Chapter 4

Model Formulation

4.1. Problem Statement

Refrigerated vehicles are uses in many industries to distribute products which is expanding and contributes to the increasing CO_2 emissions. Distribution process without optimum path expands the emissions more. These emissions can be minimized by utilizing a model which will provide the optimum distribution path considering CO_2 emissions. The transportation cost, customer satisfaction are also foremost matter for an industries distribution process. Hence, a multi objective optimization model for distribution path is formed considering CO_2 emissions, transportation cost and customer satisfaction.

The following assumptions are taken under consideration to formulate the model

1. The customer's demands and details, including the number, the positions and time windows are known as well as the number of refrigerated vehicles.
2. There is only one . All distribution vehicles begins from the distribution center and bring it back to the distribution center after accomplishing the transfer job at hand.
3. All the products are delivered by analogous refrigerator vehicles.
4. The storage capacity of each refrigerator vehicle and the volume are equal to or less than the capacity of the vehicle.
5. Each path is distributed by one vehicle and each vehicle ha only one route.

4.2. Parameters

N number of customers

d_{ij} distance between node i and node j

v_{ij} Average speed from customer i to customer j

p_i total volume of products ordered by customer i

g_i total weight of products ordered by customer i

A_i arriving time of customer i

E_{ij} unit fuel consumption from node i to node j

F_{ij} carbon emissions from node i to node j

$[e_{i,} l_i]$ time window ordered by customer i

x_{ijk} binary variable, if refrigerator can k goes to node j after servicing node i, x_{ijk} =1, otherwise x_{ijk} =0

y_{ij} binary variable, if node i is serviced by refrigerator vehicle k, y_{ijk}=1, otherwise y_{ijk}=0.

u_i time penalty weight when a vehicle arrives early

u_2 time penalty when a vehicle is delayed

w_{ij} weight of the products on refrigerator vehicle from node i to node j

m carbon emissions coefficient of vehicle fuel

ω carbon emission from refrigeration by distributing unit weight

f_k unit fuel cost

4.3. Objective functions

The objective function of this topic consists of three parts: transportation cost, customer satisfaction and CO_2 emissions, where transportation cost and CO_2 emissions have to be minimized and customer satisfaction has to be maximized.

i. Transportation cost:

The transportation cost of refrigerated products during shipments is considered as fuel cost only, of which magnificent linearity is found with transportation distance. The transportation cost in distribution is the fuel cost is the fuel cost consumed by all vehicles, which is related to vehicle consumption and unit fuel cost. The total transportation cost can be expressed as:

$$C=\sum_{k=1}^{K} \sum_{i=0}^{N} \sum_{j=0}^{N} E_{ij}.d_{ij} . x_{ijk..} f_k \tag{1}$$

E_{ij} is unit fuel consumption from node i to node j, w_{ij} is weight of the products on the refrigerator car from node i to node j, more concretely, unit fuel consumption per kilometer is calculated as follows:

$$E_{ij} =\beta_0 + \beta_1 w_{ij} +\frac{\beta_2}{{v_{ij}}^2} \tag{2}$$

β_0 denotes unit fuel consumption when the vehicle is empty, β_1 denotes influence factors on unit mileage fuel consumption of vehicle under extra load, β_2 denotes influence factors of vehicle speed on unit distance fuel consumption.

ii. Customer satisfaction

Satisfaction is characterized as the criterion of the period that the distribution center reflects the needs of the customer. If it will be in the timeframe of the customer, the satisfaction benchmark will also be high. The expected period of customer is denoted by an interval $[e_i, l_i]$, the arrival time of the delivery vehicle is denoted by A_i and the number of customers is denoted by n. besides, the total customer satisfaction is 100 for a shipment. The early and late delivery time penalty factors are respectively u_1, u_2, where $u_1 < u_2$.

The satisfaction S_i of a single customer is denoted by:

$$S_i=\begin{cases}\frac{100}{N}-u_1\frac{e_i-A_i}{e_i}, if\ e_i>A_i\\ \frac{100}{N} \qquad if\ e_i<A_i<l_i\\ \frac{100}{N}-u_2\frac{A_i-l_i}{l_i}, if\ l_i>A_i\end{cases} \tag{3}$$

$$S_i=\left(\frac{100}{N}-u_1\frac{e_i-A_i}{e_i}\right)+\left(\frac{100}{N}\right)+\left(\frac{100}{N}-u_2\frac{A_i-l_i}{l_i}\right) \tag{4}$$

iii. Carbon emissions

Carbon emissions in the process of cold chain distribution are considered from two situations:

a. The emissions of the fuel consumption of the vehicle and
b. The other produced by the refrigerated tool of the vehicle

The CO_2 emissions from fuel consumption during vehicle driving can be determined through the fuel consumption and CO_2 emissions coefficient. Therefore, the CO_2 emission expressed as:

$$T_1=m.\sum_{k=1}^{K}\sum_{i=0}^{N}\sum_{j=0}^{N} E_{ij}.d_{ij}\,.\,x_{ijk} \tag{5}$$

The CO_2 emissions caused by refrigeration during the whole distribution are related to the distance and load weight of the vehicle, this part of emission can be expressed as:

$$F_{ij}=\omega.\ w_{ij}.\ d_{ij} \tag{6}$$

It is noted that ω is unit carbon emissions when a refrigerator vehicle transfering a unit of product travels per kilometer. The CO_2 emission is

$$T_2=\sum_{k=1}^{K}\sum_{i=0}^{N}\sum_{j=0}^{N} F_{ij}.x_{ijk}$$

$$=\omega. \sum_{k=1}^{K} \sum_{i=0}^{N} \sum_{j=0}^{N} w_{ij}.d_{ij} . x_{ijk} \quad (7)$$

Therefore, total carbon emissions

$T= T_1+ T_2$

$$= m. \sum_{k=1}^{K} \sum_{i=0}^{N} \sum_{j=0}^{N} E_{ij}.d_{ij} . x_{ijk} + \omega. \sum_{k=1}^{K} \sum_{i=0}^{N} \sum_{j=0}^{N} w_{ij}.d_{ij} . x_{ijk} \quad (8)$$

iv. Objective function:

From the above expressions of the transportation cost, customer satisfaction and CO_2 emissions, the final objective function model can be written as follows:

$$Z=\left\{\sum_{k=1}^{K} \sum_{i=0}^{N} \sum_{j=0}^{N} E_{ij} d_{ij} x_{ijk} f_k\right\} - \left\{\left(\frac{100}{N} - u_1 \frac{e_i - A_i}{e_i}\right) + \left(\frac{100}{N}\right) + \left(\frac{100}{N} - u_2 \frac{A_{i-} l_i}{l_i}\right)\right\} + \left\{m. \sum_{k=1}^{K} \sum_{i=0}^{N} \sum_{j=0}^{N} E_{ij}. d_{ij}. x_{ijk} + \omega. \sum_{k=1}^{K} \sum_{i=0}^{N} \sum_{j=0}^{N} w_{ij}. d_{ij}. x_{ijk}\right\}$$

Such that,

$$\sum_{k=1}^{K} \sum_{i=0}^{N} x_{ij} = 1, \ j=1,2,\ldots\ldots\ldots N \quad (10)$$

$$\sum_{k=1}^{K} \sum_{j=0}^{N} x_{ij} = 1, \ i=1,2,\ldots\ldots\ldots N \quad (11)$$

$$\sum_{k=1}^{K} y_{ij} = 1 \quad (12)$$

$$\sum_{i=1}^{N} g_i y_{ki} \leq w, \text{ k=1,2,......K} \tag{13}$$

$$\sum_{i=1}^{N} b_i y_{ki} \leq V, \text{ k=1,2,......K} \tag{14}$$

$$E_{ij} = \beta_0 + \beta_1 w_{ij} + \frac{\beta_2}{v_{ij}^2} \tag{15}$$

$$w_{ij} = \sum_{i=1}^{N} g_i y_{ki} - \sum_{i=1}^{i} g_i y_{ki}, \text{ k=1,2,3,..................K} \tag{16}$$

$$e_i \leq A_i \leq l_i, \text{ i} \in N \tag{17}$$

Equation (10) and (11) ensures that all customers are serviced.

Equation (12) expresses that each customer is serviced by only one refrigerator vehicle. N Equation (13) restricts that the total amount on each refrigerator vehicle are limited by the capacity while constraint (14) restricts the total volume.

Equation (15) expresses the calculation of unit fuel consumption.

Equation (16) represents the weight on the vehicle during the trip from node i to node j.

Constraint (17) represents arrival time of customer i is within time window.

4.4. Genetic algorithm design

Genetic manipulation

1. Chromosome coding. Chromosome coding is followed through by natural number coding.

2. Fitness function. In the genetic algorithm, the higher the fitness f, the finer the chromosome, the smaller the total objective function Z. Zi will represent the objective function of the i-th sub path.

$f(i)=1/Z_i$, $i = 1, \ldots N$.

3. Select operation. The parent generation of the cross was sorted out by the roulette wheel selection strategy. At the same time, elect reservation mechanism is adopted based on roulette.

4. Cross operation. The partial mapped crossover rule is used to prevent the genetic algorithm from getting into the local optimum and the result from getting the optimal value.

Chapter 5
Model Implementation

5.1 Case Description

In this chapter, optimal distribution paths are proposed considering CO_2 emissions, transportation cost and customer satisfaction for an ice cream industry's factory at Dhaka in Bangladesh which delivered their product by using single refrigerated vehicle to only one dealer because they prioritized customer satisfaction only but their single vehicle capacity is more than enough for one dealer specially in winter season. In Dhaka district five dealers are selected and the products are distributed to those dealers from Dhaka factory.

In this case,

No of Factory, F=1

No of Dealers, D=5

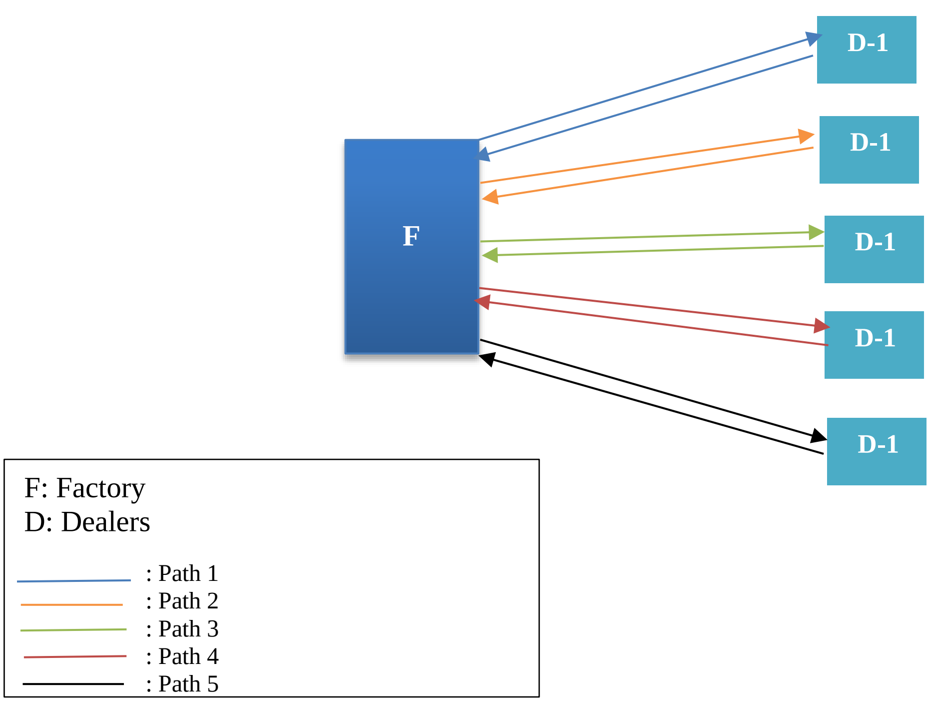

Fig 5.1: General distribution path of supply chain

Fig 5.1 shows the general distribution paths of the supply chain of this thesis in which ingle vehicle delivered products to single dealer and come back to the factory

Dhaka factory is located at Dhaka-Narayanganj Highway road .D-1, D-2, D-3, D-4 and D-5 indicates five dealers at Shimanto Square, Siddheswari, VojoHori Shaha, basaboo Madeatek and Pragoti Ave. respectively.

5.2 Data Collection

For analyzing the model in real-life scenario, some actual data required are collected from the factory and sources. The data includes all parameter values such as the distance between the factory and dealers, between dealers to dealers, volume and weight of product ordered by each dealer, time window required by each dealer, refrigerated vehicle capacity, unit fuel cost and other essential data. The collected data are presented below.

Table 5.1: Order Data (in Volume and Weight)

Dealers	Volume (liter)	Weight (kg)
Shimanto square	600	350
Siddheswari	800	460
Vojohori Saha	500	300
Bashabo Madartek	700	400
Pragati avenue	1000	570

Table 5.1 shows Volume and Weight Data of products in one order. For example, 600 liter (350 kg) products are ordered by Shimanto square Dealer.

Table 5.2: Distance between factory and dealers in Km

Factory / Dealers	Dhaka-Narayanganj Highway
Shimanto square	13 km
Siddheswari	13km
Vojohori Saha	8.7km
Bashabo Madartek	11km
Pragati avenue	18.4km

Table 5.2 shows the distance between the factory and dealer such as the distance between Dhaka-Narayanganj Highway and Siddheswari is 13 km.

Table 5.3: Distance between dealer and dealer in Km

Dealers / Dealers	Shimanto square	Siddheswari	Vojohori Saha	Bashabo Madartek	Pragati
Shimanto square	0	4.9km	7km	7.9km	3.1km
Siddheswari	4.9km	0	4.3km	3.6km	8.9km
Vojohori Saha	6.7km	5.4km	0	6km	11.6km
Bashabo Madartek	7.9km	3.3km	6km	0	8.6km
Pragati	3.1km	8.9km	11.6km	8.6km	0

Table 5.3 shows the distance between one dealer to another such as the distance between Vojohori Saha and Bashabo Madartek is 6 km.

Table 5.4: Average shipping time between factory and dealers in min

Dhaka Factory to dealer	Shipping time
Shimanto square	45min
Siddheswari	50min
Vojohori Saha	50min
Bashabo Madartek	49min
Pragati avenue	75min

Table 5.4 shows the average shipping time between the factory and dealer such as the distance between Dhaka-Narayanganj Highway and Shimanto square is 45min.

Table 5.5: Average shipping time between dealer to dealer

	Shimanto square	Siddheswari	Vojohori Saha	Bashabo Madartek	Pragati
Shimanto square	0	30min	40min	45min	18min
Siddheswari	32min	0	30min	20min	45min
Vojohori saha	40min	32min	0	30min	55min
Bashabo Madartek	50min	20min	35min	0	40min
pragoti	20min	50min	55min	40min	0

Table 5.5 shows the average shipping time between the dealer and dealer such as the distance between Siddheswari and pragoti is 50 min.

Table 5.6: Time window and service time data

Dealers	Time Window	Service time9min)
Shimanto square	[7.00-10.00]	45
Siddheswari	[8.00-12.00]	45
Vojohori saha	[7.00-9.00]	45
Bashabo Madartek	[9.00-1.00]	45
pragoti	[8.00-12.00]	45

Table 5.7:Vehicle capacity data

Weight Capacity(kg)	Volume Capacity (liter)
3000	2000

Table 5.8: Other essential data

Parameters	Meanings	Value
u_1	Penalty weight when a car arrives early	.05%
u_2	Penalty weight when a car arrives early	.05%
$\beta 0$	Unit fuel consumption when the vehicle is empty	.3L
β_1	Influence factors on unit mileage fuel consumption f vehicle under extra load	$8*10^{-5}$
β_2	Influence factors of vehicle speed on unit mileage fuel consumption	200
f_k	Unit fuel price	110tk/L
m	Carbon emissions coefficient of vehicle fuel	2.778kg CO_2/L
ω	Carbon emission from refrigeration by distributing unit weight goods per unit distance	.0066