into the nuanced intricacies of transportation optimization, the bar chart becomes a compelling tool to underscore the strategic alignment of our dual objectives—maximizing food distribution and minimizing costs within the transportation domain. This graphical insight not only enriches the narrative of our research but also provides a tangible and comprehensive depiction of the optimization outcomes, reinforcing the robustness of our approach.

7.2 Integration of Case-Specific Priority

7.2.1 Scenario 1 (Emphasizing Transportation Cost)

In the first scenario, we elevated the emphasis on transportation costs while maintaining a consistent level of food distribution. This adjustment involved augmenting the weighting factor for transportation costs and correspondingly diminishing the weighting factors for other components of the objective function. This deliberate modification was undertaken to scrutinize the resulting outcomes of the model, particularly to assess if there is a discernible impact on emphasizing transportation costs. The graphical representations exhibit a subtle deviation from the baseline scenario, highlighting the nuanced effects of this adjustment.

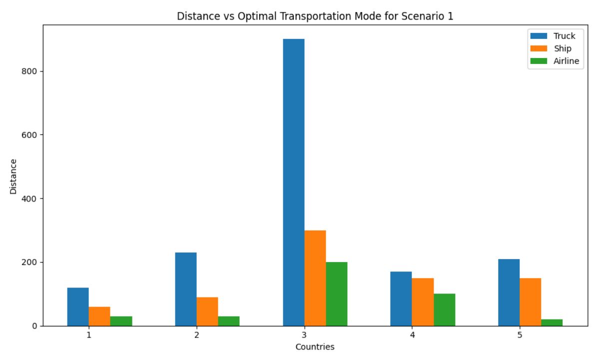

Figure 4: Distance vs Optimal Transportation Mode for Scenario 1

Essentially, this scenario serves as a diagnostic test, affirming the applicability of our model in instances where specific focal points, such as transportation costs, necessitate heightened emphasis. This iterative process allows us to gauge the model's responsiveness to priority adjustments and contributes to showcasing its versatility in accommodating variations tailored to specific considerations crucial for effective food distribution strategies.

7.2.2 Scenario 2 (Emphasizing Transportation Time Cost)

In the second scenario, we increased the emphasis on transportation time costs while keeping food distribution constant. This adjustment involved elevating the weighting factor for transportation time costs and concurrently reducing the weighting factors for other components of the objective function. The main objective was to analyze the model's outcomes and determine if there is a need to highlight the importance of transportation time costs. The graphical representations show a subtle deviation from the baseline scenario, indicating a minimal impact.

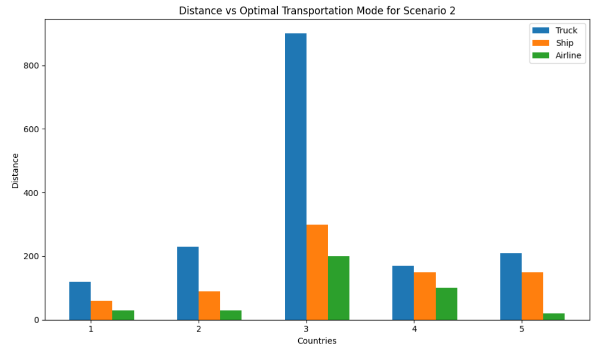

Figure 5: Distance vs Optimal Transportation Mode for Scenario 2

Essentially, this scenario confirms the adaptability of our model in situations where transportation time costs, require heightened consideration. This iterative process allows us to evaluate the model's responsiveness to priority adjustments, emphasizing its flexibility in accommodating variations tailored to specific considerations critical for effective food distribution strategies.

7.2.3 Scenario 3 (Emphasizing Maximum Capacity of Transports)

In the second scenario, we amplified the focus on the Maximum Capacity of Transports while maintaining a steadfast commitment to maximizing food distribution. This adjustment entailed augmenting the weighting factor for the maximum capacity of transports while simultaneously diminishing the weighting factors for other components within the objective function. The primary aim was to scrutinize the outcomes of the model and ascertain whether there is a necessity to underscore the significance of the maximum capacity of transports. The visual depictions reveal a subtle divergence from the baseline scenario, suggesting a minimal impact.

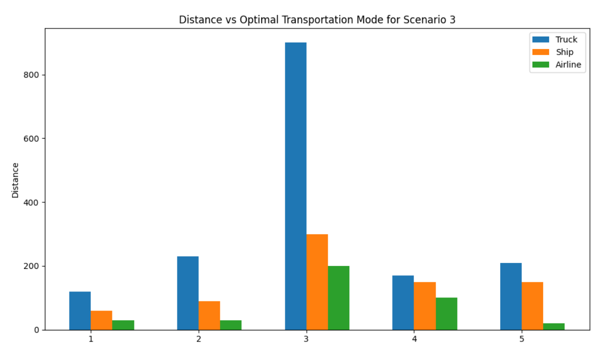

Figure 6: Distance vs optimal transportation mode for scenario 3

Fundamentally, this scenario serves as validation that our model is applicable in scenarios where specific factors, such as the maximum capacity of transports, demand heightened consideration. This iterative process enables us to assess the model's responsiveness to adjustments in priorities, highlighting its adaptability in accommodating variations tailored to specific considerations crucial for effective food distribution strategies.

8 Pareto Optimal

As our food distribution optimization model operates on a multiobjective function, a thorough examination of the Pareto optimal front becomes indispensable. The potential conflicts among sub-objectives necessitate a thorough analysis to identify areas for potential improvement without compromising other aspects. In this undertaking, we conducted a comprehensive optimization alongside three distinct case-specific scenarios, systematically prioritizing and weighting each facet of the multi-objective in isolation.

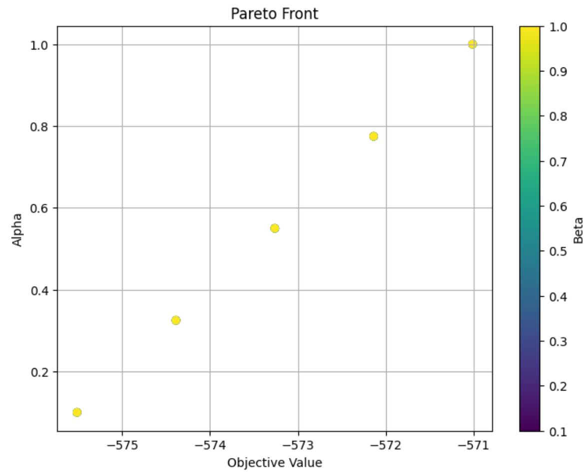

Figure 7: Visualization of Pareto optimal

The Pareto optimal graph serves as a visual representation of the trade-offs between two distinct weight factors, alpha, and beta, concerning a specific objective value. Each dot on the graph signifies a potential combination of these weight factors, depicting the diverse scenarios where emphasis on one factor is altered while keeping the other constant. The graph allows for a comprehensive exploration of the Pareto frontier, showcasing the range of possibilities for optimizing the defined objectives. As the weight factors vary, the graph provides insights into how adjustments in priorities impact the overall objective value. This visualization aids in making informed decisions about the optimal balance between competing factors, offering a nuanced perspective on the trade-offs inherent in the optimization process.

However, the exploration of the Pareto Optimal solution extends beyond these initial analyses, seeking to uncover alternative solutions that might offer a more optimal trade-off. This examination is crucial for achieving the utmost efficiency in balancing the objective of maximum food distribution to countries and the concurrent minimization of associated transportation costs. Moreover, the robust nature of these solutions affords users and stakeholders the flexibility to align their priorities with specific objectives, catering to the diverse conditions and preferences of each country. The Pareto Optimal Solution thus serves as a pivotal tool in providing a nuanced and customizable ground for decision-making in the realm of food distribution optimization.

9 Tolerance

Within the framework of our food distribution model, the implementation of tolerance checks emerges as a pivotal step, crucial for ensuring the precision, stability, and practical applicability of our optimization solutions. These checks play a central role in ensuring that the outcomes of our model align precisely with the desired accuracy levels, thereby preventing inaccuracies that may arise from numerical instability, rounding errors, or ill-conditioned problems.

The contribution of tolerance checks to the robustness of our food distribution model is substantial. By mitigating the model's excessive sensitivity to minor alterations in input data or algorithm parameters, we bolster the stability and reliability of our solutions—integral factors in the optimization of food distribution processes. To assess the tolerance level, we scaled down the data to smaller values to observe its response during the analysis. This exercise aims to illustrate the distinction between the scenarios before and after incorporating tolerance. The code effectively executes the analysis under these conditions.

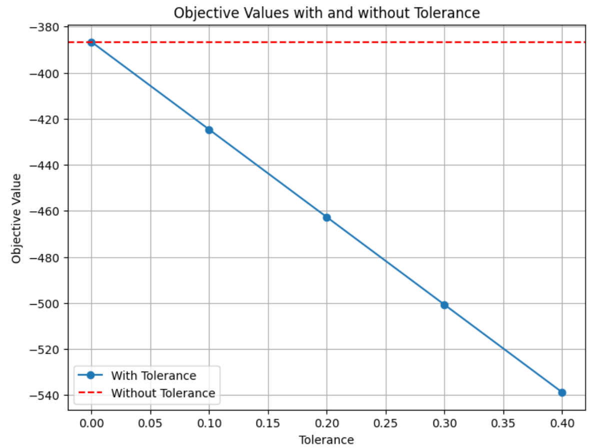

Figure 8: Visualization of Tolerance

Integral to our model, feasibility analysis receives substantial benefits from the incorporation of tolerance checks. These checks enable a pragmatic evaluation of constraint violations, allowing us to identify solutions that only marginally deviate from constraints. This aligns our outcomes with the practical considerations inherent in the complex landscape of food distribution.

Without the application of tolerance, the model exhibits no discernible visual changes. However, upon introducing tolerance with random values, the graph demonstrates a distinctive downward linearity. This observation underscores the model's sensitivity to alterations or infringements in constraints and parameters, emphasizing the potential impact on the optimal solution. The integration of tolerance allows us to gauge the system's robustness and responsiveness to variations, providing valuable insights into the stability of the optimization outcomes under dynamic conditions.

Furthermore, tolerance checks play a facilitating role in sensitivity analysis—a cornerstone of our decision-making process. Offering valuable insights into the impacts of changes in input parameters or model assumptions on our food distribution solutions, they empower us to make well-informed decisions and critically assess the robustness of our optimization strategies within dynamic and evolving environments.

10 Future Work

Achieving all our objectives through a single conducted study may prove challenging in a single endeavor. Consequently, our team has strategically positioned its future trajectory towards the expansion of research initiatives, refining solution frameworks, and broadening the scope of our objectives. This entails a concerted effort to align with the Sustainable Development Goals (SDGs) established by the World Food Programme (WFP), wherein we endeavor to advance our line of work by diligently crafting and implementing feasible sustainability remedies in pursuit of overarching global objectives. Given that specific constraints have already been unveiled in the conducted study, such as the challenge of amassing precise information about the transportation infrastructure of each country and contingency measures in the event of infeasibility, the forthcoming objectives center around the comprehensive consideration of meteorological factors and their corresponding impact on transportation infrastructure. This strategic approach aims to ensure that the set objectives are attained with utmost precision and devoid of any errors. Moreover, acknowledging certain limitations, such as the storage capacity of hubs and ports, becomes imperative. Realistically, these constraints possess inherent temporal and storage limitations in practical scenarios. Hence, our research endeavors extend to encompassing these constraints, allowing for a meticulous evaluation of results grounded in the practicalities of time and storage considerations. This deliberate integration of real-world constraints enhances the authenticity and applicability of the study, aligning it more closely with real-time situations.

11 Conclusion

In summation, the efficacious distribution of food donations to economically disadvantaged nations constitutes a multifaceted undertaking demanding scrupulous risk assessment and nuanced strategic optimization. Integral components encompass intricate geographical hazard analyses, exhaustive documentation of procedural intricacies, and the cognizance of challenges manifesting across diverse levels. Leveraging advanced mathematical modeling, sophisticated software tools, and comprehensive evaluations provides a viable framework to navigate these complexities, thereby enhancing the resilience and efficacy of food supply chains to the benefit of vulnerable communities. This approach underscores the paramount importance of adaptability and unwavering diligence in ensuring the triumphant distribution of vital food resources to those facing dire needs.

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Table 5: Evaluation of Contribution

Criteria	**Sadiah Karim**	**Soptorsi Paul Shrestha**	**Lamiya Sadaf**
Proposal topics	High	High	High
Related works	Adequate	Adequate	High
System model and problem formulation	High	High	High
Result presentation and analysis	Adequate	High	Adequate
Writing and presentation quality	High	High	High
Formatting and references	High	High	Adequate
Overall average contribution	High	High	High