Enhancing Supply Chain Efficiency for Humanitarian Aid in Disaster Response

IE685: MSc Research Project I

by

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Abstract

This study has come up with an optimization-based tool to help make decisions in the Humanitarian supply chain for relief operations. The goal is to create a simple optimization model for three key areas in humanitarian logistics: figuring out where to stock up on supplies beforehand, deciding the best spots for facilities, and planning evacuations. The aim is to improve how the humanitarian supply chain is set up.

Chapter 1

Introduction

1.1 Motivation:

Reliefweb is a humanitarian information service provided by the United Nations Office for the Coordination of Humanitarian Affairs (OCHA). According to Reliefweb in 2023, heavy rains in Assam caused floods, impacting over 34,000 people in 11 districts. Lakhimpur district was the most severely affected, with landslides cutting off some areas. Throughout India, monsoon rains led to floods, landslides, and severe weather, resulting in casualties and damage. Delhi experienced unprecedented flooding, affecting water supply and displacing thousands. Several states faced infrastructure damage and casualties, including Himachal Pradesh, Uttarakhand, Punjab, Haryana, and Delhi. Over 208 people lost their lives, and Assam recorded 111,258 affected individuals. In July, a landslide in Maharashtra caused casualties and trapped people, while Telangana faced flooding with 23 deaths. Odisha and Chhattisgarh were also affected, leading to casualties and evacuations. By August, Himachal Pradesh faced additional challenges, including landslides, deaths, and widespread damage. In Kullu, a landslide resulted in over 10 deaths. The Kedarnath valley in Uttarakhand and the Kullu Manali districts in Himachal Pradesh were severely affected, with over 227 people losing their lives in Himachal and more than 50 in Uttarakhand. In September, eastern India, especially Odisha, faced heavy rainfall, resulting in fatalities and injuries due to lightning. Over the weeks, floods and weather incidents affected Gujarat, Himachal Pradesh, Kerala, Madhya Pradesh, Maharashtra, Punjab, and Rajasthan, leading to evacuations and damage. In October, Sikkim and West Bengal experienced flash floods and river overflow, causing casualties, evacuations, and extensive damage. The death toll reached 100, with many missing, and thousands were affected. In summary, India faced various

challenges, including floods, landslides, and severe weather, resulting in casualties, evacuations, and widespread damage across multiple states.

1.2 Problem statement:

To make it easier and faster to help people in need after a disaster.

How:

- Figure out the best places to store supplies ahead of time so they're ready when needed.
- Choose the best locations for buildings like hospitals and warehouses so it's easy to send help to everyone who needs it.
- Make a plan for how to safely move people away from dangerous areas.

To address these challenges, an optimization-based tool has been developed to assist in decision-making within the humanitarian supply chain for disaster relief. The goal is to establish a simple model for three critical aspects: identifying optimal pre-stocking locations for supplies, selecting suitable spots for facilities, and planning evacuations. The objective is to enhance the organization of the humanitarian supply chain.

1.3 Problem Discussion

In our model, we assume two supply chains first relief item chain figure(1.1) and the second evacuation chain figure(1.2). The relief item chain has three stages suppliers (like private and government agencies, and NGOs), LDCs (where emergency supplies are stored), and the areas affected by the disaster (AAs). The evacuation chain consists of evacuation camps (temporary residences for people rescued from AAs) and the AAs.

There are multiple routes between the stages, and we also have various modes of transportation, such as trucks and helicopters. Each supplier has a limited number of relief items, and each local distribution center (LDC) has a capacity for carrying relief items. Each evacuation camp also has a capacity for accommodating injured people. When choosing the locations for relief and evacuation camps, we need to think about their capacity, the distance to AAs (to minimize transportation costs),

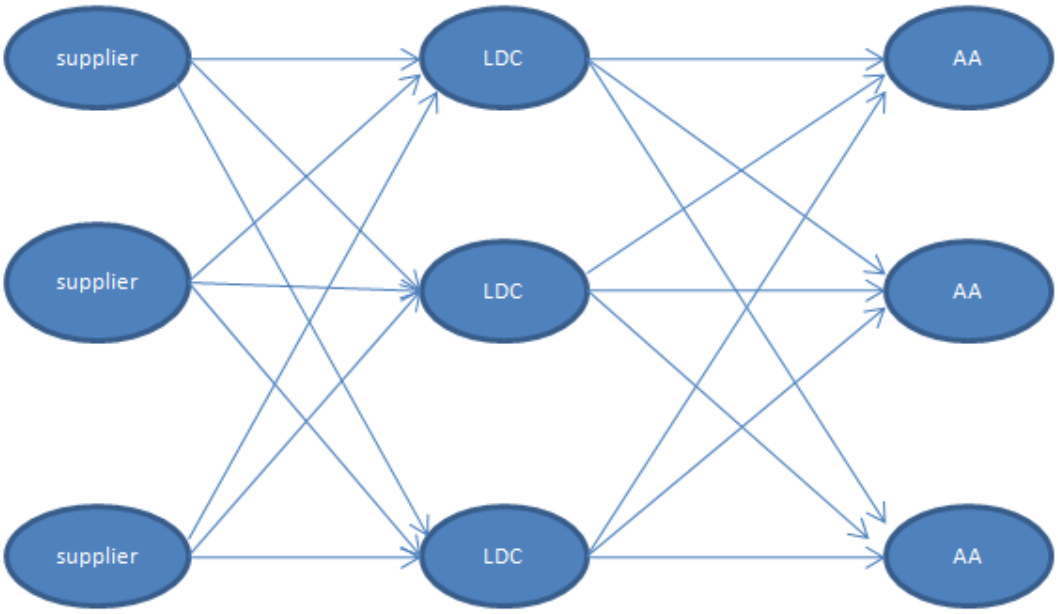

Figure 1.1: Relief item chain

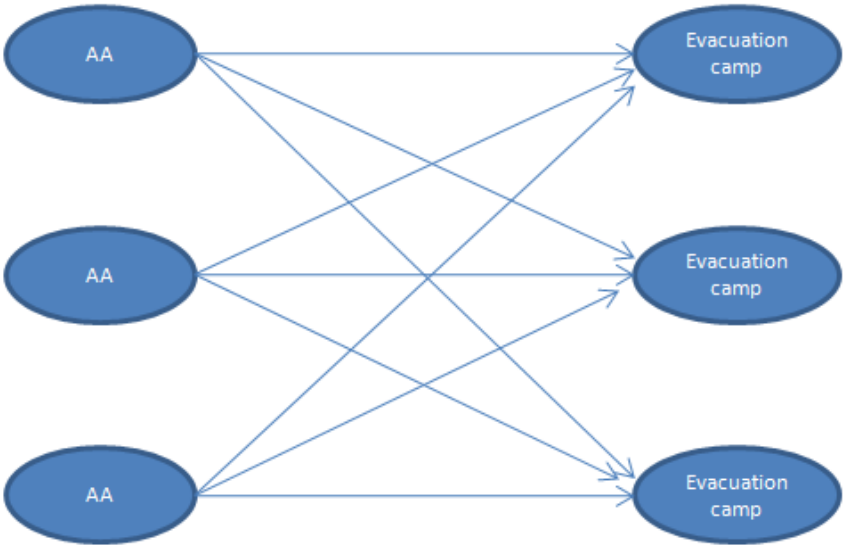

Figure 1.2: Evacuation chain

the likelihood of disruption due to destruction, and the risk associated with different paths. Factors like damage to transportation routes and camps can vary in different scenarios, and we've considered various possibilities. In simple terms, our model aims to figure out the best places for camps, considering capacity, distance, and potential risks, to make the humanitarian response more effective.

Several assumptions have been taken into account:

1. We know where help is needed (AAs or demand points) and where the supplies come from (suppliers).
2. The suppliers' capacity remains unaffected in the event of a disaster or any disruption to transportation infrastructure and facilities.
3. Instead of including multiple commodities in our model, we have considered a single package, which consists of different commodities such as food, water, or medicine.
4. LDCs or evacuation camps can be established in one of three configurations: small, medium, or large. The cost associated with setting up a relief camp or evacuation center is directly tied to its size.
5. Multiple LDCs and evacuation camps have the capability to serve each AA.
6. A singular route is chosen for transportation connecting a specific LDCs or evacuation center to an assembly area (AA)
7. Relief items should be supplied from LDCs only if it is open.
8. Injured victims can be taken to evacuation camps only when the camps are open.

Keywords: LDCS(Local distribution centers),AAs(Affected areas),EVs(Evacuation camps)

Chapter 2

Mathematical Model

2.1 Indices

- i: be the supplier $\forall i = 1, 2, 3, \ldots, m$
- j: be the Local distribution centers(LDCs)$\forall j = 1, 2, 3, \ldots, n$
- k: be the affected areas $\forall k = 1, 2, 3, \ldots, o$
- l: be the evacuation camps $\forall l = 1, 2, 3, \ldots, p$
- r: be the configurations: small, medium, or large $\forall r \in \{S, M, L\}$

2.2 Perametes

- FC_j^r: Fixed cost of operating LDCs
- FCE_l^r: Fixed cost of operating EVs
- d_{ij}: distance from supplier to LDCS
- d_{jk}: distance from LDCs to AAs
- d_{kl}: distance from AAs to EVs
- c_{ij}: transportation cost per relief item from the supplier to LDCs per km
- c_{jk}: transportation cost per relief item from the LDCs to AAs per km

- c_{kl}: transportation cost per injured person from the AAs to EVs per km
- QS_i: Highest amount of relief items available at supply point
- QH_j^r: Maximum Carrying capacity of relief items in LDCs
- S_l: Stay cost at evacuation camp
- E_l^r: Maximum capacity of evacuation camp
- d_k: Affected area demand.
- D_k: The Number of victims required to be evacuated from AAs
- λ: Penalty for relief item chain
- μ: Penalty for evacuation chain

2.3 Decision variables

- a_{ij}: The Number of units assigned from potential supply sites i to LDC j
- b_{jk}: The Number of units assigned from LDC j to AA's demand point k.
- y_j^r: Binary variable that is equal to 1 if LDCs at j are selected otherwise 0.
- y_l^r: Binary variable that equals 1 if EVs camp l is selected otherwise 0.

2.4 Mathematical Formulation

$$\text{Minimize } \sum_{j=1}^{n}\sum_{r} FC_j^r Y_j^r + \sum_{i=1}^{m}\sum_{j=1}^{n} C_{ij}d_{ij}a_{ij} + \sum_{j=1}^{n}\sum_{k=1}^{o} C_{jk}d_{jk}b_{jk} + \lambda(\sum_{k} d_k - \sum_{j}\sum_{k} b_{jk}) \quad (1)$$

$$\text{Minimize } \sum_{l=1}^{p}\sum_{r} FCE_l^r Y_l^r + \sum_{k=1}^{o}\sum_{l=1}^{p} C_{kl}d_{kl}N_{kl} + \sum_{k=1}^{o}\sum_{l=1}^{p} S_l N_{kl} + \mu(\sum_{k} D_k - \sum_{k}\sum_{l} N_{kl}) \quad (2)$$

Subject To:

$$\sum_{i=1}^{m} a_{ij} \leq QS_i \quad \forall j = 1, 2, \ldots, n \quad (3)$$

$$\sum_{i=1}^{m} a_{ij} \leq \sum_{r} QH_j^r \cdot Y_j^r \quad \forall j = 1, 2, \ldots, n \quad \forall r \in \{S, M, L\} \quad (4)$$

$$\sum_{k=1}^{n} b_{jk} - \sum_{r} Y_j^r \cdot \sum_{k=1}^{o} d_k \leq 0 \quad \forall j = 1, 2, \ldots, o \forall r \in \{S, M, L\} \quad (5)$$

$$\sum_{k=1}^{o} N_{kl} - \sum_{r} Y_l^r \cdot \sum_{l=1}^{p} E_l^r \leq 0 \quad \forall l = 1, 2, \ldots, p \forall r \in \{S, M, L\} \quad (6)$$

$$\sum_{j=1}^{n} b_{jk} \leq d_k \quad \forall k = 1, 2, \ldots, o \quad (7)$$

$$\sum_{k=1}^{o} b_{jk} = \sum_{i=1}^{m} a_{ij} \quad \forall j = 1, 2, \ldots, n \quad (8)$$

$$\sum_{k=1}^{o} N_{kl} \leq \sum_{r} E_l^r \cdot Y_l^r \quad \forall l = 1, 2, \ldots, p \forall r \in \{S, M, L\} \quad (9)$$

$$\sum_{l=1}^{p} N_{kl} \leq Dk \quad \forall k = 1, 2, \ldots, n \quad (10)$$

$$\sum_{r} Y_j^r \leq 1 \quad \forall j = 1, 2, \ldots, n \forall r \in \{S, M, L\} \quad (11)$$

$$\sum_{r} Y_l^r \leq 1 \quad \forall l = 1, 2, \ldots, n \forall r \in \{S, M, L\} \quad (12)$$

$$Y_j^r \in \{0, 1\} \quad \forall j = 1, 2, \ldots, n \forall r \in \{S, M, L\} \quad (13)$$

$$a_{ij} \geq 0 \quad \forall i, j \quad (14)$$

$$b_{jk} \geq 0 \quad \forall j, k \quad (15)$$

$$Y_l^r \in \{0, 1\} \quad \forall l = 1, 2, \ldots, p \forall r \in \{S, M, L\} \quad (16)$$

$$N_{kl} \geq 0 \quad \forall k, l \quad (17)$$

2.5 Model Description:

"We aim to minimize the overall cost by optimizing two objectives: one for the relief item supply chain and the other for the evacuation chain. Equation (1) shows the total cost incurred by the relief item supply chain, involving total fixed costs only when local distribution centers (LDCs) are open, total transportation costs to transfer relief items from suppliers to LDCs and LDCs to affected areas (AAs), and As all constraints in our minimization problem involve less than symbols, they inherently satisfy zero. To account for this, we introduce penalty terms a supplementary cost reflecting the dissatisfaction of affected individuals when their needs remain unmet. Equation (2) shows the total cost incurred by the evacuation chain, involving total fixed costs only when evacuation camps (EVs) are open, total transportation costs to rescue injured people from affected areas to evacuation camps, total accommodation costs when injured people stay in evacuation camps, and penaly cost associated with the dissatisfaction of injured people when their needs are unmet."

Equation (3) constraint ensures that the total transfer of relief items from the suppliers must be less than or equal to the number of relief items available in the supply points. Equation (4) ensures that the total transfer of relief items from suppliers to Local Distribution Centers (LDCs) must be less than or equal to the capacity of LDCs.Equation(5) ensures that relief items moving from LDCs to AAs only if LDCs open must be less than the total relief item demanded in AAs.Equation (6) ensures that the number of injured people rescued from the affected area must be less than or equal to the capacity of the evacuation camp if it opens. Equation (7) ensures that total relief item transfer from the LDCs to the particular AA must be less than or equal to the total relief items demanded in the particular AA Equation(8) guarantees that relief items shipping from supply points to LDcs must be equal to relief items shipping from LDCs to AAs. Equation (9) ensures that the number of injured people being transported from AAs to the evacuation camp is less than the capacity of the evacuation camp if it is open. Equation (10) ensures that the number of injured people being transported from AAs is less than or equal to the required demand for injured people Equation(11) ensures that only one configuration (small, medium, large) is possible at a time if LDCs are open similary for the Equation(12).Equation(13) ensures that the Binary variable that is equal to 1 is LDCs otherwise 0 similarly for Equation(16).Equations (14),(15), and (17) ensure that constraints must be nonnegative integers.

Chapter 3

Data Discussion

3.1 Data collection

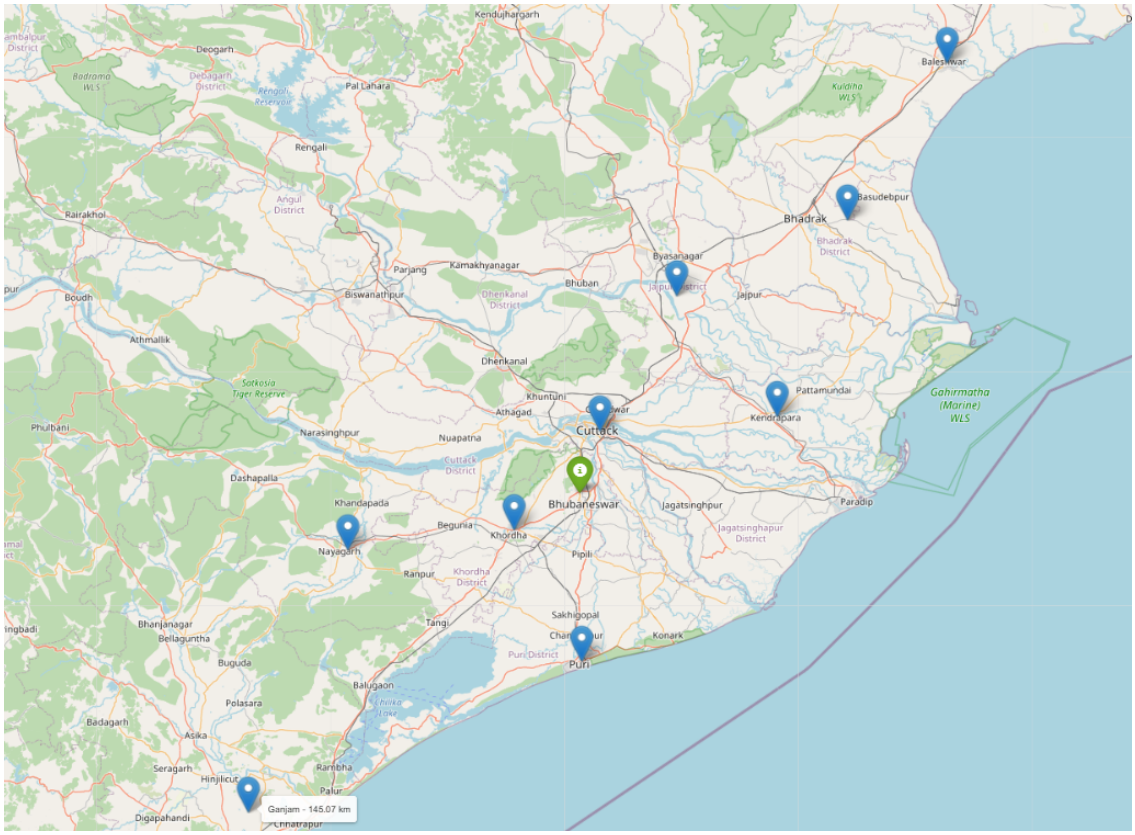

Figure 3.1: Map

The data we are using is from the Orissa Cyclone Fani (2019). In Figure 3.1, nine affected areas are marked as blue locations. We are assuming that there is only one

supplier, Bhubaneswar, marked in Figure 3.1 as the green location. Additionally, we are assuming a safe zone 10 km away from each affected area, where Local Distribution Centers (LDCs) can be opened.

supplier/LDCs	Cuttack	khordha	Nayagarh	Ganjam	Puri	kendrapara	Balasore	Bhadak	Jajpur
Bhubaneswar	19.6	24.08	75.21	145.07	53.44	66.22	175.85	118.88	67.91

Figure 3.2: Distance from Supplier to LDCs(km)

LDCs/AAs	Cuttack	khordha	Nayagarh	Ganjam	Puri	kendrapara	Balasore	Bhadak	Jajpur
Cuttack	10.00	32.26	88.67	162.02	72.29	56.26	156.01	93.22	63.94
khordha	32.26	10.00	81.15	81.15	140.23	66.70	180.68	117.73	88.36
Nayagarh	88.67	81.15	10.00	87.07	83.17	142.95	240.43	179.28	151.06
Ganjam	162.02	140.39	87.07	10.00	114.80	206.92	318.03	255.15	115.70
Puri	72.02	40.23	83.17	114.80	10.00	97.97	217.04	154.82	126.06
kendrapara	56.46	66.70	142.95	206.92	97.97	10.00	120.76	61.65	38.87
Balasore	156.01	180.68	240.43	318.03	217.04	120.76	10.00	63.07	92.61
Bhadak	93.22	117.73	179.28	255.15	154.82	61.65	63.07	10.00	29.54
Jajpur	63.94	88.36	151.06	115.70	126.06	38.87	92.61	29.54	10.00

Figure 3.3: Distance from LDCs to AAs(km)

The distances from the supplier to the LDCs are given in Figure 3.2. also, the distance from LDCs to AAs is given in Figure 3.3. we consider that LDCs and evacuation camps can be open in the same location so we use the distance LDCs to AAs as the distance from AAs to Evacuation camps. To find these distances we used the geopy library in Python. Also, we consider that the cost incurred to transfer relief items and injured people is 1 Rs. per Kilometer. In Figure 3.4 we can see how many people were affected and how many people were injured also we can see the configuration size and corresponding fixed cost and capacity in Figure 3.5 these data we taken from the given references.

District	Cuttack	khordha	Nayagarh	Ganjam	Puri	kendrapara	Balasore	Bhadak	Jajpur
Population Affected(10^5 units)	31	25	3	20	20	15	11	10	22
Injured Victims(10^3 units)	197	84	52	301	129	116	238	62	96

Figure 3.4: Demands of relief item and Evacuation camps

S.no.	Size	FC of LDCs(10^5Rs)	Capacity of LDCs(10^5 units)	FC of Evs(10^3 Rs)	Capacity of Evs(10^3 units)
1.	Small	10	0-50	200	0-500
2.	Medium	20	51-100	400	501-1000
3.	Large	30	101-200	600	1001-2000

Figure 3.5: Confirguration matrix

3.2 Data analysis

In Figure 3.6, upon analyzing the data, the average distance from the LDCs to affected areas is as follows: from Cuttack, it is 81.65; from Khordha, it is 84.19; from Nayagarh, it is 118.19; from Ganjam, it is 168.89; from Puri, it is 101.82; from Kendrapara, it is 89.12; from Balasore, it is 155.40; from Bhadrak, it is 107.16; and from Jajpur, it is 97.79. If we prefer LDCs with a lower average distance from the affected area, and if we rank the preferred LDCs based on distances, the order would be Cuttack, Khordha, Kendrapara, Jajpur, Puri, Bhadrak, Nayagarh, Balasore, and then Ganjam.

Also in Figure 3.7, if we rank based on the higher number of the population affected, then the preferred LDCs order would be Cuttack, Khordha, Jajpur, Ganjam, Puri, Kendrapara, Balasore, Bhadrak, and Nayagarh. based on these analysis we roughly estimate the location for the opening LDCs if we want to open one LDC it would be Cuttack if we want to open two LDCs then it would be Cuttack and Khordha if we want to open three LDCs then it would be Cuttack, Khordha and Jajpur if want to Open four LDCs it would be Cuttack, Khordha, Jajpur and Puri if we want to open all LDCs then rank preferred locations would Cuttack, Khordha, Jajpur, Puri, Kendrapara, Bhadrak, Balasore, Nayagarh, Ganjam.In Figure 4.7 if we do the same analysis we got the rough rank of preferred evacuation

camps would be Ganjam, Balasore, Cuttack, Puri, Kendrapara, Jajpur, Khordha, Bhadrak, Nayagarh After solving the model, we'll see optimal estimation.

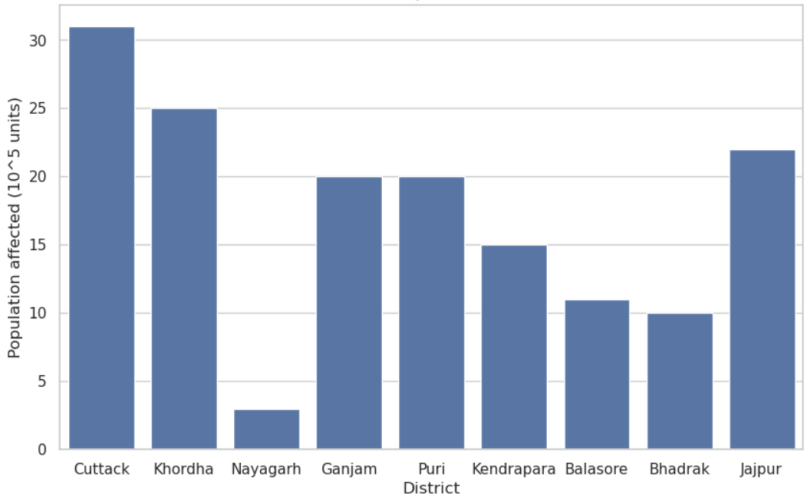

Figure 3.6: District Vs affected people

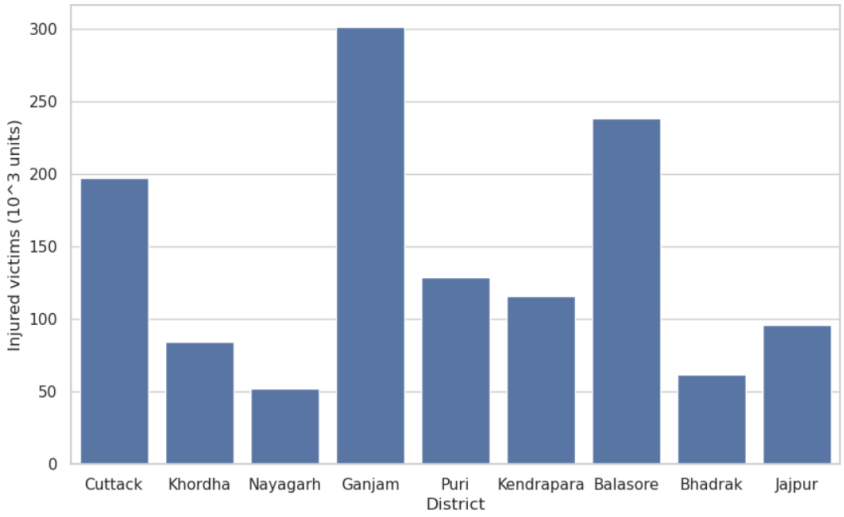

Figure 3.7: District Vs Injured victims

Chapter 4

Solution

4.1 Solution Approach

To solve our optimization problem, we used Pyomo and Gurobi as our main tools. Numpy and Pandas helped us handle and organize our data. For a closer look at the data, we used Seaborn and Matplotlib.To measure distances between stages, we used the Geopy library. To visualize affected areas and suppliers on a map, we brought in Folium. In short, we set up our environment in Pyomo, used Gurobi to solve the problem, and relied on user-friendly libraries like Numpy, Pandas, Seaborn, Matplotlib, Geopy, and Folium for different aspects of our analysis.

4.2 Results

Size	Cuttack	Khordha	Nayagarh	Ganjam	Puri	Kendrapara	Balasore	Bhadrak	Jajpur
Small	×	×	×	×	×	×	×	×	×
Medium	✓	✓	✓	✓	✓	×	×	×	✓
Large	×	×	×	×	×	×	×	×	×

Figure 4.1: LDCs status open or closed

In Figure 4.1, we can see that the optimal number of six LDCs are open, and all six are the same size(medium) for transferring relief items to the affected area. the

Size	Cuttack	Khordha	Nayagarh	Ganjam	Puri	Kendrapara	Balasore	Bhadrak	Jajpur
Small	✓	✓	✓	✓	✓	×	✓	✓	×
Medium	×	×	×	×	×	×	×	×	✓
Large	×	×	×	×	×	×	×	×	×

Figure 4.2: Evacuation camps status open or closed

total cost incurred to open LDCs is 12×10^6 Rs. Also in Figure 4.2, we can see that the optimal number of nine evacuation camps are open, and for all of the nine eight are small size and one is medium size for the rescued injured people from the affected areas. total fixed for the open eight small-size evacuation camps is 14×10^5 Rs and for the medium it is 4×10^5 Rs therefore total cost incurred to open evacuation camp is 18×10^5 Rs. In Figure 4.3, we can see the number of relief items shipped

Supplier/LDCs	Cuttack	Khordha	Nayagarh	Ganjam	Puri	Kendrapara	Balasore	Bhadrak	Jajpur
Bhubaneswar	46	25	3	20	20	_	_	_	40.59730

Figure 4.3: Number of the relief item shipping from Supplier to LDCs (10^5 units)

from the supplier Bhubaneswar to LDCs. Some entities have "-" values, indicating that there are no relief items shipped from Bhubaneswar. This occurs because those LDCs are not open. the total transportation cost incurred to transport the relief items supplier Bhubaneswar to the LDCs is 84.56392643×10^8 Rs.In Figure 4.4 we can see which LDCs transported relief items to which affected areas. total optimal transportation cost incurred to transport relief items from LDCs to AAs is 31.48495953×10^8 Rs. and In Figure 4.5 we can see which AAs transported injured people to which Evacuation camps. total optimal transportation cost incurred to transport injured people from affected areas to the evacuation camp is 16.241220×10^6 Rs.the total optimal relief chain cost is 11.724888596×10^8 Rs.total evacuation chain cost 14.5541220×10^7, therefore, the total overall optimal cost for the operation entire supply chain is 13.18030079×10^8 Rs.total dissatisfaction of affected people when their needs are unmet 24027.0 and total dissatisfaction of injured people when their needs are unmet zero. the cost summary we can see in the figure(4.6).

LDCs\AAs	Cuttack	Khordha	Nayagarh	Ganjam	Puri	Kendrapara	Balasore	Bhadrak	Jajpur
Cuttack	31	_	_	_		15	_	_	_
Khordha	_	25	_	_	_	_	_	_	_
Nayagarh	_	_	3	_	_	_	_	_	_
Ganjam	_	_	_	20	_	_	_	_	_
Puri	_	_	_	_	20	_	_	_	_
Kendrapara	_	_	_	_	_	_	_	_	_
Balasore	_	_	_	_	_	_	_	_	_
Bhadrak	_	_	_	_	_	_	_	_	_
Jajpur	_	_	_	_	_	_	8.59730	10	22

Figure 4.4: Number of the relief item shipping from LDCs to AAs(10^5 units)

AAs\EVs	Cuttack	Khordha	Nayagarh	Ganjam	Puri	Kendrapara	Balasore	Bhadrak	Jajpur
Cuttack	197	_	_	_	_	_	_	_	_
Khordha	_	84	_	_	_	_	_	_	_
Nayagarh	_	2	50	_	_	_	_	_	_
Ganjam	_	_	_	301	_	_	_	_	_
Puri	_	_	_	_	129	_	_	_	_
Kendrapara	_	_	_	_	_	_	_	_	116
Balasore	_	_	_	_	_	_	238	_	_
Bhadrak	_	_	_	_	_	_	_	62	_
Jajpur	_	_	_	_	_	_	_	_	96

Figure 4.5: Number of injured people rescued from AAs to EVs (10^3 units)

Category	cost
Fixed cost when opening small LDC	_
Fixed cost when opening medium LDC	12000000.0
Fixed cost when opening large LDC	_
Total Fixed cost incurred for LDCs	12000000.0
Total transportation cost (LDC i to Affected area j)	845639264.3
Total transportation cost (LDC j to Affected area k)	314849595.3
Fixed cost when opening small evacuation camp	1400000.0
Fixed cost when opening Medium evacuation camp	400000.0
Fixed cost when opening Large evacuation camp	_
Total Fixed cost incurred for evacuation camps	1800000.0
Total transportation cost (Affected area k to camp l)	16241220.0
Total dissatisfaction of affected people unmet needs	240270.0
Total dissatisfaction of injured people unmet needs	0.0
Total cost for relief item chain	1172488859.6
Total cost for evacuation chain	145541220.0
Total cost	1318030079.6

Figure 4.6: Cost Summary

Chapter 5

Sensitive Analysis

5.1 Case(I): if the supplier has an unlimited number of relief items

To examine this case, we relaxed the constraint (equation (3)), which ensures that the total transfer of relief items from suppliers doesn't exceed the supply at the points. After doing this and solving the objectives, we found that the dissatisfaction of affected and injured people, when their needs are unmet, is zero. This can be observed in Figure 5.3. It implies that everyone's relief items and evacuation camp needs have been met because we are now fulfilling the demand that was not met when we had a limited number of relief items. This is reflected in the increased total cost, as shown in Figure 5.4. In Figures 5.1, 5.2, and 5.3, we can observe which LDCs are open, which evacuations are open, and the quantity of relief items being transported from suppliers to LDCs. Additionally, we can see the flow of relief items from LDCs to AAs, the movement of injured people, and the connections between AAs and evacuation camps.

Supplier/LDCs	Cuttack	Khordha	Nayagarh	Ganjam	Puri	Kendrapara	Balasore	Bhadrak	Jajpur
Bhubaneswar	46	25	30	20	20	_	_	_	43

Figure 5.1: Case(I) relief items from supplier to LDC(10^5 units)

LDCs\AAs	Cuttack	Khordha	Nayagarh	Ganjam	Puri	Kendrapara	Balasore	Bhadrak	Japur
Cuttack	31	_	_	_	_	15	_	_	_
Khordha		25	_	_	_	_	_	_	_
Nayagarh	_	_	3	_	_	_	_	_	_
Ganjam	_	_	_	20	_	_	_	_	_
Puri	_	_	_	_	20	_	_	_	_
Kendrapara	_	_	_	_	_	_	_	_	_
Balasore	_	_	_	_	_	_	_	_	_
Bhadrak	_	_	_	_	_	_	_	_	_
Jajpur	_	_	_	_	_	_	11	10	22

Figure 5.2: Case(I) relief items from LDCs to AAs (10^5 units)

AAs\EVs	Cuttack	Khordha	Nayagarh	Ganjam	Puri	Kendrapara	Balasore	Bhadrak	Jajpur
Cuttack	197	_	_	_	_	_	_	_	_
Khordha	_	84	_	_	_	_	_	_	_
Nayagarh	_	2	50	_	_	_	_	_	_
Ganjam	_	_	_	301	_	_	_	_	_
Puri	_	_	_	_	129	_	_	_	_
Kendrapara	_	_	_	_	_	_	_	_	116
Balasore	_	_	_	_	_	_	238	_	_
Bhadrak	_	_	_	_	_	_	_	62	_
Jajpur	_	_	_	_	_	_	_	_	96

Figure 5.3: Case(I) injured people from AAs to EVs(10^3 units)

Category	cost
Fixed cost when opening small LDC	6000000.0
Fixed cost when opening medium LDC	_
Fixed cost when opening large LDC	_
Total Fixed cost incurred for LDCs	6000000.0
Total transportation cost (LDC i to Affected area j)	861956000.0
Total transportation cost (LDC j to Affected area k)	337101000.0
Fixed cost when opening small evacuation camp	1400000.0
Fixed cost when opening Medium evacuation camp	400000.0
Fixed cost when opening Large evacuation camp	_
Total Fixed cost incurred for evacuation camps	1800000.0
Total transportation cost (Affected area k to camp l)	16241220.0
Total dissatisfaction of affected people unmet needs	0.0
Total dissatisfaction of injured people unmet needs	0.0
Total cost for relief item chain	1205057000.0
Total cost for evacuation chain	145541220.0
Total cost	1350598220.0

Figure 5.4: Case(I) cost summary

5.2 Case(II) if some routes are disrupt

We assume that disrupted routes are from the supplier in We make the assumption that the disrupted routes are those that connect the supplier in Bhubaneswar to the Local Distribution Centers (LDCs) in Cuttack, Puri, and Jajpur. Additionally, we presume that the routes with the shortest distance from the LDCs to the affected areas and from affected areas to evacuation camps have been compromised. When we assign an excessively large value to these assumed distances, the solver tends to disregard them. This phenomenon is evident in Figure 5.5, where it appears that no relief items are being shipped from the supplier in Bhubaneswar to the LDCs of Cuttack, Puri, and Jajpur. Furthermore, in examining Figures 5.6 and 5.7, it becomes apparent that entries along the diagonal are consistently zero. This outcome arises due to our assumption that the shortest routes are damaged, and we have assigned larger values to these distances. Consequently, the solver actively avoids considering these routes as viable options. As a direct consequence of the disruption to routes at each stage, there is an observable increase in the distances required for both the transportation of relief items and the conveyance of people from affected areas to evacuation camps. This increase in transportation distances inevitably results in higher transportation costs. This upward cost trend is clearly illustrated in Figure 5.8, where both the total cost for the relief item chain and the total cost for the evacuation chain experience a notable escalation. In summary, the overall expenses incurred within the supply chain witness a considerable increase. In summary, we can say that the number of damaged routes increases the overall supply chain cost increases.

Supplier/LDCs	Cuttack	Khordha	Nayagarh	Ganjam	Puri	Kendrapara	Balasore	Bhadrak	Jajpur
Bhubaneswar	_	69	20	20	_	32	_	8.59730	_

Figure 5.5: Case(II) relief items from supplier to LDC(10^5 units)

LDCs\AAs	Cuttack	Khordha	Nayagarh	Ganjam	Puri	Kendrapara	Balasore	Bhadrak	Japur
Cuttack	_	_	_	_	_	_	_	_	_
Khordha	31	_	30	_	20	15	_	_	_
Nayagarh	_	_	_	20	_	_	_	_	_
Ganjam	_	_	_	_	_	_	_	_	_
Puri	_	25	_	_	_	_	_	_	_
Kendrapara	_	_	_	_	_	_	_	10	22
Balasore	_	_	_	_	_	_	_	_	_
Bhadrak	_	_	_	_	_	_	8.59730	_	_
Jajpur	_	_	_	_	_	_	_	_	_

Figure 5.6: Case(II) relief items from LDCs to AAs (10^5 units)

AAs\EVs	Cuttack	Khordha	Nayagarh	Ganjam	Puri	Kendrapara	Balasore	Bhadrak	Jajpur
Cuttack	_	197	_	_	_	_	_	_	_
Khordha	84	_	_	_	_	_	_	_	_
Nayagarh	_	52	_	_	_	_	_	_	_
Ganjam	_	_	301	_	_	_	_	_	_
Puri	_	129	_	_	_	_	_	_	_
Kendrapara	_	_	_	_	_	_	_	_	116
Balasore	_	_	_	_	_	_	_	238	_
Bhadrak	_	_	_	_	_	_	_	_	_ 62
Jajpur	_	_	_	_	_	_	_	96	_

Figure 5.7: Case(II) injured people from AAs to EVs(10^3 units)

Category	cost
Fixed cost when opening small LDC	3000000.0
Fixed cost when opening medium LDC	4000000.0
Fixed cost when opening large LDC	_
Total Fixed cost incurred for LDCs	7000000.0
Total transportation cost (LDC i to Affected area j)	764280702.4
Total transportation cost (LDC j to Affected area k)	780963171.1
Fixed cost when opening small evacuation camp	600000.0
Fixed cost when opening Medium evacuation camp	800000.0
Fixed cost when opening Large evacuation camp	_
Total Fixed cost incurred for evacuation camps	1400000.0
Total transportation cost (Affected area k to camp l)	68869500.0
Total dissatisfaction of affected people unmet needs	240270.0
Total dissatisfaction of injured people unmet needs	0.0
Total cost for relief item chain	1552243873.5
Total cost for evacuation chain	197769500.0
Total cost	1750013373.5

Figure 5.8: Case(II) cost summary

5.3 Case(III) if Increases the number of suppliers

To execute this scenario, we introduced an additional supplier, Jagatsinghpur. We assumed that both Jagatsinghpur and Bhubaneswar have an equal number of relief items for the Local Distribution Centers (LDCs). Initially, we calculated the distances from Jagatsinghpur to all LDCs using the Python library geopy.

Upon solving, we analyzed the results and observed that with the inclusion of another supplier, the potential routes for transferring relief items expanded. Surprisingly, the transportation cost decreased. This finding is illustrated in Figure 5.12.

The addition of Jagatsinghpur as a supplier appears to have optimized the routing of relief items, leading to cost-effective solutions. The implications of this can be visualized in Figure 5.12, where the transportation cost is reduced compared to the previous scenario.

Supplier/LDCs	Cuttack	Khordha	Nayagarh	Ganjam	Puri	Kendrapara	Balasore	Bhadrak	Jajpur
Bhubaneswar	31	25	3	20	18.29865	_	_	_	_
Jagatsinghpur	_	_	_	17.59730	1.70135	37	_	11	10

Figure 5.9: Case(III) relief items from supplier to LDC(10^5 units)

LDCs\AAs	Cuttack	Khordha	Nayagarh	Ganjam	Puri	Kendrapara	Balasore	Bhadrak	Japur
Cuttack	31	_	_	_	_	_	_	_	_
Khordha	_	25	_	_	_	_	_	_	_
Nayagarh	_	_	3	_	_	_	_	_	_
Ganjam	_	_	_	17.59730	_	_	_	_	_
Puri	_	_	_	_	20	_	_	_	_
Kendrapara	_	_	_	_	_	15	_	_	22
Balasore	_	_	_	_	_	_	_	_	_
Bhadrak	_	_	_	_	_	_	11	_	_
Jajpur	_	_	_	_	_	_	_	10	_

Figure 5.10: Case(III) relief items from LDCs to AAs (10^5 units)

AAs\EVs	Cuttack	Khordha	Nayagarh	Ganjam	Puri	Kendrapara	Balasore	Bhadrak	Jajpur
Cuttack	197	_	_	_	_	_	_	_	_
Khordha	_	84	_	_	_	_	_	_	_
Nayagarh	_	2	50	_	_	_	_	_	_
Ganjam	_	_	301	_	_	_	_	_	_
Puri	_	_	_	_	129	_	_	_	_
Kendrapara	_	_	_	_	_	_	_	_	116
Balasore	_	_	_	_	_	_	238	_	_
Bhadrak	_	_	_	_	_	_	_	62	_
Jajpur	_	_	_	_	_	_	_	_	96

Figure 5.11: Case(III) injured people from AAs to EVs(10^3 units)

Category	cost
Fixed cost when opening small LDC	5000000.0
Fixed cost when opening medium LDC	6000000.0
Fixed cost when opening large LDC	_
Total Fixed cost incurred for LDCs	11000000.0
Total transportation cost (LDC i to Affected area j)	831643761.09
Total transportation cost (LDC j to Affected area k)	296028300.0
Fixed cost when opening small evacuation camp	1400000.0
Fixed cost when opening Medium evacuation camp	400000.0
Fixed cost when opening Large evacuation camp	_
Total Fixed cost incurred for evacuation camps	1800000.0
Total transportation cost (Affected area k to camp l)	16241220.0
Total dissatisfaction of affected people unmet needs	240270.0
Total dissatisfaction of injured people unmet needs	0.0
Total cost for relief item chain	1138672061.1
Total cost for evacuation chain	145541220.0
Total cost	1284213281.1

Figure 5.12: Case(III) cost summary

5.4 Case(IV)if reducing the capacity of LDCs and EVs

To perform the case, we reduced the capacities of all three types of configurations for the Local Distribution Centers (LDCs) and evacuation camps. After solving, we observed that almost all large and medium types of LDCs, as well as evacuation camps, are now operational. This outcome is illustrated in Figure 5.13, where all LDCs are shown as open.

This situation arose due to the reduced capacities of the LDCs, leading to a lack of available capacity. Consequently, the solver opted for the larger and medium-sized LDCs, as they had more available capacity to accommodate the demand. Figure 5.13 visually represents this outcome, highlighting the effect of the capacity constraints on the LDCs.

In summary, the decision to lower the capacities influenced the solver to favor larger and medium-sized LDCs and evacuation camps, as they could better meet the demand within the constraints imposed by the reduced capacities. This trade-off is evident in the results presented in Figure 5.13. In Figure 5.16, the total dissatisfaction of affected people, unmet needs, and total dissatisfaction of injured people with unmet needs are very high values.

Supplier/LDCs	Cuttack	Khordha	Nayagarh	Ganjam	Puri	Kendrapara	Balasore	Bhadrak	Jajpur
Bhubaneswar	2000	2000	2000	2000	2000	2000	2000	2000	2000

Figure 5.13: Case(IV) relief items from supplier to LDC(10^5 units)

LDCs\AAs	Cuttack	Khordha	Nayagarh	Ganjam	Puri	Kendrapara	Balasore	Bhadrak	Japur
Cuttack	2000	_	_	_	_	_	_	_	_
Khordha	_	2000	_	_	_	_	_	_	_
Nayagarh	_	_	2000	_	_	_	_	_	_
Ganjam	_	_	_	2000	_	_	_	_	_
Puri	_	_	_	_	2000	_	_	_	_
Kendrapara	_	_	_	_	_	2000	_	_	_
Balasore	_	_	_	_	_	_	2000	_	_
Bhadrak	_	_	_	_	_	_	_	2000	_
Jajpur	_	_	_	_	_	_	_	_	2000

Figure 5.14: Case(IV) relief items from LDCs to AAs (10^5 units)

AAs\EVs	Cuttack	Khordha	Nayagarh	Ganjam	Puri	Kendrapara	Balasore	Bhadrak	Jajpur
Cuttack	200	_	_	_	_	_	_	_	_
Khordha	_	200	_	_	_	_	_	_	_
Nayagarh	_	_	200	_	_	_	_	_	_
Ganjam	_	_	_	200	_	_	_	_	_
Puri	_	_	_	_	200	_	_	_	_
Kendrapara	_	_	_	_	_	200	_	_	_
Balasore	_	_	_	_	_	_	200	_	_
Bhadrak	_	_	_	_	_	_	_	200	_
Jajpur	_	_	_	_	_	_	_	_	200

Figure 5.15: Case(IV) injured people from AAs to EVs(10^3 units)

Category	cost
Fixed cost when opening small LDC	_
Fixed cost when opening medium LDC	_
Fixed cost when opening large LDC	27000000.0
Total Fixed cost incurred for LDCs	27000000.0
Total transportation cost (LDC i to Affected area j)	1492520.0
Total transportation cost (LDC j to Affected area k)	180000.0
Fixed cost when opening small evacuation camp	200000.0
Fixed cost when opening Medium evacuation camp	_
Fixed cost when opening Large evacuation camp	4800000.
Total Fixed cost incurred for evacuation camps	5000000.0
Total transportation cost (Affected area k to camp l)	21000.0
Total dissatisfaction of affected people unmet needs	15682000.0
Total dissatisfaction of injured people unmet needs	1272900.0
Total cost for relief item chain	28672520.0
Total cost for evacuation chain	5251000.0
Total cost	33923520.0

Figure 5.16: Case(IV) cost summary

5.5 Case(V)if not consider the satisfaction of affected people

Figure (5.17) indicates that no Local Distribution Centers (LDCs) are open, and no relief items are being transported. This outcome is attributed to the over-optimization of the model. Upon closer inspection, it is apparent that all constraints are less than their corresponding upper bounds. If we neglect the satisfaction of affected people, the constraints are still satisfied with values approaching zero. As a result, the model minimizes the overall cost by not opening any LDCs or transporting relief items, effectively yielding a total cost of zero.

Supplier/LDCs	Cuttack	Khordha	Nayagarh	Ganjam	Puri	Kendrapara	Balasore	Bhadrak	Jajpur
Bhubaneswar	_	_	_	_	_	_	_	_	_

Figure 5.17: Case(V) relief items from supplier to LDC(10^5 units)

LDCs\AAs	Cuttack	Khordha	Nayagarh	Ganjam	Puri	Kendrapara	Balasore	Bhadrak	Japur
Cuttack	_	_	_	_	_	_	_	_	_
Khordha	_	_	_	_	_	_	_	_	_
Nayagarh	_	_	_	_	_	_	_	_	_
Ganjam	_	_	_	_	_	_	_	_	_
Puri	_	_	_	_	_	_	_	_	_
Kendrapara	_	_	_	_	_	_	_	_	_
Balasore	_	_	_	_	_	_	_	_	_
Bhadrak	_	_	_	_	_	_	_	_	_
Jajpur	_	_	_	_	_	_	_	_	_

Figure 5.18: Case(V) relief items from LDCs to AAs (10^5 units)

AAs\EVs	Cuttack	Khordha	Nayagarh	Ganjam	Puri	Kendrapara	Balasore	Bhadrak	Jajpur
Cuttack	_	_	_	_	_	_	_	_	_
Khordha	_	_	_	_	_	_	_	_	_
Nayagarh	_	_	_	_	_	_	_	_	_
Ganjam	_	_	_	_	_	_	_	_	_
Puri	_	_	_	_	_	_	_	_	_
Kendrapara	_	_	_	_	_	_	_	_	_
Balasore	_	_	_	_	_	_	_	_	_
Bhadrak	_	_	_	_	_	_	_	_	_
Jajpur	_	_	_	_	_	_	_	_	_

Figure 5.19: Case(V) injured people from AAs to EVs(10^3 units)

Category	cost
Fixed cost when opening small LDC	0
Fixed cost when opening medium LDC	0
Fixed cost when opening large LDC	0
Total Fixed cost incurred for LDCs	0
Total transportation cost (LDC i to Affected area j)	0
Total transportation cost (LDC j to Affected area k)	0
Fixed cost when opening small evacuation camp	0
Fixed cost when opening Medium evacuation camp	0
Fixed cost when opening Large evacuation camp	0
Total Fixed cost incurred for evacuation camps	0
Total transportation cost (Affected area k to camp l)	0
Total dissatisfaction of affected people unmet needs	0
Total dissatisfaction of injured people unmet needs	0
Total cost for relief item chain	0
Total cost for evacuation chain	0
Total cost	0

Figure 5.20: Case(V) cost summary

Chapter 6

Conclusion

This study has created a tool that helps humanitarian organizations make better decisions about how to deliver aid. The tool considers three important factors: where to store supplies, where to build facilities, and how to plan evacuations. The goal is to make sure that aid gets to people who need it quickly and efficiently. The tool is a simple optimization model that takes into account factors such as location, cost, and capacity. It can help organizations make better decisions about how to allocate resources, stock supplies, and plan evacuation routes. The tool has the potential to make a big difference in the way that humanitarian aid is delivered. It can help organizations save lives and improve the lives of people affected by crises.

Future Work

1. In our present model, the consideration of time constraints has not been included. Exploring the integration of temporal factors remains an area for further investigation.

2. In our current approach, using large fixed penalty values (λ and μ) might not accurately represent the dynamics of humanitarian supply chains. Reassessing the appropriateness of these fixed penalties is an important consideration for improving the realism of our models in addressing real-world complexities.

Chapter 7

References

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