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Project Report

Co-Packing Network Optimization

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Certificate

This is certify that this report, titled

Co-Packing Network Optimization,

authored by

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describes the project work carried out by the author under our supervision during the period from January 2020 to June 2020. This work represents the project component of the Master of Technology (M.Tech.) Programme in Modeling and Simulation at the Center for Modeling and Simulation, Savitribai Phule Pune University.

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Abstract

Optimization means using the available resources and existing technology in the best possible way. Mathematical models like linear programming, integer programming, etc help to get better results. The various problem in operation planning can be solved with the help of such mathematical models.

Co-packing is the process of assembling product into its final form. Co-packing is generally out-sourced to packaging companies due to the special requirement of technology, staff, etc. Here we need to find the optimum co-packing location based on the transportation cost. This problem is solved using integer programming.

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Contents

Chapter 1

Introduction

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Any product which we use has already been through multiple processes before getting its final form. These processes include collecting raw materials, manufacturing, and then transporting them to the customer. These processes form a network. And this network is called a supply chain network.

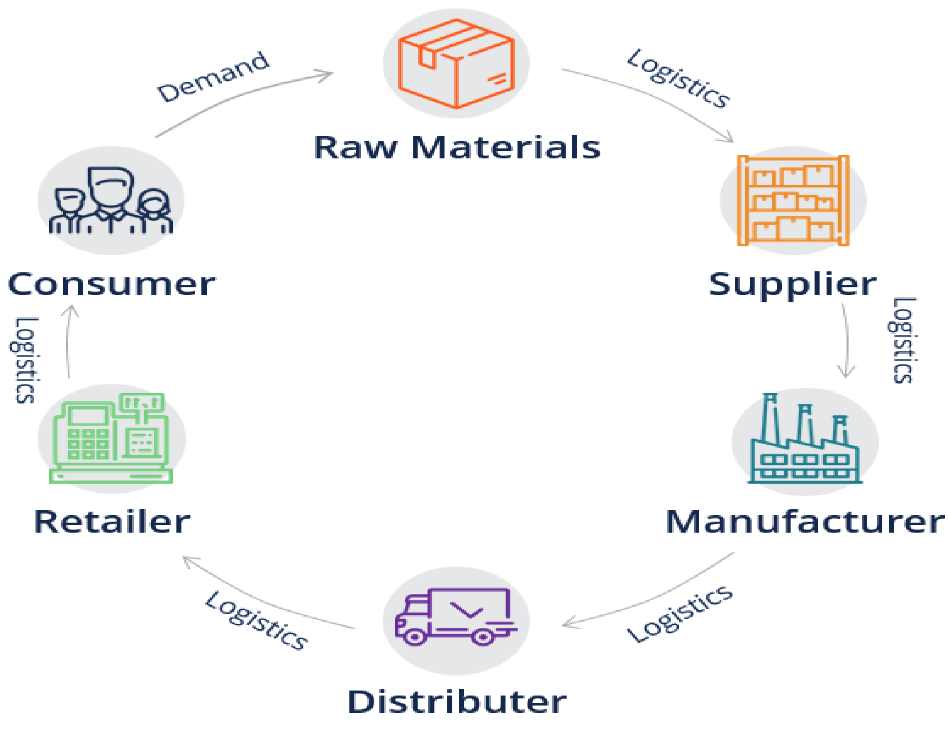

Figure 1.1: Supply Chain Flow [1]

Customization of RCCP: RCCP is a long term capacity planning tool used to maintain a balance between required and available capacity. There are different challenges faced by the planners while capacity planning and hence they require customized templates. Here we have implemented SKU priority-based line loading.

Co-pack location optimization: Co-pack product have significant demand in the market. And these products are out-sourced for packing to the packaging companies. So it is necessary to find an optimum co-packing location. Here we have tried to find optimum co-packing locations based on the transportation cost of products.

Chapter 2

Rough Cut Capacity Planning

Rough Cut Capacity Planning is a long term capacity planning tool used to maintain a balance between required and available capacity. RCCP helps us to verify whether we have enough capacity available to meet the capacity requirements of the master schedules. With the help of RCCP, we can negotiate the changes with the master schedule or available capacity. You can change the master schedule by changing dates, increasing, or decreasing master schedule quantities. You can also change the shift pattern. It is a gross capacity planning technique that does not consider inventory quantities while calculating capacity requirements. RCCP is therefore a statement of capacity required to meet gross production requirements.

2.1 RCCP Tool

RCCP template is generally used to calculate capacity, demand, C/D ratio and the utilization of a line. This is calculated with the help of forecasted demand, line loading, line efficiency, available hours for production, etc. Based on the market survey demand of the each product is estimated.

Line loading means the load allocated to the line and load means the quantity of work. In simple words, it is the quantity of work assigned to the production line. Line loading was a manual input in the old version of RCCP template. Based on the requirement of a few business units we have customized the RCCP template. Now we can calculate line loading based on the priority of SKU given by the planner. In this new template, the planner has to select the priority of the SKU to be manufactured on that line. Then based upon the factors like time availability, throughput rate, etc line loading is calculated.

2.2 Calculation

2.2.1 Demand:

The sum of demand for all SKU's that can be produced on a line is called the demand of line.

Example: SKU1 has demand of 100 tons.SKU2 has demand of 200 tons. Both this SKU are produced on line A.
Total demand on line A is 300 tons.

2.2.2 Capacity:

Capacity means the maximum output that can be obtained through a certain production line. The capacity of a line is based on hours available for production, line efficiency, etc.

Example: SKU1 can be produced on Line A and Line B. Throughput rate on Line A is 1000 kg/hr, available time for production is 700 hrs and efficiency is 90%. And throughput rate on Line B is 1200 kg/hr, available time for production is 600 hrs and efficiency is 80%. Line loading for Line A and Line B is 100 tons and 200 tons respectively.
Therefore we can see that Line loading Split is 33.33% on Line A and 66.67% on Line B.

$$Capacity\ of\ LineA = 1000 * 700 * .9 * .33$$
$$= \ 207.9\ tons$$

$$Capacity\ of\ LineB = 1200 * 600 * .8 * .67$$
$$= \ 385.92\ tons$$

2.2.3 C/D ratio:

The capacity to demand ratio ensures that you have enough capacity to fulfill the demand. C/D ratio should always be greater than or equal to 1.

$$C/D\ ratio\ = \frac{Capacity}{Demand}$$

Example: Consider Line A with demand 200 tons and capacity of 300 tons. And Line B with demand 200 tons and capacity of 180 tons.

$$C/D for\ Line\ A\ = 1.5$$
$$C/D for\ Line\ B\ = .9$$

Hence we can see that the customer demand for SKU's which are produced on Line B cannot be satisfied. So we need to improve the manufacturing technology, etc

2.2.4 Capacity Utilization:

CU represents how well the organization uses its productive capacity. It helps to understand the ability of the organization to cope up with increasing demands.

$$CU = \frac{Production}{Capacity}$$

Example: Consider Line A with demand 200 tons and Line loading of 250 tons.

$$CU of line A = 1.25$$

2.2.5 Line Loading:

Line loading means the load allocated to the line and load means the quantity of work. In simple words, it is the quantity of work assigned to the production line.

Old Version:

The capacity planner schedules the production pattern of each line based on the demand, time, efficiency, etc. It was a manual input sheet in the old RCCP template.

New Version:

The planner can schedule the production based on the priority of the SKU. SKU with the highest priority gets produced first.

Below are the steps used to calculate the line loading.
First step is to calculate total hours available for production.

$$total\ hours\ available\ for\ production = hours\ per\ day\ *\ days\ per\ week\ *\ weeks\ per\ month$$
$$-\ total\ downtime$$

A line can produce multiple SKU as well as multiple SKU can be produced on a line. The nominal throughput rate of SKU differs based on the line.
Consider a line were,

$$X_n\ is\ number\ of\ SKU \qquad n \in 1:\ number\ of\ SKU\ produced\ on\ that\ line$$

$$D_n\ is\ the\ demand\ of\ those\ SKU's\ in\ tons$$

$$S_n\ is\ the\ nominal\ throughput\ rate\ (kg/hrs)$$

$$Theoretical\ Capacity\ Needed\ in\ hours\ to\ produce\ Xn\ = D_n * 1000/\ (Sn * efficiency)$$

$$Theoretical\ Capacity\ Needed\ in\ hours\ to\ produce\ Xn\ = D_n * 1000/\ (Sn * efficiency)$$

$$Capacity\ utilized\ in\ hours\ for\ Xn = Total\ hours\ available - Theoretical\ Capacity\ Needed\ in\ hours.$$

$$Capacity\ utilized\ in\ tons\ for\ Xn = \frac{Capacity\ utilized\ in\ hours\ *\ Sn *\ efficiency}{1000.}$$

$$Additional\ capacity\ needed\ for\ Xn =\ Demand - Capacity\ utilized\ in\ tons$$

example: X1 & X2 are produced on a line with demand 200 100 tons respectively with throughput 1000 kg/hr and 200 kg/hr And total hours available for production is 700 hrs with line efficiency of 90% .

$$Theoretical\ Capacity\ Needed\ in\ hours\ to\ produce\ X1\ = 200 * 1000/\ (1000 * .9)$$
$$= 222.222$$

$$Capacity\ available\ in\ hours\ for\ X1\ =\ 700–222.222$$
$$= 477.88$$

$$\begin{aligned} Capacity\ utilized\ in\ tons\ for\ X1 &= \frac{477.88 * \ 1000 * \ .9}{1000.} \\ &= 200 \end{aligned}$$

$$\begin{aligned} Theoretical\ Capacity\ Needed\ in\ hours\ to\ produce\ X2 &= 100 * 1000/\ (200 * .9) \\ &= 555.56 \end{aligned}$$

$$\begin{aligned} Capacity\ available\ in\ hours\ for\ X2 &= 477.88 - 555.56 \\ &= -77.68 \end{aligned}$$

we can see that line does not have capacity to fulfill the entire demand of X2 hence using maximum available hours of that line.

$$\begin{aligned} Capacity\ available\ in\ tons\ for\ X2 &= \frac{477.88 * \ 1000 * \ .9}{1000.} \\ &= 86.02 \end{aligned}$$

$$\begin{aligned} Additional\ capacity\ needed\ in\ tons\ for\ X2 &= 100 - 86.02 \\ &= 13.98 \end{aligned}$$

Thus we have line loading as

$$200\ tons\ of\ X1\ on\ Line\ 1$$
$$86.02\ tons\ of\ X2\ on\ Line\ 1$$
$$13.98\ tons\ of\ X2\ on\ Line\ 2$$

Line utilization summary:

Line Name	Parameters	Jan-20	Feb-20	Mar-20	Apr-20
Line Name	Total Demand	D1	D2	D3	D4
Select Capacity	Total Production	P1	P2	P3	P4
w/o Premium	Total Capacity	C1	C2	C3	C4
Line Name	C:D	1.00	1.00	1.03	2.14
Line Name	C/D (quarterly)	1.01			
Line Name	C/D (annually)				
Line Name	CU	100%	100%	97%	47%
Line Name	Shift Pattern	24*7	24*7	24*7	24*7
Line Name	Shift Pattern Quar	24*7			24*7
Line Name	PU (Annual)				
Line Name	Period				

Figure 2.1: Line Utilization Summary

2.3 RCCP visualization:

Monthly RCCP templates are updated by the respective BU. Later this templates are connected together with the help of alteryx workflow. And the above data is visualized using tableau dashboard.

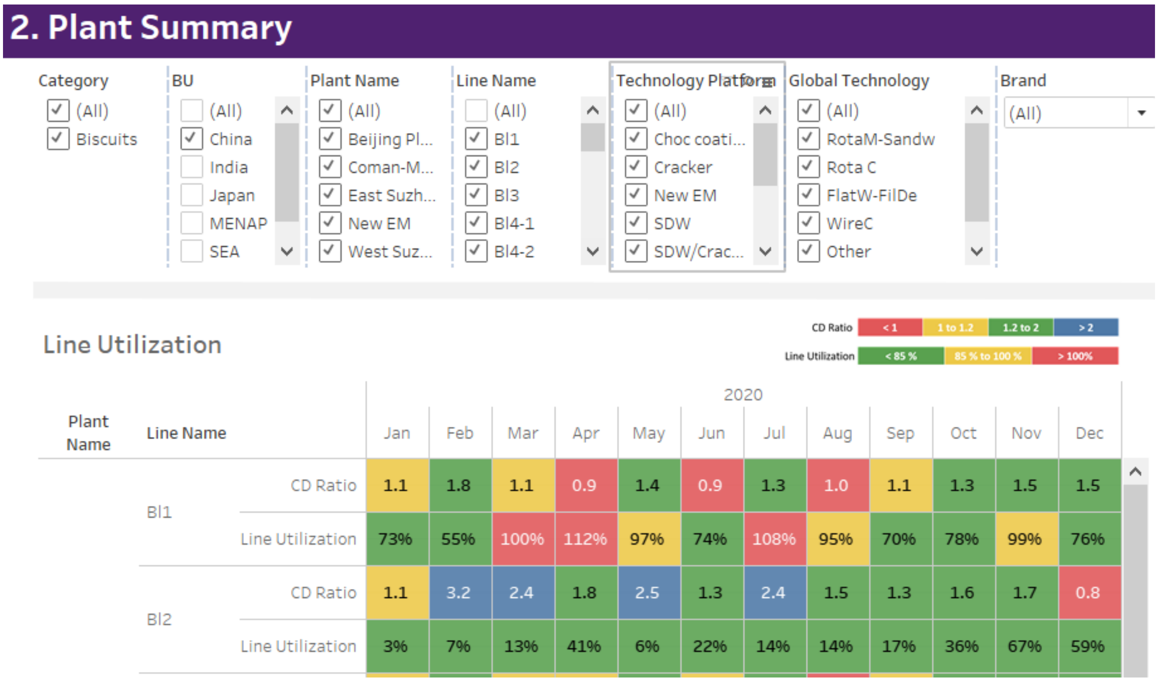

Figure 2.2: Plant Summary in Tableau Dashboard

Chapter 3

Co-packing Network Optimization

3.1 Problem

The objective of the problem is to find an ideal co-packing location based on transportation costs. The following problem is a multi-stage transportation problem.

Co-pack item: Product that requires multiple packing before getting its final form is called a co-pack item. It may be consist of single semi-finished good or multiple semi-finished good.
example:
Single SKU co-pack product: Cadbury Dark Milk has plastic covering and external packing of box.
Multiple SKU co-pack product: Cadbury Celebration has multiple SKU like Perk, 5star, Gems, etc

Co-packing:

It is the process of assembling a product or any good into its final form. Depending on the product, the final packaging may come in a variety of forms, including a thermoformed, blister packaging, a plastic bag, etc. Because of the short-term and medium to high-volume nature of product packaging fulfillment, combined with the demand for specialized equipment and staffing hours, contract packaging services are typically outsourced to contract packaging companies. These packaging companies are experts and are specialized at handling varying levels of the contract packaging sequence They have many in-house resources or outside partners to respond to specific product packaging needs on time. This gives product managers and product manufacturers great flexibility in defining the packaging process based on the needs of the product.

Transportation flow:

Co-pack items or the finished good are formed with the help of semi-finished goods. This SFG's are manufactured at the plants/ factory. Then they are shipped to a co-packing location where the SFG's are processed/packed and are converted into a finished good. And these FG's are shipped to distribution centers based on the demand. We can see that here we have 3 stage transportation.

- Plant to warehouse.
- Warehouse to co-packer.
- Co-packer to warehouse.

Figure 3.1: Co-pack Product Flow

Transshipment

Transportation problem which consist of intermediate destination is called as transshipment. Transshipment is a subgroup of transportation problem. Main objective of transshipment is cost minimization or time minimization. Here our objective is cost minimization. In the following problem warehouse and co-packing location are the intermediate destinations.

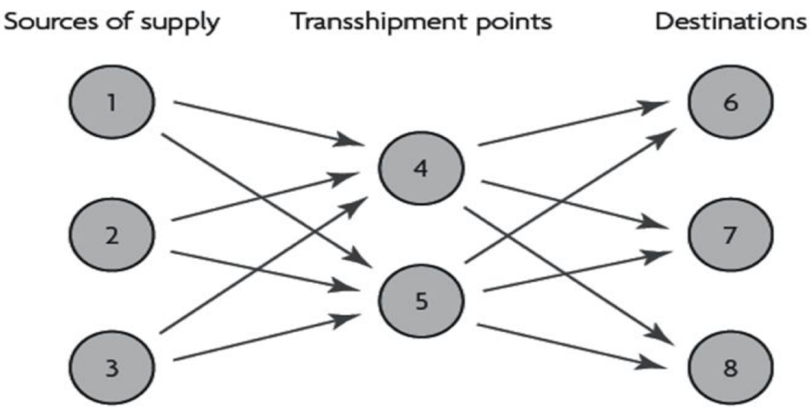

Figure 3.2: Transshipment

Palletization: To understand how goods are transported we need to understand how they are packed and loaded in trucks. Any goods or materials are either packed or placed on the pallet for transportation. As pallet provides a good base and ease in handling. And this process is called as palletization. Here we have assume as 26 pallets per truck.

Figure 3.3: Palletization [2]

3.2 Mathematical model

We are considering single commodity multi-stage transportation. Items are transported from plant, warehouse, co-packer, and then back to the distribution center. Here we have allocated the demand to DC.

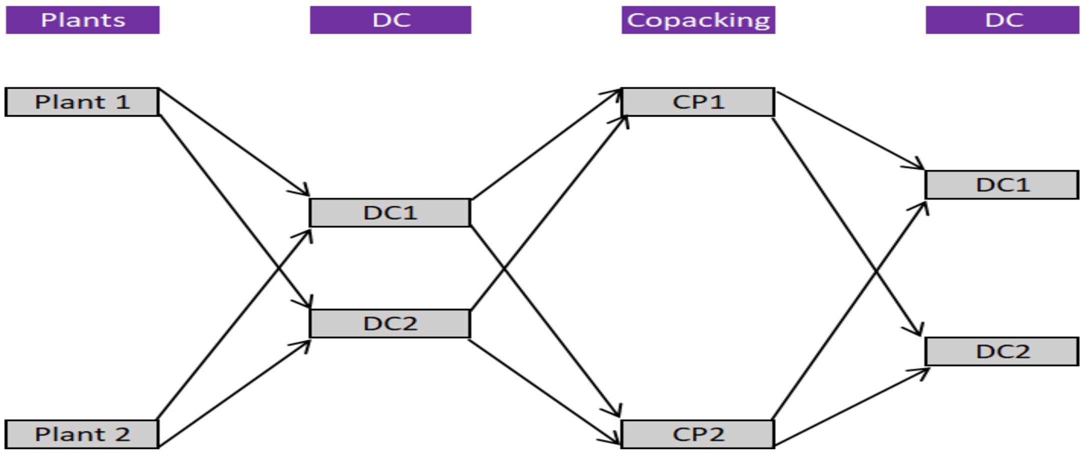

Figure 3.4: Co-pack Product Flow Network

$$X_{ij} = \ Quantity\ supplied\ from\ plant\ i\ to\ warehouse\ j$$

$$Y_{jk} = \ Quantity\ transported\ from\ warehouse\ j\ to\ co-packer\ k$$

$$Z_{kl} = \ Quantity\ transported\ from\ co-packer\ k\ to\ warehouse\ l$$

$$C_{ij} = \ Unit\ cost\ of\ transportation\ from\ plant\ i\ to\ warehouse\ j$$

$$C_{jk} = \ Unit\ cost\ of\ transportation\ from\ warehouse\ j\ to\ co-packer\ k$$

$$C_{kl} = \ Unit\ cost\ of\ transportation\ from\ co-packer\ k\ to\ warehouse\ l$$

$$a_i = \ Quantity\ available\ in\ plant\ i$$

$$b_l = \ Quantity\ required\ by\ warehouse\ l\ (demand)$$

The objective is to Minimize :

$$\sum X_{ij}C_{ij} \sum Y_{jk}C_{jk} \sum Z_{kl}C_{kl}$$

Subject to

$$\sum_j X_{ij} \leq a_i\ where\ i = 1, 2, ..., m$$

$$\sum_i X_{ij} \geq \sum_k Y_{jk}\ where\ j = 1, 2, ..., p$$

$$\sum_k Y_{jk} \geq \sum_l Z_{kl}\ wherek = 1, 2, ..., q$$

$$\sum_j X_{ij} \geq b_i\ where\ i = 1, 2, ..., n$$

3.3 Approach

Transportation Cost: Transportation cost is present at the lane level. We have the truck cost for transporting product from one place to another. Here we have assume 26 pallets per truck and 100% truck utilization.

Example: Cost from Plant1 to Warehouse1 is 80$.

Following are the steps followed to solve the problem:

- Convert demand of FG in cases to kilogram.
- Calculate SFG requirement in kilogram.
- Convert transportation cost from per pallet to per kilogram.
- Convert Transshipment problem to transportation.

- **Convert demand of FG in cases to kilogram:**
  Here we can observe that the numbers of cases get reduced in the product flow. As multiple cases of semi-finished goods are required to form finished goods. Just in case the product requires external packing to itself then only the number of cases remains the same. So here our basic step is to have a standard unit that remains constant throughout the process of co-packing. We can see that weight of goods before and after co-packing remains the same.

  Example: Celebration has a demand of 100 cases but it requires 100 cases of SFG1 and 200 cases of SFG2. We can see that we require 300 cases of SFG's and 100 cases of FG.

- **Calculate SFG requirement:**
  We have semi-finish good to finish good conversion ratio. This ratio helps us to understand how many units of SFG's are required to form one FG. With the help of this ratio, we can calculate the demand of FG we can calculate the SFG requirement in kilograms.
  Example: To form one X product we require 1 unit of A and 3 units of B. And demand for X is 100 units. We can see the SFG to FG ratio for A is .25 and for B is .75. So we will require 100 units of A and 300 units of B.

FG	SFG SKU CODE	SFG DESCRIPTION	NET WEIGHT OF CSE(SFG)	SFG to FG ratio	CSE's PER PALETT	Source Plant of SFG
FG-1	424260	CDM Heroes WIP 10.92g	1	18%	1	Plant1
FG-2	424263	Caramel Heroes WIP 10.98g	1	18%	1	Plant2
FG-3	422374	Buttons 14.4g Treatsize Bag	5.76	18%	70	Plant3
FG-4	CP86011012	Cad Mini Snowballs 31.9g WIP bag	6.061	9%	70	Plant4
FG-5	4023903	Mini Santas Adaption from Milka	8.712	27%	12	Plant1
FG-6	669000	CDM MINI HOLLOW SANTAS 9x 75G	0.675	9%	187	Plant2

Figure 3.5: SFG to FG details

- **Convert transportation cost from per pallet to per kilogram:**
We have transportation cost between two destination and our assumption is 26 pallets per truck. So we can convert this transportation cost in the form of cost/kg.

$$cost/kg = \frac{truck\ cost}{26 * (cases/pallet) * (kg/case)}$$

- **Convert Transshipment problem to transportation:**
A transportation problem allows only shipments that go directly from supply points to demand points. In our situation, goods must be shipped to the co-packing center before shipping them to the demand point.
a. Construct original transportation problem by ignoring transshipment points.
b. Balance the original transportation problem.
c. Add a row and a column for each transshipment point. Each transshipment point has supply and a demand both equal to total original supply.
And solve this transportation problem to obtain the product flow and transportation cost.

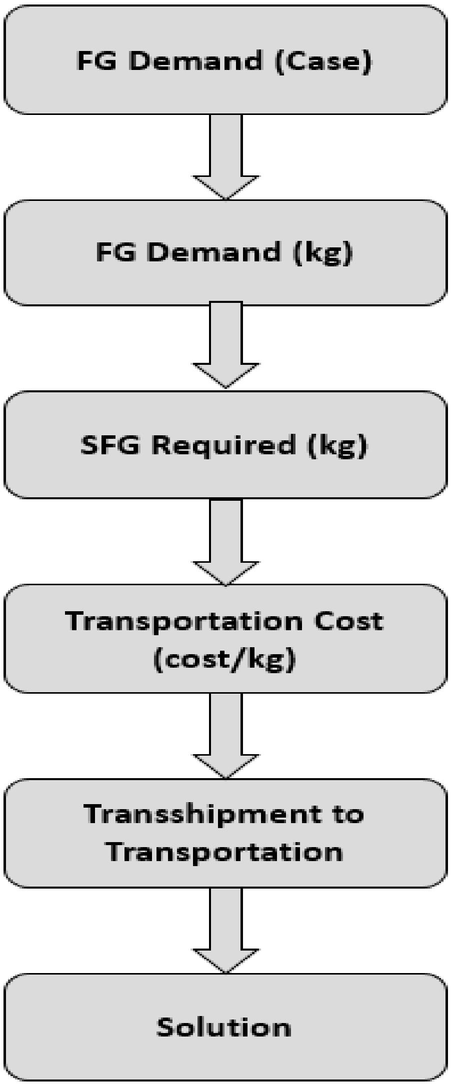

Figure 3.6: Flowchart of approach

Chapter 4

Results

The location optimization model is build with the help of excel and R. Below are the result of the location optimization model. Based on the input data provided.

4.1 Result

Product Flow Summary					
Volume (Kg)	Warehouse	Co-packer_1	Co-packer_2	DC-1	DC-2
Plant1	34,092.00	-	-	-	-
Plant2	20,456.00	-	-	-	-
Plant3	13,637.00	-	-	-	-
Plant4	6,815.00	-	-	-	-
Plant5	-	-	-	-	-
Warehouse	-	75,000.00	-	-	-
Co-packer_1	-	-	-	75,000.00	-
Co-packer_2	-	-	-	-	-

Figure 4.1: Product Flow

:

- Plant to warehouse: We can see that the SFG are supplied from Plant1, Plant2, Plant3 and Plant4 to the warehouse.
- Warehouse to co-packer: Products are transported from Warehouse to Co-packer_1 which is a co-packing center.
- Co-packer to DC-1: DC-1 is the demand point and it receives FG from Co-packer_1.

4.1.1 Cost Table:

Cost Summary	$
Total Transporation cost	3,035.7114
Total Labour and Co pack Cost	2,93,728.8851
Transporation cost per Ton	40.4765
Labour Co Pack cost per Ton	3,916.4219

Figure 4.2: Cost Table

4.2 Cost Comparison

Summary			
	SKU	FG-1	
Parameter	Co-packing Network Optimization Model	Current Cost	Savings
Total Transportation cost	3035.71143	3075.820053	40.10862276
Transportation cost per Ton	40.47653234	41.01093404	0.534401697
Total Labour and Packaging Cost	293728.8851	296804.7052	3075.820053
Labour and packaging cost per Ton	3916.421897	3957.396069	40.97417189

Figure 4.3: Cost Summary

We can see that with the help of new model we can save money which is approximately 1% for the current cost.

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