A Case Study on Optimisation of Distribution Network Using MILP Model

P.A. Cinto and N. Jayasree

Abstract --- The effective and efficient management of logistic is a serious concern for every manufacturing firm. Competitive business environment of present scenario demands the firm to operate their logistic very efficiently and effectively. The project is based on a chemical firm which manufacture and supplies FMCG (Fast Moving Consumer Goods) products. It is found that the distribution expense of the firm is as high as it will count approximately thirty percentage of the product's cost which is a major cause of concern for the firm. The project aims to propose a model which will reduce the distribution expense of the firm.

In order to attain the goal a detailed study of the existing transportation system is done. A mathematical Mixed Integer Linear Programming (MILP) model considering the limitation and facilities there were formulated and solved using AMPL-CPLEX software. The distribution cost of current system and developed system is compared and it is found that the transportation mode of operation given by the model is better than existing system.

Keywords--- Logistics, Distribution Networks, Vehicle Routing, Optimisation, MILP

I. INTRODUCTION

According to Stern and El-Ansary (1988), 'the term Logistics Management encompasses the total flow of materials, from acquisition of raw materials to the delivery of the finished product to the ultimate consumer and the counter-flow of information that controls and records the material movement'. Various activities associated with logistics are as follows: movement of raw materials, manufacturing activity, primary movement of goods to distribution centres, secondary movement of goods, Business to Business (B2B) and Business to Consumer (B2C) distribution, export–import (EXIM) activities, after-sales services, warehousing, and inventory.

From the recent literature review it is found that that the Indian logistics cost is one of the highest in the world. Competitive business environment of present scenario demands the firm to operate their logistic very efficiently and effectively in order to sustain. Finding efficient vehicle routes is an important logistics problem which has been studied for several decades. When a firm is able to reduce the length of its delivery routes or is able to decrease its number of vehicles, it is able to provide better service to its customers, operate in a more efficient manner and possibly increase its market share. A typical vehicle routing problem includes simultaneously determining the routes for several vehicles from a central supply depot to a number of customers and returning to the depot without exceeding the capacity constraints of each vehicle. Different solution techniques are employed to find the optimal route. There are exact and heuristic methods. Exact method which considers all possible solution and find the best one from that.Heuristic methods perform a relatively limited exploration of the search space and typically produce good quality solutions within modest computing times. Constraint Programming (CP is a paradigm for representing and solving a wide variety of problems. Problems are expressed in terms of variables, domains for those variables and constraints between the variables.(Shaw 1998) If the

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problem have bilinear and integer variables and all the constraints and objective are linear equations then the problem can be termed as Mixed Integer Linear Programming) problem (MILP). These problems are solved using complete search techniques such as depth-first search (for satisfaction) and branch and bound (for optimisation). The richness of the language used to express problems in CP makes it an ideal candidate for VRPs. (AMPL) A Mathematical Programming Language, General Algebraic Modeling System (GAMS), OptimJ are some of modelling languages used widely to express the problem. A modeling language works like a compiler: the model and input are put into an intermediate form which can be read by a solver. The solver actually finds an optimal solution to the problem by reading in the intermediate file produced by the modeling language and applying an appropriate algorithm. CPLEX, LINDO, SNOPT (for 'Sparse Nonlinear OPTimizer') are some of commonly used solvers to solve the MILP problem.

The purpose of the project is to reduce the distribution cost of a Small Scale company which manufactures and supplies chemical products. FMCG are products that are sold in large quantities that have a relatively low profit margin and that, if not available, are quickly substituted by a competitor's product. Some examples of FMCG are ice cream, Floor cleaner and shampoo. The production process in the FMCG industry typically contains a single production stage followed by the packing of the final products (Bilgen & Günther, 2010). This production process is known as a make-and-pack production process.

The remainder of the report is organised as follows. Current transportation system followed by the firm is discussed in Section 2.Section 3 describe the proposed model. The transportation cost for the vehicle routing in current system and developed system is evaluated in Section 4. The limitations of the model is discussed in Section 5.Finally conclusion based on the evaluation is given in Section 6.

II. CURRENT DISTRIBUTION SYSTEM

A. *Details of Existing Distribution System*

The firm manufactures and supply seven different types of products. The list of products is given in table 2.1.1.

Table 2.1.1: List of Products

PRODUCT TYPES	NAME	QUANTITY IN ml
1	FLOOR CLEANER WHITE	1000
2	FLOOR CLEANER COLOUR	1000
	FLOOR CLEANER COLOUR	500
3	FLOOR CLEANER BLACK	500
4	DISH WASH GEL	225
	DISH WASH GEL	500
5	TOILET CLEANER	500
6	FLOOR CLEANER ESSENCE	80
	FLOOR CLEANER ESSENCE	120
7	FABRIC STIFFNER	200

These products are packed in customised boxes. Box for each product have different capacity. Box for product type 1 can hold 12 number of unit products while box for product type 3 can hold 24 number of unit product. Capacity of different boxes are given in table 4.1.2.Demand is considered in number of boxes not in number of unit products. Each box occupies certain space and has unique weight as given in table 4.1.2.The box containing product type one is named as P01,type three as P03 and so on. The product type two have two different variations which are named as P021 and P022.

Table 2.2: Details of the Packages

PRODUCT TYPES	CAPACITY OF BOX	WEIGHT	VOLUME
	n	kg	m3
P01	12	12	0.01552
P021	12	12	0.01552
P022	24	12	0.0225
P03	12	6	0.01125
P04	24	6	0.01125
P051	12	6	0.01125
P052	12	6	0.01125
P061	72	6	0.01152
P062	72	9	0.01152
P07	24	5	0.01125

The distributors are located in different routes. Route 1 consists of 7 distributors, route 2 consists of 3 distributors and route 3 consists of 8 distributors. The distributors list is given in table 2.3.

The distribution facility includes a set of vehicle owned by the firm and those which are hired from outside. The detail of the vehicle, their carrying capacity is given in table 2.1.3.The firm owns two vehicle V1 and V2. The third vehicle V3 is hired from outside if necessary.

Table 2.1.2: List of Distributors

ROUTE	DISTRIBUTORS
1	S01
	S02
	S03
	S04
	S05
	S06
	S07
2	S08
	S09
	S10
3	S11
	S12
	S13
	S14
	S15
	S16
	S17
	S18

Table 2.1.3: List of Vehicles and its Capacity

VEHICLES	WEIGHT CAPACITY	VOLUME CAPACITY
	kg	m^3
V1	1000	5
V2	1200	5.5
V3	1000	5

B. Evaluation of Transportation Expenses

Transportation cost is found out by multiplying the distance travelled by the vehicle and cost per distance. The cost per distance of the vehicles owned by the company is calculated using a depreciation chart. The useful life period for the vehicles is taken as 15 years. The depreciation chart for vehicle V1 and V2 is shown in table 2.2. The depreciation cost chart for each vehicle is prepared after considering the amount spends for buying the vehicle, tax, insurance and modification done for the vehicles body. The chart is prepared for n year that is 15 years. The expense per km for the vehicle is calculated by totalling the fixed and variable cost per km for the vehicles.

Cost per distance =fixed cost per distance + Variable cost per distance

Fixed cost per distance = (Depreciation cost for current year + maintenance cost per year +driver's fixed salary per year)/ Average distance the vehicle is expected to travel for current year

Variable cost per distance = Driver's incentive per distance + fuel expenses per distance

Table 2.2: Depreciation Chart for V1and V2

YEAR	DEPRECIATION COST CHART FOR VEHICLE V1	DEPRECIATION COST CHART FOR VEHICLE V2
1	42872	49367
2	38974	44879
3	35431	40799
4	32210	37090
5	29282	33718
6	26620	30653
7	24200	27866
8	22000	25333
9	19800	22800
10	17820	20520
11	16038	18468
12	14434	16621
13	12991	14959
14	11692	13463
15	10523	12117

Fixed cost includes the vehicle cost obtained from the depreciation chart for the current year, maintenance cost, and driver's fixed salary for a year. The variable cost include the driver's incentive for every km the vehicle runs, the fuel expense. Maintenance has to be done for every 3000 km and an average of Rs 2000 is expected to spend for the same. So annual maintenance cost is found to be Rs 20000. Driver's fixed salary per month is Rs 3000 and he charge Rs 2 for every km running. So Rs 30000 is to spend annually for driver's fixed salary. Each vehicle is assumed to travel 30000 km annually. This data is obtained from previous experience and from the discussion with the sales manager. Fixed cost per km running is found out by dividing the total fixed cost by the expected distance each vehicle will travel. The vehicles are expected to travel a distance of 30000 km in a year. Fuel expenses are found by dividing the fuel expense for a month and km reading from the vehicle for a month. The cost per distance for vehicle V1 is calculated as 8.34 Rs per km and V2 is calculated as 8.49 Rs per km. Vehicle V3 is hired from outside if necessary. The outside party charges Rs 19 per km for the vehicle including driver's expenses.

The distance travelled by the vehicle can easily found from the distance matrix. The distance matrix is constructed using the distance required to reach the nodes by road. Distance matrix is as shown in Appendix 2.

C. *Working of Current Distribution System*

The demand is collected from all distributors prior to one week by telephonic method or by email facilities. The total demand in each route is calculated. Looking into vehicle capacity and demand from the distributors of each route vehicles are allocated manually. The demand data for twelve weeks are collected from January 2014 to march 2014.The demand data for twelve weeks are given in Appendix1.

Table 2.3.1: Vehicle Routing For Current System

WEEK 1	ROUTE	VEHICLE	TRIP	VISITING ORDER				
	1	V1	1	PL1	S04	S06	PL1	
			2	PL1	S05	S07	PL1	
		V2	1	PL1	S01	S02	S03	PL1
	2	V2	2	PL1	S08	S09	PL1	
	3	V1	3	PL1	S13	S14	PL1	
		V2	3	PL1	S11	S15	PL1	
			4	PL1	S16	S17	S18	PL1

WEEK 2	ROUTE	VEHICLE	TRIP	VISITING ORDER			
	1	V1	1	PL1	S04	S07	PL1
		V2	1	PL1	S05	S06	PL1
		V3	1	PL1	S01	S03	PL1
	2	V1	2	PL1	S10	PL1	
		V2	2	PL1	S08	S09	PL1
	3	V1	3	PL1	S15	S16	PL1
		V2	3	PL1	S17	S18	PL1
			4	PL1	S13	S14	PL1

WEEK 3	ROUTE	VEHICLE	TRIP	VISITING ORDER				
	1	V1	1	PL1	S03	S05	PL1	
			2	PL1	S07	PL1		
		V2	1	PL1	S01	S02	PL1	
			2	PL1	S04	S06	PL1	
	2	V1	3	PL1	S09	PL1		
		V3	1	PL1	S08	PL1		
	3	V1	4	PL1	S09	PL1		
		V2	3	PL1	S11	S14	PL1	
			4	PL1	S16	S17	S18	PL1

WEEK 4	ROUTE	VEHICLE	TRIP	VISITING ORDER				
	1	V1	1	PL1	S03	S04	S05	PL1
			2	PL1	S07	PL1		
		V2	1	PL1	S01	S02	PL1	
	2	V1	3	PL1	S08	PL1		
		V2	2	PL1	S09	PL1		
	3	V1	4	PL1	S13	S14	PL1	
			5	PL1	S18	PL1		
		V2	3	PL1	S16	S17	PL1	

WEEK	ROUTE	VEHICLE	TRIP	VISITING ORDER				
WEEK 5	1	V1	1	PL1	S03	S04	S05	PL1
			2	PL1	S07	PL1		
		V2	1	PL1	S01	S02	PL1	
	2	V1	3	PL1	S09	PL1		
		V2	2	PL1	S08	PL1		
	3	V1	4	PL1	S11	S13	PL1	
		V2	3	PL1	S16	S17	PL1	
WEEK 6	ROUTE	VEHICLE	TRIP	VISITING ORDER				
	1	V1	1	PL1	S07	PL1		
		V2	1	PL1	S04	S05	PL1	
	2	V1	2	PL1	S08	PL1		
		V2	2	PL1	S09	PL1		
	3	V1	3	PL1	S13	PL1		
			4	PL1	S17	PL1		
		V2	3	PL1	S16	PL1		
WEEK 7	ROUTE	VEHICLE	TRIP	VISITING ORDER				
	1	V1	1	PL1	S01	PL1		
		V2	1	PL1	S05	PL1		
	2	V1	2	PL1	S10	PL1		
		V2	2	PL1	S08	S09	PL1	
	3	V1	3	PL1	S11	PL1		
		V2	3	PL1	S16	PL1		
WEEK 8	ROUTE	VEHICLE	TRIP	VISITING ORDER				
	1	V1	1	PL1	S02	PL1		
			2	PL1	S06	PL1		
		V2	1	PL1	S03	PL1		
	2	V1	3	PL1	S08	PL1		
		V2	2	PL1	S09	PL1		
	3	V1	4	PL1	S11	PL1		
			5	PL1	S12	PL1		
			6	PL1	S15	PL1		
		V2	3	PL1	S16	PL1		
			4	PL1	S17	PL1		
WEEK 9	ROUTE	VEHICLE	TRIP	VISITING ORDER				
	1	V1	1	PL1	S03	S04	S05	PL1
			2	PL1	S07	PL1		
		V2	1	PL1	S01	S02	PL1	
	2	V1	3	PL1	S09	PL1		
		V2	2	PL1	S08	PL1		
	3	V1	4	PL1	S17	S18	PL1	
		V2	3	PL1	S16	PL1		
			4	PL1	S13	S14	PL1	
WEEK 10	ROUTE	VEHICLE	TRIP	VISITING ORDER				
	1	V1	1	PL1	S03	PL1		
		V2	1	PL1	S06	PL1		
	2	V1	2	PL1	S10	PL1		
	3	V1	3	PL1	S11	PL1		
		V2	3	PL1	S12	PL1		
			4	PL1	S13	PL1		
WEEK 11	ROUTE	VEHICLE	TRIP	VISITING ORDER				
	1	V1	1	PL1	S01	PL1		
		V2	1	PL1	S02	PL1		
			2	PL1	S05	PL1		
	2	V1	2	PL1	S09	PL1		
		V2	3	PL1	S08	PL1		
	3	V1	3	PL1	S16	PL1		
		V2	4	PL1	S18	PL1		
WEEK 12	ROUTE	VEHICLE	TRIP	VISITING ORDER				
	1	V1	1	PL1	S03	PL1		
	2	V1	2	PL1	S09	PL1		
		V2	1	PL1	S08	S09	PL1	
	3	V1	3	PL1	S13	PL1		
			4	PL1	S17	PL1		
		V2	3	PL1	S16	S18	PL1	

III. PROPOSED MODEL

A. *Model Assumptions*

Prior to the development of model we made certain assumptions which are given below. They are

- The demand from every distributor is deterministic and known prior to one week.
- A vehicle only can load lots of product from the base (factory) where it is situated and can provide delivery services to multiple distributors.
- Several products can be transported on the same vehicle, but its weight/volume capacity must never be exceeded. The weight and volume of a single unit of product are problem data.
- A customer request can include more than one type of product.
- Every customer location can be visited at most by one vehicle.Partial shipments to end-users are not allowed.
- The production is ready to meet any demand from the distributor.
- The demand from one distributor is assumed to be less than the quantity a vehicle can hold.
- Each vehicle is assumed to travel a maximum distance of 1800 km in a week. This assumption is taken after the discussion with the sales department head.
- Each vehicle must start and end its route at the production facility.
- The fuel expense per km is assumed to be constant for all routes.

B. *Model Formulation*

The current distribution system of firm includes one production facility (i), which is represented as set plant in the model and eighteen distributors (j) which are expressed as set distributors in model. The production facility and the distributors are considered as nodes (i1,i2) which is shown as set I in model. The products (k) produced by the firm is represented as set producttype. The products are packaged in customised box as discussed earlier. The specification of the box that is weight and volume are expressed as $weight_k$ and $volume_k$ respectively. The demand from the distributors is taken in number of boxes not in number of unit products. The demand from the distributors j for each producttype k is known prior to one week and is expressed as $d_{j,k.}$ The firm owns two heterogeneous vehicle v represented in set V Their volume and weight capacity are represented as $capv_v$ and $capw_v$ respectively. Vehicles are supposed to station at production plan after delivering the products to distributors. Vehicles start from production facility and return to the facility after delivering the products to the distributors. First node i visited by the vehicle is represented by a binary variable $INI_{i,v}$ and the final node i by $FI_{i,v}$. The intermediate nodes i1,i2 visited by the vehicles are expressed by binary variable $PR_{i1,i2,v}$.Demand from the distributors are expected to satisfy in that week itself. Each vehicle is not supposed to carry above the capacity of vehicle. The case of shortages is not included in model. The vehicle will be loaded with different types of product and these products are unloaded by the vehicle to different distributors. The loaded and unloaded quantity of products is represented by variables $LOAD_{v,k}$ and $UNLOAD_{i,v,k..}$ The objective function is defined so as to reduce the transportation cost. The input parameter given to the model includes the demand $d_{j,k}$, vehicle capacity ($capv_{v,}$ $capw_v$)and cost per distance ($vvc_{v)}$,product specifications($weight_k$,$volume_k$)and distance matrix $dist_{i1,i2}$. The model gives the route sequencing for each vehicle so that total transportation cost is reduced. The parameters, variables, objective function and constraints used in the model are given below.

C. Nomenclature

a. Subscripts

i1,i2,i3	nodes.
i	plants.
k	producttype.
v	vehicles.

b. Sets

plant	set of plants.
distributors	set of distribution centers.
V	set of vehicles.
I	set of nodes.

c. Parameters

Demand in distribution Centre for product k for current week.

$$d_{j,k}$$

Unit distance cost for vehicle v

$$vvc_v$$

$dist_{i1,i2}$	km distance between node i1 and i2.
MCP	An upper bound.
$capv_v$	Volume capacity of vehicle v.
$capw_v$	weight capacity of vehicle v.
$volume_k$	unit volume of product k.
$weight_k$	unit weight of product k.

d. Variables

$LOAD_{v,k}$ Total amount of product k loaded on vehicle v

$UNLOAD_{I,v,k}$ Total amount of product allocated to distributor i by vehicle v

e. Binary variables

$IN_{i,v}$ Variable determining node i1 is the first one visited in the route of vehicle v.

$FI_{i,v}$ variable determining that node i is the last one visited in the route of vehicle v.

$PR_{i1,i2,v}$ variable determine that node i1 is visitedright before node i2 in the route of vehicle v

H_v variable determining vehicle v is used to supply the product.

$VA_{i,v}$ variable determining that node i is visited by vehicle v.

f. Objective Function

The objective function tries to minimize transportation cost. The distance travelled by the each vehicle from the facility to first node and the final node to facility is represented in first expression. The distance travelled by each vehicle to cover the intermediate node is expressed in second phrase. The transportation cost can be found out by multiplying the distance travelled by each vehicle to the cost per distance for that vehicle that is vvc_v.

$$Zmin = \{[\sum_{(i1\in plant)}\sum_{(i2\in distributors)}\sum_{v\in V}(IN_{i2,v}+FI_{i2,v}) * dist_{i1,i2} + \sum_{(i1\in distributors)}\sum_{(i2\in distributors)}\sum_{v\in V} PR_{i1,i2,v} * dist_{i1,i2}]\} * vvc_v$$

g. Constraints

1. Demand Constraints

The demand constraints suggest that demand from the distribution centers must meet by the quantity unloaded by all the vehicle v.

$$d_{j,k} \le \sum_{v\in V} UNLOAD_{j,v,k}$$
$$\forall j\in distributors, v\in V$$

2. Flow Constraint

The total amount of product unloaded by a vehicle must never be greater than the total amount of product loaded in the vehicle.

$$\sum_{i\in I} UNLOAD_{i,v,k} \le LOAD_{v,k}$$
$$\forall v\in V, k\in producttype$$

3. Vehicle loading constraints

These pair of equation implies that the total cargo transported by each truck must never be greater than the maximum volumetric capacity and weight capacity of the vehicle.

$$\sum_{k\in producttype} (LOAD_{v,k} * weight_k) \le capw_v * H_v \quad \forall v\in V$$

$$\sum_{k\in producttype} (LOAD_{v,k} * volume_k) \le capv_v * H_v \quad \forall v\in V$$

4. Transportation Constraints

This constraint enforces the condition that a delivery operation performed by vehicle v at customer node i can only takes place if vehicle v is assigned to node i.MCP is used as an upper bound.

$$MCP * VA_{j,v} \le UNLOAD_{j,v,k}$$
$$\forall j\in distributors, v\in V, k\in producttype$$

The following constraint indicates that every customer location i ε distributors can at most be visited by a single vehicle during planning horizon.

$$\sum_{v\in V} VA_{j,v} \le 1$$
$$\forall j\in distributors, v\in V$$

5. Route Sequencing

If vehicle *v* is used, exactly one location must be first visited and exactly one location is the last to be visited in the route of *v*. These constraints are enforced by the pair of following Equations.

$$\sum_{i\in I} FI_{i,v} = H_v \quad \forall v\in V$$
$$\sum_{i\in I} IN_{i,v} = H_v \quad \forall v\in V$$

A single location i can be the first/last to be visited by vehicle *v*, only if this node was assigned to *v*. It represented by the set of following Equations.

$$IN_{i,v} \le VA_{i,v} \quad \forall i \in I, v \in V$$

$$FI_{i,v} \le VA_{i,v} \quad \forall i \in I, v \in V$$

Whenever a pair of nodes i1, i2 are related through the immediate precedence relationship, i.e. $PR_{i1,i2,v} = 1$, both locations must be visited by the same vehicle *v*. This condition is imposed through following Equations.

$$PR_{i1,i2,v} \le VA_{i1,v} \quad \forall i1 \in I, i2 \in I, v \in V$$

$$PR_{i1,i2,v} \le VA_{i2,v} \quad \forall i1 \in I, i2 \in I, v \in V$$

A node i can be visited by vehicle *v* either in the first place ($IN_{i,v} = 1$) or right after another location i' ($PR_{i2,i1,v} = 1$), called its immediate predecessor. Moreover, every node i can be either allocated to the last position in the route of vehicle *v* ($FI_{i,v} = 1$), or right before another node i2($PR_{i1,i2,v} = 1$), called its immediate successor. These constraints are represented by the pair of following Equations.

$$IN_{i1,v} + \sum_{i2 \in I, i1 \ne i2} PR_{i1,i2,v} = VA_{i1,v} \quad \forall i1 \in I, v \in V$$

$$FI_{i1,v} + \sum_{i2 \in I, i1 \ne i2} PR_{i1,i2,v} = VA_{i1,v} \quad \forall i1 \in I, v \in V$$

6. *Time Constraints*

We are not taking the time into consideration Instead each vehicle is assumed to travel a distance of 1800 km in a week using the practical experience. These constraints are represented by the following equation.

$$\sum_{i1 \in I}\sum_{i2 \in I}\left(IN_{i2,V} + FI_{i2,V}\right) * \mathrm{dist}_{i1,i2} + \sum_{i1 \in I}\sum_{i2 \in I} \mathrm{PR}_{i1,i2,V} * \mathrm{dist}_{i1,i2} \le 1800 \quad \forall v \in V$$

D. *Implementation*

The MILP model is solved using AMPL-CPLEX software. Text files are used for I/O operation. The Computer used for the purpose have following configuration Intel Core I3 processor with 4 GB ram. Two different approaches are used to optimise the distribution system. The two different approaches are described following as method 1 and method 2.

a. *Method 1*

In method 1 optimal vehicle routing is done considering the demand from the distributors located in each route separately. These routes are followed by the firm as mentioned before. Demand data for route 1, route 2 and route 3 are given separately. Each trip of the vehicle in that route and the visiting order is to be found out using the model. The transportation cost is found out for the obtained vehicle route. The vehicle routing obtained using method 1 is given in table 3.4.1.

Table 3.4.1: Vehicle Routing For Method 1

	ROUTE	VEHICLE	TRIP	VISITING ORDER				
WEEK 1	1	V1	1	PL1	S01	PL1		
			2	PL1	S03	S04	S02	PL1
		V2	1	PL1	S06	S07	S05	PL1
	2	V1	3	PL1	S08	S09	PL1	
	3	V1	3	PL1	S11	PL1		
			4	PL1	S16	S18	S17	PL1
		V2	2	PL1	S13	S15	S14	PL1
	ROUTE	VEHICLE	TRIP	VISITING ORDER				
WEEK 2	1	V1	1	PL1	S06	S07	PL1	
			2	PL1	S01	S03	PL1	
		V2	1	PL1	S04	S05	PL1	
	2	V1	3	PL1	S08	S09	PL1	
	3	V1	4	PL1	S17	S18	PL1	
		V2	2	PL1	S14	S16	PL1	
			3	PL1	S13	S15	PL1	
	ROUTE	VEHICLE	TRIP	VISITING ORDER				
WEEK 3	1	V1	1	PL1	S06	S07	S05	PL1
			2	PL1	S01	S02	PL1	
		V2	1	PL1	S03	S04	PL1	
	2	V2	2	PL1	S08	S09	PL1	
	3	V1	3	PL1	S11	PL1		
			4	PL1	S17	S18	S16	PL1
		V2	3	PL1	S13	S15	S14	PL1

WEEK	ROUTE	VEHICLE	TRIP	VISITING ORDER				
WEEK 4	1	V1	1	PL1	S01	PL1		
			2	PL1	S02	S05	PL1	
		V2	1	PL1	S07	S04	S03	PL1
	2	V1	3	PL1	S09	PL1		
		V2	2	PL1	S08	PL1		
	3	V1	4	PL1	S16	S18	PL1	
			5	PL1	S13	PL1		
		V2	3	PL1	S14	S17	PL1	

WEEK	ROUTE	VEHICLE	TRIP	VISITING ORDER				
WEEK 5	1	V1	1	PL1	S02	S05	PL1	
			2	PL1	S01	PL1		
		V2	1	PL1	S04	S03	S07	PL1
	2	V1	3	PL1	S09	PL1		
		V2	2	PL1	S08	PL1		
	3	V1	4	PL1	S17	S16	S13	PL1
		V2	3	PL1	S11	PL1		

WEEK	ROUTE	VEHICLE	TRIP	VISITING ORDER			
WEEK 6	1	V1	1	PL1	S05	S07	PL1
		V2	1	PL1	S04	PL1	
	2	V1	2	PL1	S09	PL1	
		V2	2	PL1	S08	PL1	
	3	V1	3	PL1	S13	PL1	
		V2	3	PL1	S16	S17	PL1

WEEK	ROUTE	VEHICLE	TRIP	VISITING ORDER			
WEEK 7	1	V1	1	PL1	S01	PL1	
		V2	1	PL1	S05	PL1	
	2	V1	2	PL1	S10	PL1	
		V2	2	PL1	S08	S09	PL1
	3	V1	3	PL1	S14	PL1	
			4	PL1	S16	PL1	
		V2	3	PL1	S11	PL1	
			4	PL1	S17	S18	PL1

WEEK	ROUTE	VEHICLE	TRIP	VISITING ORDER			
WEEK 8			1	PL1	S03	PL1	
		V1	2	PL1	S06	PL1	
	1	V2	1	PL1	S02	PL1	
		V1	1	PL1	S09	PL1	
	2	V2	2	PL1	S08	PL1	
			1	PL1	S15	PL1	
		V1	2	PL1	S16	S17	PL1
			1	PL1	S12	PL1	
	3	V2	2	PL1	S11	PL1	

WEEK	ROUTE	VEHICLE	TRIP	VISITING ORDER				
WEEK 9	1	V1	1	PL1	S01	PL1		
			2	PL1	S02	S05	PL1	
		V2	1	PL1	S03	S04	S05	PL1
	2	V1	3	PL1	S09	PL1		
		V2	2	PL1	S08	PL1		
	3	V1	4	PL1	S16	PL1		
			5	PL1	S14	PL1		
		V2	3	PL1	S17	S18	PL1	

WEEK	ROUTE	VEHICLE	TRIP	VISITING ORDER		
WEEK 10	1	V1	1	PL1	S06	PL1
			2	PL1	S03	PL1
	2	V1	3	PL1	S10	PL1
	3	V1	4	PL1	S13	PL1
			5	PL1	S12	PL1
		V2	1	PL1	S11	PL1

WEEK	ROUTE	VEHICLE	TRIP	VISITING ORDER			
WEEK 11	1	V1	1	PL1	S03	PL1	
	2	V1	2	PL1	S09	PL1	
		V2	1	PL1	S08	S09	PL1
	3	V1	3	PL1	S13	PL1	
			4	PL1	S17	PL1	
		V2	3	PL1	S16	S18	PL1

WEEK	ROUTE	VEHICLE	TRIP	VISITING ORDER			
WEEK 12	1	V1	1	PL1	S03	PL1	
	2	V1	1	PL1	S09	PL1	
		V2	1	PL1	S08	PL1	
	3	V1	1	PL1	S13	S16	PL1
		V2	1	PL1	S17	S18	PL1

b. Method 2

In method 2 optimal vehicle routing is done considering the demand from all the distributors at the same time. Here the results obtained are different route for each vehicle in each trip.The model tries to solve the problem considering all possible option. The transportation cost is found out for the vehicle routing. Vehicle routing obtained for method 2 is given in table 3.4.2

Table 3.4.2: Vehicle Routing for Method 2

WEEK	ROUTE	VEHICLE	TRIP	VISITING ORDER				
WEEK 1	1	V1	1	PL1	S01	PL1		
	2		2	PL1	S17	S18	S16	PL1
	3		3	PL1	S09	S08	S11	PL1
	4	V2	1	PL1	S04	S07	S06	PL1
	5		2	PL1	S02	S05	S03	PL1
	6		3	PL1	S13	S15	S14	PL1

WEEK	ROUTE	VEHICLE	TRIP	VISITING ORDER				
WEEK 2	1	V1	1	PL1	S13	S15	S11	PL1
	2		2	PL1	S08	S10	S01	PL1
	3		3	PL1	S17	S18	PL1	
	4		4	PL1	S07	S06	PL1	
	5	V2	1	PL1	S14	S16	PL1	
	6		2	PL1	S03	S09	PL1	
	7		3	PL1	S04	S05	PL1	

WEEK	ROUTE	VEHICLE	TRIP	VISITING ORDER				
WEEK 3	1	V1	1	PL1	S05	S07	S06	PL1
	2		2	PL1	S13	S15	S14	PL1
	3		3	PL1	S17	S18	S16	PL1
	4	V2	1	PL1	S09	S02	PL1	
	5		2	PL1	S08	S11	PL1	
	6		3	PL1	S03	S04	PL1	
	7	V3	1	PL1	S01	PL1		

WEEK	ROUTE	VEHICLE	TRIP	VISITING ORDER				
WEEK 4	1	V1	1	PL1	S16	S18	PL1	
	2		2	PL1	S07	S04	S13	PL1
	3		3	PL1	S02	S05	S03	PL1
	4	V2	1	PL1	S01	S08	PL1	
	5		2	PL1	S14	S17	PL1	
	6		3	PL1	S09	PL1		

WEEK	ROUTE	VEHICLE	TRIP	VISITING ORDER				
WEEK 5	1	V1	1	PL1	S09	PL1		
	2		2	PL1	S02	S05	PL1	
	3		3	PL1	S17	S16	S13	PL1
	4	V2	1	PL1	S01	S11	PL1	
	5		2	PL1	S03	S07	S04	PL1

WEEK	ROUTE	VEHICLE	TRIP	VISITING ORDER				
WEEK 6	1	V1	1	PL1	S05	S07	PL1	
	2		2	PL1	S04	PL1		
	3		3	PL1	S13	PL1		
	4	V2	1	PL1	S14	S16	S17	PL1
	5		2	PL1	S08	PL1		
	6		3	PL1	S09	PL1		

WEEK	ROUTE	VEHICLE	TRIP	VISITING ORDER				
WEEK 7	1	V1	1	PL1	S01	S14	PL1	
	2		2	PL1	S05	PL1		
	3		3	PL1	S13	S15	S16	PL1
	4	V2	1	PL1	S10	S11	S17	PL1
	5		2	PL1	S08	S09	PL1	
	6		3	PL1	S17	S81	PL1	

WEEK 8	1	V1	1	PL1	S17	S16	S14	PL1
	2		2	PL1	S03	PL1		
	3		3	PL1	S12	PL1		
	4		4	PL1	S13	S16	S14	PL1
	5	V2	1	PL1	S06	S09	PL1	
	6		2	PL1	S02	PL1		
	7		3	PL1	S08	PL1		
	8		4	PL1	S11	PL1		
WEEK 9	ROUTE	VEHICLE	TRIP	VISITING ORDER				
	1	V1	1	PL1	S01	PL1		
	2		2	PL1	S02	S05	PL1	
	3		3	PL1	S09	PL1		
	4		4	PL1	S16	PL1		
	5		5	PL1	S14	PL1		
	6	V2	1	PL1	S03	S04	S05	PL1
	7		2	PL1	S08	PL1		
	8		3	PL1	S17	S18	PL1	
WEEK 10	ROUTE	VEHICLE	TRIP	VISITING ORDER				
	1	V1	1	PL1	S06	PL1		
	2		2	PL1	S03	PL1		
	3		3	PL1	S10	PL1		
	4		4	PL1	S13	PL1		
	5		5	PL1	S12	PL1		
	6	V2	1	PL1	S11	PL1		
WEEK 11	ROUTE	VEHICLE	TRIP	VISITING ORDER				
	1	V1	1	PL1	S13	S15	S16	PL1
	2		2	PL1	S05	PL1		
	3		3	PL1	S18	PL1		
	4	V2	1	PL1	S08	S09	PL1	
	5		2	PL1	S02	PL1		
	6		3	PL1	S01	PL1		
WEEK 12	ROUTE	VEHICLE	TRIP	VISITING ORDER				
	1	V1	1	PL1	S03	PL1		
	2		1	PL1	S09	PL1		
	3		1	PL1	S13	PL1		
	4		2	PL1	S17	PL1		
	5	V2	2	PL1	S08	PL1		
	6		1	PL1	S16	S18	PL1	

IV. Comparison of Existing Transportation System and by Using Model

The total distance travelled by all vehicles and the total cost due to the distance travelled is calculated for the existing, method 1 and method 2 for twelve weeks. It is represented in table 6.1.The solutions are compared based on relative percentage deviation. Relative percentage deviation for transportation cost using method 1 than the current system is represented by % RD1. Relative percentage deviation for transportation cost using method 2 than the current system is represented by % RD2.Transpotation cost for distance travelled by the vehicle using the vehicle routing by current system is termed as TC. Transportation cost for distance travelled by the vehicle using the vehicle routing by method 1 is termed as TM1. Transportation cost for distance travelled by the vehicle using the vehicle routing by method 2 is termed as TM2.The two equations given below shows how the relative percentage deviation is calculated.

$$\% \text{ RD1}= \left(\frac{(TM1-TC)}{TC}\right) * 100 \text{ ,}$$

$$\% \text{ RD2} = \left(\frac{(TM2-TC)}{TC}\right) * 100$$

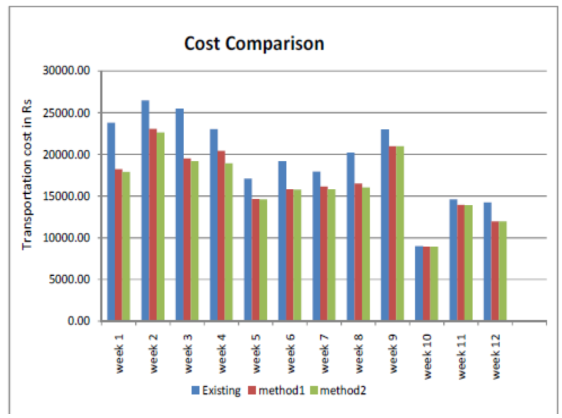

Figure 4.1: Transportation Expense Comparison for Twelve Weeks for Method 1 and Method 2

Table 4.1: Comparison of Distance and Cost implied by Existing and using Model for Method 1 and Method 2

WEEK	MODE OF ESTIMATION	DISTANCE TRAVELLED BY ALL VEHICLES	TRAVEL EXPENSES
		km	Rs
1	EXISTING SYSTEM	2827	23782.23
	CASE 1	2160	18207.75
	CASE 2	2121	17882.49
		% RD 1 =	23.44
		% RD 2 =	24.81
2	EXISTING SYSTEM	2844	26468.72
	CASE 1	2744	23058.81
	CASE 2	2692	22635.18
		% RD 1 =	12.88
		% RD 2 =	14.48
3	EXISTING SYSTEM	2972	25457.70
	CASE 1	2323	19494.27
	CASE 2	2266	19185.42
		% RD 1 =	23.42
		% RD 2 =	24.64

4	EXISTING SYSTEM	2746	23020.29
	CASE 1	2430	20431.20
	CASE 2	2257	18924.03
	% RD 1		11.25
	% RD 2		17.79
5	EXISTING SYSTEM	2039	17109.36
	CASE 1	1745	14648.70
	CASE 2	1737	14594.28
		% RD 1 =	14.38
		% RD 2 =	14.70
6	EXISTING SYSTEM	2281	19174.59
	CASE 1	1880	15809.55
	CASE 2	1880	15784.05
		% RD 1 =	17.55
		% RD 2 =	17.68
7	EXISTING SYSTEM	2122	17934.18
	CASE 1	1920	16137.45
	CASE 2	1882	15820.53
		% RD 1 =	10.02
		% RD 2 =	11.79
8	EXISTING SYSTEM	2396	20174.34
	CASE 1	1973	16513.92
	CASE 2	1906	16008.39
		% RD 1 =	18.14
		% RD 2 =	20.65
9	EXISTING SYSTEM	2684	22985.43
	CASE 1	2442	20981.70
	CASE 2	2442	20981.70
		% RD 1 =	8.72
		% RD 2 =	8.72
10	EXISTING SYSTEM	1068	9016.62
	CASE 1	1068	8922.42
	CASE 2	1068	8922.42
		% RD 1 =	1.04
		% RD 2 =	1.04
11	EXISTING SYSTEM	1730	14598.30
	CASE 1	1661	13938.09
	CASE 2	1661	13900.14
		% RD 1 =	4.52
		% RD 2 =	4.78
12	EXISTING SYSTEM	1694	14226.96
	CASE 1	1422	11955.63
	CASE 2	1422	11955.63
		% RD 1 =	15.96
		% RD 2 =	15.96

V. LIMITATIONS

A. *Not a General Design*

This particular design is not a general design that can be used for all type of transportation, though the same method could be used for all type of transportation problem.

B. *Time Constraints*

This particular design didn't consider the time window for the transportation, Since the delivery time wasn't included as a constrain to this problem.

C. *Demand Variation*

This design was developed considering the maximum transportation capacity of vehicle and the current maximum possible demand, so there would be situation to run another vehicle if the demand exceeds than the usual

VI. CONCLUSION

From the comparison it was found that the relative percentage deviation in transportation cost using method1 on average is 15 % and 15.21 % for method2. It was found that when demand from each distributor is close to the vehicle capacity the relative percentage deviation for both the methods get reduced. The method followed by the firm is manual. But in the world of high competition it is necessary to use the modern technologies to reduce the cost and smooth operation. This model can be used for taking the decision regarding the how much quantity each vehicle must carry where to deliver and which route should be used for delivering so that the transportation cost can be reduced.

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APPENDIX 1

Appendix 1: Demand Data

WEEK 1 demand										
Demand	P01	P021	P022	P03	P04	P051	P052	P061	P062	P07
S01	5	0	5	0	0	0	5	0	0	0
S02	20	0	5	0	5	0	0	0	0	0
S03	0	0	40	0	0	0	0	0	0	0
S04	0	0	0	0	0	0	20	0	5	5
S05	0	0	20	0	0	0	0	0	0	0
S06	20	0	0	0	15	0	20	0	0	0
S07	30	0	0	0	0	20	0	0	0	0
S08	10	0	0	0	10	0	10	0	0	0
S09	0	0	0	0	0	0	0	0	5	5
S10	0	0	0	0	0	0	0	0	0	0
S11	0	0	10	10	15	0	10	0	0	0
S12	0	0	0	0	0	0	0	0	0	0
S13	0	0	20	0	5	0	20	0	5	5
S14	0	0	20	0	10	0	0	0	0	0
S15	0	0	0	0	0	0	50	0	0	0
S16	0	0	0	0	10	10	0	0	0	0
S17	20	0	0	0	0	0	0	0	0	0
S18	10	0	10	0	10	0	0	0	5	5
WEEK 2 demand										
Demand	P01	P021	P022	P03	P04	P051	P052	P061	P062	P07
S01	10	5	10	0	0	0	0	0	5	5
S02	0	0	0	0	0	0	0	0	0	0
S03	20	20	0	0	0	0	0	0	0	0
S04	15	0	20	0	0	0	0	0	0	5
S05	10	0	20	0	0	0	10	0	5	20
S06	10	10	15	0	0	0	0	0	0	0
S07	30	0	10	0	0	0	0	0	0	0
S08	30	0	0	0	0	0	0	0	0	0
S09	20	10	10	0	0	0	0	0	5	20
S10	30	0	0	0	0	0	0	0	0	0
S11	0	0	0	0	0	0	0	0	0	0
S12	0	0	0	0	0	0	0	0	0	0
S13	10	0	20	0	5	0	0	0	0	5
S14	30	0	20	0	10	0	0	0	0	0
S15	10	10	10	0	0	0	0	0	5	5
S16	20	0	0	0	10	10	0	0	0	0
S17	20	10	0	0	0	0	0	0	0	0
S18	25	10	0	0	10	0	0	0	10	10
WEEK3 demand										
Demand	P01	P021	P022	P03	P04	P051	P052	P061	P062	P07
S01	20	0	10	0	0	0	30	0	0	0
S02	10	0	15	0	10	0	0	0	0	0
S03	10	10	40	0	0	0	0	0	0	0
S04	10	10	0	0	0	0	20	0	10	5
S05	0	0	20	0	0	0	0	0	0	0
S06	10	0	0	0	15	0	20	0	0	0
S07	25	0	0	0	0	20	0	0	0	0
S08	30	0	0	0	10	0	10	0	0	0
S09	25	15	0	0	0	0	20	0	5	5
S10	0	0	0	0	0	0	0	0	0	0
S11	0	0	10	10	15	0	10	0	0	0
S12	0	0	0	0	0	0	0	0	0	0
S13	0	0	20	0	5	0	20	0	5	5
S14	0	0	20	0	10	0	0	0	0	0
S15	0	0	0	0	0	0	25	0	0	0
S16	0	0	0	0	10	10	0	0	0	0
S17	20	0	0	0	0	0	0	0	0	0
S18	10	0	20	0	10	0	0	0	5	5

WEEK 4 demand										
Demand	P01	P021	P022	P03	P04	P051	P052	P061	P062	P07
S01	5	10	0	0	10	0	0	5	0	20
S02	0	10	0	0	10	0	0	5	0	20
S03	10	0	0	0	0	0	15	0	0	0
S04	20	0	0	0	0	0	0	0	0	5
S05	20	0	0	0	0	0	0	0	5	20
S06	0	0	0	0	0	0	0	0	0	0
S07	20	10	0	0	0	20	10	5	5	10
S08	10	40	0	0	0	0	0	0	0	0
S09	20	40	0	0	0	0	0	0	10	10
S10	0	0	0	0	0	0	0	0	0	0
S11	0	0	0	0	0	0	0	0	0	0
S12	0	0	0	0	0	0	0	0	0	0
S13	0	0	0	0	5	0	0	0	0	5
S14	30	20	10	0	10	0	0	0	0	0
S15	0	0	0	0	0	0	0	0	0	0
S16	10	20	0	0	0	0	0	5	0	20
S17	10	10	10	0	0	0	0	0	0	10
S18	20	0	20	0	0	0	0	0	0	0
WEEK 5 demand										
Demand	P01	P021	P022	P03	P04	P051	P052	P061	P062	P07
S01	5	10	0	0	10	0	20	5	0	0
S02	0	10	0	0	10	0	20	5	0	0
S03	10	0	0	0	0	0	0	0	0	0
S04	20	0	0	0	0	0	5	0	0	5
S05	20	0	0	0	0	0	20	0	5	0
S06	0	0	0	0	0	0	0	0	0	0
S07	20	10	20	0	0	10	0	5	5	10
S08	10	50	0	0	0	0	15	0	0	0
S09	20	40	0	0	0	0	10	0	5	10
S10	0	0	0	0	0	0	0	0	0	0
S11	30	10	10	0	0	0	0	0	0	5
S12	0	0	0	0	0	0	0	0	0	0
S13	0	0	0	0	0	0	0	0	0	5
S14	0	0	0	0	0	0	0	0	0	0
S15	0	0	0	0	0	0	0	0	0	0
S16	10	20	0	0	0	0	20	0	0	0
S17	10	10	10	0	0	0	0	0	0	15
S18	0	0	0	0	0	0	0	0	0	0
WEEK 6 demand										
Demand	P01	P021	P022	P03	P04	P051	P052	P061	P062	P07
S01	0	0	0	0	0	0	0	0	0	0
S02	0	0	0	0	0	0	0	0	0	0
S03	0	0	0	0	0	0	0	0	0	0
S04	10	10	20	5	0	0	0	0	0	0
S05	0	0	0	0	0	0	20	0	5	0
S06	0	0	0	0	0	0	0	0	0	0
S07	20	10	20	0	0	10	10	0	5	10
S08	10	50	0	0	0	0	0	0	0	0
S09	20	40	0	0	0	0	0	0	10	10
S10	0	0	0	0	0	0	0	0	0	0
S11	0	0	0	0	0	0	0	0	0	0
S12	0	0	0	0	0	0	0	0	0	0
S13	30	20	0	0	0	0	15	0	5	5
S14	0	0	0	0	0	0	0	0	0	0
S15	0	0	0	0	0	0	0	0	0	0
S16	20	30	10	0	0	0	0	0	0	20
S17	0	0	0	0	0	0	50	0	0	0
S18	0	0	0	0	0	0	0	0	0	0

WEEK 7 demand

Demand	P01	P021	P022	P03	P04	P051	P052	P061	P062	P07
S01	20	10	0	0	5	0	10	0	0	10
S02	0	0	0	0	0	0	0	0	0	0
S03	0	0	0	0	0	0	0	0	0	0
S04	0	0	0	0	0	0	0	0	0	0
S05	20	30	10	0	0	0	0	0	5	20
S06	0	0	0	0	0	0	0	0	0	0
S07	0	0	0	0	0	0	0	0	0	0
S08	10	50	0	0	0	0	0	0	0	0
S09	0	40	0	0	0	0	0	0	0	0
S10	10	0	0	0	0	0	0	0	0	0
S11	20	20	20	0	0	0	15	0	0	0
S12	0	0	0	0	0	0	0	0	0	0
S13	0	0	0	0	0	0	0	0	0	0
S14	10	0	20	0	0	0	5	0	5	0
S15	0	0	0	0	0	0	0	0	0	0
S16	20	20	20	0	0	0	20	0	0	0
S17	0	0	0	0	0	0	50	0	0	0
S18	20	20	20	5	0	0	0	0	0	20

WEEK 8 demand

Demand	P01	P021	P022	P03	P04	P051	P052	P061	P062	P07
S01	0	0	0	0	0	0	0	0	0	0
S02	20	10	30	0	0	0	0	0	0	0
S03	15	10	25	0	0	0	20	0	0	10
S04	0	0	0	0	0	0	0	0	0	0
S05	0	0	0	0	0	0	0	0	0	0
S06	10	10	0	20	0	0	10	0	0	20
S07	0	0	0	0	0	0	0	0	0	0
S08	10	50	0	0	0	0	0	0	0	0
S09	0	40	0	0	0	0	15	0	0	0
S10	0	0	0	0	0	0	0	0	0	0
S11	30	30	10	0	0	0	5	0	0	10
S12	25	30	10	0	0	0	5	5	5	5
S13	0	0	0	0	0	0	0	0	0	0
S14	0	0	0	0	0	0	0	0	0	0
S15	40	40	0	0	0	0	0	0	0	0
S16	0	0	0	20	0	0	10	0	0	20
S17	10	20	0	0	0	0	0	0	0	50
S18	0	0	0	0	0	0	0	0	0	0

WEEK 9 demand

Demand	P01	P021	P022	P03	P04	P051	P052	P061	P062	P07
S01	5	10	0	0	10	0	0	5	0	0
S02	0	10	0	0	10	0	35	5	0	0
S03	10	0	0	0	0	0	0	0	0	0
S04	20	0	0	0	0	0	0	0	0	5
S05	20	0	0	0	0	0	20	0	5	5
S06	0	0	0	0	0	0	0	0	0	0
S07	20	10	20	0	0	0	20	5	0	10
S08	10	50	0	0	0	0	0	0	0	0
S09	20	50	0	0	0	0	0	0	5	10
S10	0	0	0	0	0	0	0	0	0	0
S11	0	0	0	0	0	0	0	0	0	0
S12	0	0	0	0	0	0	0	0	0	0
S13	0	0	0	0	5	0	0	0	0	5
S14	30	20	25	0	10	0	0	0	0	0
S15	0	0	0	0	0	0	0	0	0	0
S16	10	20	0	0	0	0	20	5	0	0
S17	10	10	10	0	0	0	10	0	0	0
S18	20	0	20	0	0	0	0	0	0	0

WEEK 10 demand

Demand	P01	P021	P022	P03	P04	P051	P052	P061	P062	P07
S01	0	0	0	0	0	0	0	0	0	0
S02	0	0	0	0	0	0	0	0	0	0
S03	20	20	0	0	0	0	30	0	5	0
S04	0	0	0	0	0	0	0	0	0	0
S05	0	0	0	0	0	0	0	0	0	0
S06	25	10	20	0	0	0	25	0	0	0
S07	0	0	0	0	0	0	0	0	0	0
S08	0	0	0	0	0	0	0	0	0	0
S09	0	0	0	0	0	0	0	0	0	0
S10	50	10	10	0	0	0	0	0	5	5
S11	20	10	10	0	0	0	25	5	5	10
S12	30	20	10	0	0	0	0	0	0	0
S13	20	20	15	0	0	0	10	0	5	20
S14	0	0	0	0	0	0	0	0	0	0
S15	0	0	0	0	0	0	0	0	0	0
S16	0	0	0	0	0	0	0	0	0	0
S17	0	0	0	0	0	0	0	0	0	0
S18	0	0	0	0	0	0	0	0	0	0

WEEK 11 demand

Demand	P01	P021	P022	P03	P04	P051	P052	P061	P062	P07
S01	15	25	10	0	0	0	30	0	0	0
S02	20	25	30	0	0	0	15	0	0	0
S03	0	0	0	0	0	0	0	0	0	0
S04	0	0	0	0	0	0	0	0	0	0
S05	10	10	25	0	25	0	15	0	0	0
S06	0	0	0	0	0	0	0	0	0	0
S07	0	0	0	0	0	0	0	0	0	0
S08	20	10	10	0	0	0	25	0	0	20
S09	20	0	0	0	0	0	20	0	0	20
S10	0	0	0	0	0	0	0	0	0	0
S11	0	0	0	0	0	0	0	0	0	0
S12	0	0	0	0	0	0	0	0	0	0
S13	0	0	0	0	0	0	0	0	0	0
S14	0	0	0	0	0	0	0	0	0	0
S15	0	0	0	0	0	0	0	0	0	0
S16	10	10	0	5	0	0	20	5	0	20
S17	0	0	0	0	0	0	0	0	0	0
S18	25	35	0	0	0	0	0	0	0	25

WEEK 12 demand

Demand	P01	P021	P022	P03	P04	P051	P052	P061	P062	P07
S01	0	0	0	0	0	0	0	0	0	0
S02	0	0	0	0	0	0	0	0	0	0
S03	40	15	0	10	0	0	25	0	0	0
S04	0	0	0	0	0	0	0	0	0	0
S05	0	0	0	0	0	0	0	0	0	0
S06	0	0	0	0	0	0	0	0	0	0
S07	0	0	0	0	0	0	0	0	0	0
S08	10	50	0	0	0	0	0	0	0	0
S09	20	50	0	0	0	0	5	0	5	0
S10	0	0	0	0	0	0	0	0	0	0
S11	0	0	0	0	0	0	0	0	0	0
S12	0	0	0	0	0	0	0	0	0	0
S13	0	0	0	0	5	0	45	0	0	5
S14	0	0	0	0	0	0	0	0	0	0
S15	0	0	0	0	0	0	0	0	0	0
S16	10	20	0	0	0	0	0	5	0	20
S17	10	10	10	0	0	0	50	0	0	0
S18	20	0	20	0	0	0	0	0	0	0

Appendix 2: Distance matrix

Distance	PL1	S01	S02	S03	S04	S05	S06	S07	S08	S09	S10	S11	S12	S13	S14	S15	S16	S17	S18
PL1	0	9	69	118	162	179	204	294	21	77	15	36	71	90	146	158	212	232	298
S01	9	0	70	109	153	180	195	285	23	83	16	37	71	93	147	156	212	232	299
S02	69	70	0	56	100	112	142	232	92	84	86	106	126	151	205	215	270	291	358
S03	118	109	56	0	49	85	91	181	137	126	133	156	154	179	233	243	298	319	386
S04	162	153	100	49	0	88	43	133	185	174	185	190	202	68	282	291	347	367	434
S05	179	180	112	85	88	0	123	204	197	193	191	212	233	258	313	322	378	398	465
S06	204	195	142	91	43	123	0	92	226	216	221	246	244	269	323	333	388	409	476
S07	294	285	232	181	133	204	92	0	317	306	311	336	334	359	413	423	476	499	566
S08	21	23	92	137	185	197	226	317	0	62	7	18	55	74	129	138	193	214	281
S09	77	83	84	126	174	193	216	306	62	0	67	79	115	134	189	198	253	274	341
S10	15	16	86	133	185	191	221	311	7	67	0	21	58	77	131	141	196	217	284
S11	36	37	106	156	190	212	246	336	18	79	21	0	39	58	112	121	177	197	265
S12	71	71	126	154	202	233	244	334	55	115	58	39	0	30	85	94	180	170	238
S13	90	93	151	179	68	258	269	359	74	134	77	58	30	0	59	68	123	144	211
S14	146	147	205	233	282	313	323	413	129	189	131	112	95	59	0	48	65	86	153
S15	158	156	215	243	291	322	333	423	138	198	141	121	94	68	48	0	59	100	152
S16	212	212	270	298	347	378	388	476	193	253	196	177	180	123	65	59	0	60	108
S17	231	232	291	319	367	398	409	499	214	274	217	197	170	144	86	100	60	0	69
S18	298	299	358	386	434	465	476	566	281	341	284	265	238	211	153	152	108	69	0