Chapter 4

DECENTRALIZATION, FACILITY PLANNING AND LOGISTIC STRATEGIES

This chapter discusses the facility planning, logistics and decentralization strategies for the Varanasi city. The healthcare planning faces a dual challenge of reach and cost. The centralized operation can help in achieving the economies of scale and hence lower cost of operations. To maximize the reach the healthcare operations should be decentralized. The mixed approach may be keeping some of the components of care at central facility while others at each remote facility. The component of the care kept at central facility is to be used by all remote facilities.

First objective in this chapter is to identify the component of the diabetes management to be kept at central facility. The central facility is the hospital's main building where costly equipment are kept while remote facility is a sub centre of the hospital more close to community. The next objective of the research is to identify the location for the central facility and then plan a Milk-Run connecting the central facility with the remote locations. The objective of Milk-run is providing human resources and medicine at remote locations. It can be used for sample collection and pathology report delivery also.

For the above-mentioned objectives of the study, the following research questions were established:

1. Which component of the diabetes management needs to be kept at a central facility and which of them should be kept at remote nodes?

2. What should be the location of the central facility so that the overall distance traveled between nodes and central facility is minimized?
3. Given the location of the central facility, what is the Milk-Run route connecting it with all other nodes?

4.1. Methodology

This study used the focus group discussion to determine the location of nodes (remote locations) and various components of the diabetes management. The study further uses rating from three experts (other than members of the focus group) to calculate the global utility score for these components for the decision maker and is discussed in the next section. The global utility score of the components was used to take a decision of decentralization for the components of diabetes management. The methodology of the study is depicted in Figure 4.1 as below:

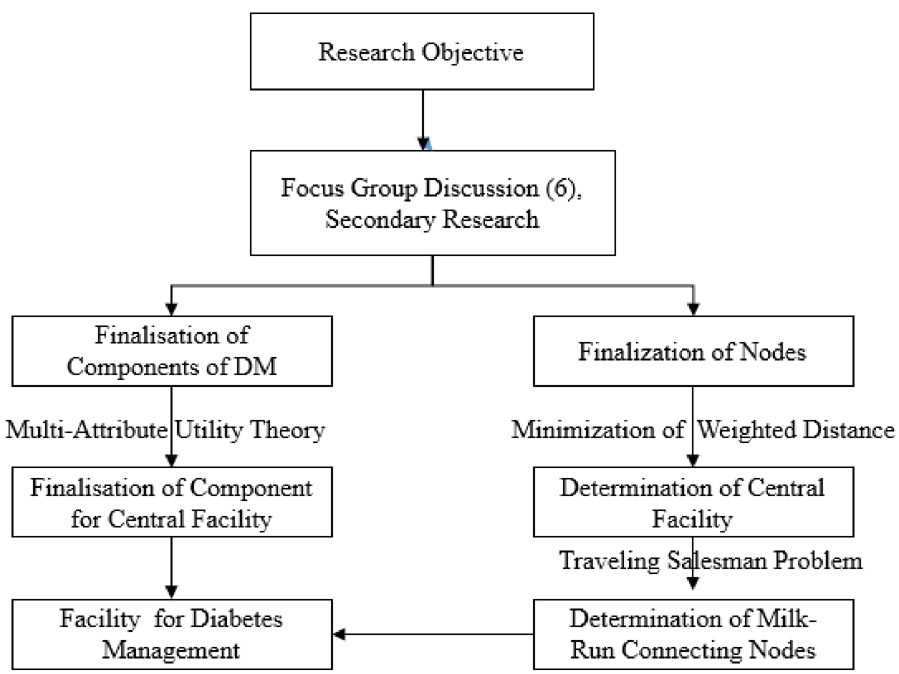

Figure 4. 1: Research Design for the Facility and Logistic Planning

A focus group of two doctors, two allied health professionals, and two social workers were created for the above-mentioned objective. The group was asked to identify the important components of healthcare delivery in the context of diabetes management. The ten components identified after the focus group discussion, were Consultancy (CONS), Hospitalization (HOSP), Foot care (FOOT), Eye Care (EYE), Medical Nutrition Therapy (MNT), Exercise (EXE), Neuropathy Detection (NPD), Pathology (PAT), Medicines (MED) and Diabetes Education (DEDN). These all components of the diabetes management are required at every node but there is a trade-off between cost and available facilities at the nodes. The focus group determined 3Cs; cost, control, and connectivity as criteria for deciding whether a facility should be kept at a central location or made available at nodes also (Figure 4.2). Multi-Attribute Utility Theory (MAUT) was used to find out which component should be kept at the central facility only.

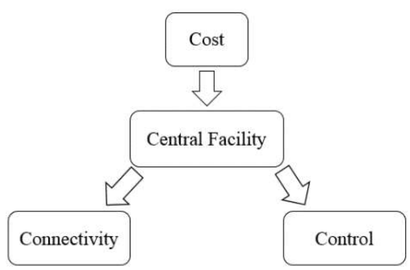

Figure 4. 2: Criteria for Central Facility

4.1.1 Multi-Attribute Utility Theory

MAUT is a widely used method to measure desirability or preference of alternatives (Ishizaka & Nemery, 2013). The decision maker's preferences can be represented by a function called utility function U (Keeney et al., 1976).The utility score is the degree of value the alternatives provide to the decision maker (healthcare facility planner). Let A be a set of the components of diabetes management denoted by small alphabets:

$$A = \{a_1, \dots, a_{10}\} \quad (4.1)$$

Each component of set A is evaluated on basis of function U and receives a utility score $U(a)$. This utility score can be used to rank the components in order of preference to keep the component at central location only. The study uses additive model to calculate the utility for q criteria (the three criteria used in the study are cost control and connectivity).

Let F be a set of q criteria given by $f_j(j = 1,2, \dots\dots, q)$. The evaluation of the components $f_j(a_i)$ is transformed into marginal utility contribution, denoted byU_j, in order to avoid scale problems. The marginal utility is then aggregated using weighted sum

$$\forall\, a_i \in A: U(a_i) = U(f_1(a_i) \dots f_q(a_i)) = \sum_{j=1}^{q} U_j(\,f_j(a_i)) * w_j \quad (4.2)$$

Where $U_j(f_j) \geq 0$ is a non-decreasing function, and w_j represents the weight of the criteria $f_j$satisfying following equation:

$$\sum_{j=1}^{q} w_j = 1 \quad (4.3)$$

To find out utility score for taking decentralization decision, cost and control should be maximized while connectivity should be minimized. The ten components identified in the earlier section are listed in Table 4.1 below:

Table 4. 1: Components of Diabetes Management

Components	**Description**
CONS	Consultancy
HOSP	Hospital
FOOT	Foot Care
EYE	Eye Care
MNT	Medical Nutrition
EXE	Exercise
NPD	Neuropathy Detection

PAT	Pathology
MED	Medicine
DEDN	Diabetes Education

The experts were asked to rate the ten components for three criteria cost, control and connectivity on a scale of one to five, Table 4.2, Table 4.3 and Table 4.4:

Table 4. 2: First Expert's Score for the Criteria

Components	**Cost**	**Control**	**Connectivity**
CONS	1	1	2
HOSP	5	5	2
FOOT	1	1	4
EYE	2	2	2
MNT	3	3	3
EXE	2	2	2
NPD	4	4	4
PAT	4	4	4
MED	4	4	4
DEDN	2	2	2

Table 4. 3: Second Expert's Score for the Criteria

Components	**Cost**	**Control**	**Connectivity**
CONS	1	1	2
HOSP	4	4	4
FOOT	1	2	1
EYE	2	2	2
MNT	3	3	3
EXE	2	2	2
NPD	3	3	3
PAT	3	3	3
MED	3	3	3
DEDN	2	2	1

Table 4. 4: Third Expert's Score for the Criteria

Components	Cost	Control	Connectivity
CONS	2	2	2
HOSP	5	5	5
FOOT	1	1	1
EYE	2	2	2
MNT	3	3	3
EXE	2	2	2
NPD	4	4	4
PAT	4	4	4
MED	4	4	4
DEDN	2	2	2

The average of the score given by three experts; for the ten components, is listed in the performance table below (Table 4.5):

Table 4. 5: Performance Table (Raw Data)

Components	Cost	Control	Connectivity
CONS	1.33	1.33	2.0
HOSP	4.67	4.67	3.7
FOOT	1.00	1.33	2.0
EYE	2.00	2.00	2.0
MNT	3.00	3.00	3.0
EXE	2.00	2.00	2.0
NPD	3.67	3.67	3.7
PAT	3.67	3.67	3.7
MED	3.67	3.67	3.7
DEDN	2.00	2.00	1.7

In order to calculate the marginal utility function, the raw data need to be rescaled to make score between 0 and 1. The rescaling is achieved using following equation when maximizing the criterion:

$$f_j'(a_i) = \frac{f_j(a_i) - \min(f_j)}{\max(f_j) - \min(f_j)} \quad (4.4)$$

Or, when minimizing the criterion.

$$f_j'(a_i) = 1 + \frac{\min(f_j) - f_j(a_i)}{\max(f_j) - \min(f_j)} \quad (4.5)$$

The rescaled performance value is listed in the following Table-4.6:

Table 4. 6: Rescaled Performance Table

Components	**Cost**	**Control**	**Connectivity**
CONS	0.09	0.00	0.83
HOSP	1	1.00	0
FOOT	0	0.00	0.83
EYE	0.27	0.20	0.83
MNT	0.55	0.50	0.33
EXE	0.27	0.20	0.83
NPD	0.73	0.70	0
PAT	0.73	0.70	0
MED	0.73	0.70	0
DEDN	0.27	0.20	1

Using the values of above table Marginal utility values of the components were calculated. The marginal utility function used for cost and control is linear, while an exponential marginal utility score for the connectivity because the utility for the hospital distance increases rapidly after a critical distance. The marginal utility of the cost and control is taken as the values in rescaled performance table, while marginal utility for the connectivity is computed as follows:

$$U_3(a_j) = \frac{e^{f'_j(a_i)^2} - 1}{e - 1} \tag{4.6}$$

The marginal utility score for ten components on three criteria is calculated and listed in Table 4.7.

Table 4. 7: Marginal Utility Score for the Components

Components	Cost	Control	Connectivity
CONS	0.091	0	0.59
HOSP	1	1	0
FOOT	0	0	0.59
EYE	0.27	0.2	0.59
MNT	0.55	0.5	0.07
EXE	0.27	0.2	0.59
NPD	0.73	0.7	0
PAT	0.73	0.7	0
MED	0.73	0.7	0
DEDN	0.27	0.2	1.00

Criteria Weight:

For calculation of the weight of the criteria, the focus group was asked to rank the criteria. The Rank Reciprocal method was used to calculate the weight of the criteria (Table 4.8) (Sullivan, 1989).

Table 4. 8: Weight of Criteria

S.N.	Rank (R_i)	Weight=$\frac{1/R_i}{\sum_{i=1}^{n} 1/R_i}$
Cost	1	0.55
Control	2	0.27
Connectivity	3	0.18

The weighted sum of the utility (equation 4.2) gives us global utility score and ranking of the component and listed in Table 4.9. The component having lower global utility value are suitable for being kept at a remote location (nodes).Taking a utility score of 0.5 as the cut-off point, we conclude that Hospitalization, Neuropathy detection, Pathology, and Medicine (Pharmacy) should be kept at the central facility.

Table 4. 9: Global Utility Scores for Components

Components	CONS	HOSP	FOOT	EYE	MNT	EXE	NPD	PAT	MED	DEDN
Global Utility	0.16	**0.82**	0.11	0.31	0.45	0.31	**0.59**	**0.59**	**0.59**	0.38

For the second and third objective, we used focus group discussion and review of secondary data, to finalized thirteen locations (nodes) as initial consideration set for the central facility. The location of post offices, administrative wards, and sanitary wards was presented in front of focus group and opinion was invited. Google Map was used to find out the latitude and longitude of the thirteen nodes (Table 4.10). The population in each region was used to calculate the weight associated with the node.

Table 4. 10: Coordinates of Nodes

Nodes	Latitude	Longitude	Weight
Dashashwamedh	25.30678	83.01062	0.88286
Chetganj	25.32101	83.00146	0.70141
Sigra	25.31108	82.98644	1.12969
Kotwali	25.32453	83.01285	0.96735
Chowk	25.31441	83.00995	0.49878
Bhelupur	25.30397	82.99001	0.666
Khojwa	25.29378	82.9945	0.76921
Nagwa	25.28737	82.98376	1.27803
Sikraul	25.35824	82.98644	0.65202
Shivpur	25.35951	82.9515	0.92607
Nadesar	25.33479	82.98913	0.46711
Adampura	25.32625	83.02059	1.14023
Jaitpura	25.32783	83.01405	1.44385

Haversine distance

Once latitude and longitude of the thirteen location are known, the distance between various locations was calculated using the 'Haversine formula' the given points as follows:

$$D = Cos^{-1}(\mathrm{Sin}(\frac{\pi}{180} * \mathrm{lat\ 1}) * \mathrm{Sin}(\frac{\pi}{180} * \mathrm{lat\ 2}) + \mathrm{Cos}(\frac{\pi}{180} * \mathrm{lat\ 1}) * \mathrm{Cos}(\frac{\pi}{180} * \mathrm{lat2}) * \mathrm{Cos}(\frac{\pi}{180} * (\mathrm{long1} - \mathrm{long2}))) * \mathrm{R}; \tag{4.7}$$

D= Distance;

R= Radius of earth (6371 Km);

Coordinates: *(lat 1, long1)* and *(lat 2, long2*)

To find out the central facility location following problem was solved using Lingo 17.0 software. The code and output of Lingo is shown in Appendix B.

$$Z = Min\{ \sum W_i * \{Cos^{-1}(Sin(\frac{\pi}{180} * lat(i)) * Sin(\frac{\pi}{180} * lat) + Cos(\frac{\pi}{180} * lat(i)) * Cos(\frac{\pi}{180} * lat) * Cos(\frac{\pi}{180} * (long(i) - long))) * 6371\}\};$$

(4.8.1)

Subject to;

$$0 \leq lat \leq 30; \quad (4.8.2)$$

$$0 \leq long \leq 90; \quad (4.8.3)$$

4.1.2 Traveling Salesman Problem

Traveling Salesman Problem was used to find out Milk-Run route connecting central facility with remote locations (Nodes). For the mathematical formulation of the problem, the following notations were used (Laporte, 1992; Desrochers & Laporte, 1991, Achuthan, 1996).

Indices: Node 1 represents the central facility whereas the remaining nodes correspond to local /remote locations.

Nodes: i, j, k

Parameters:

N = Total number of nodes (the central facility is represented by node $i = 1$ and remote centers by $i = 2, 3 \ldots\ldots N$).

d_{ij} = Distance between node i and j, where node $i, j = 1$ denotes central facility $i, j = 2, 3 \ldots. N$ denotes remote locations and $d_{ii} = d_{jj} = 0$.

U_i = Sequence Number in which node i is visited for $i = 2, 3, 4 \ldots. N$ (Sequence number is the order in which the remote centers are visited so that the distance travelled is minimized).

Decision Variables

$$x_{ij} = \begin{cases} 1, & if\ vehicle\ travels\ from\ node\ i\ to\ node\ j \\ 0, & otherwise \end{cases}$$

Problem Formulation

Minimize $\sum_{i=1}^{N} \sum_{j=1}^{N} d_{ij}\ \ x_{ij}$ (4.9.1)

Subject to,

$\sum_{\substack{i=1 \\ i \neq k}}^{N} x_{ik} = 1, k = 1,2,3, .. N$

(4.9.2)

$\sum_{\substack{j=1 \\ j \neq k}}^{N} x_{kj} = 1, k = 1,2,3, .. N$ (4.9.3)

$x_{ij} = \{0,1\}$ (4.9.4)

$x_{ii} = 0, i = 1,2 \dots N$ (4.9.5)

$U_j \geq U_k + x_{kj} - (N-2) * \left(1 - x_{kj}\right) + (N-3) * x_{jk}$ (4.9.6)

$U_k \leq N - 1 - (N-2)x_{1k}$ (4.9.7)

$U_k \geq 1 + (N-2)x_{k1}$ (4.9.8)

For all k= {2,… ,n}

This objective function (4.9.1) stands for the total distance traveled by the vehicle in a Milk-Run. The objective of the research is to minimize this distance traveled. Constraint (4.9.2) ensures that the vehicle should come from one and only one node. Constraint (4.9.3) is to take care that a vehicle reaching a node must go to some other node. It basically takes care of flow conservation meaning that a vehicle arriving at a node has to leave it definitely. Constraint (4.9.4) defines the nature of decision variables involved that is binary in nature. Constraint (4.9.5) defines that no vehicle can travel inside a particular node area. Constraint (4.9.6) is a subtour elimination constraint it eliminated all the subtour not involving node 1.If we have a subtour involving 1 then there has to be another subtour not involving 1. But since all the subtour not involving 1 has been eliminated, there exits just one full tour. Constraint (4.9.7) and Constraint (4.9.8) is just used to ensure that we know the first and last stop.

Lingo 17.0 tool was used to solve the objective functions to get the central facility location and Milk-Run route.

4.2 Results & Discussion

For taking the decision of decentralization of the components, the Global Utility Value listed in Table-4.7 is sorted and the component having higher value was recommended as a suitable one for being kept at the central facility only. A Global Utility Value of 0.5 was used as the cut-off for the classification of the components (Table-4.11).

Table 4. 11: Components at Central Facility

Central Facility Only	**Remote Facility**
Hospitalisation, Neuropathy Detection, Pathology, Pharmacy	Consultancy, Foot Care, Eye Care, Exercise and Diabetes Education, Medical Nutrition Therapy,

As the results of the study suggest, the components like hospitalization, neuropathy detection, pathology, and pharmacy should be kept at the central facility.

For determining the location of the central facility Non-Linear Programming method was used to solve the optimization problem (4.8.1). The two nonlinear variable used in the model are latitude and longitude of the central facility location. The latitude and longitude of the central facility were found as 25.31931 and 83.00276 respectively. The coordinate of the central facility is depicted in the figure below (Figure 4.3).

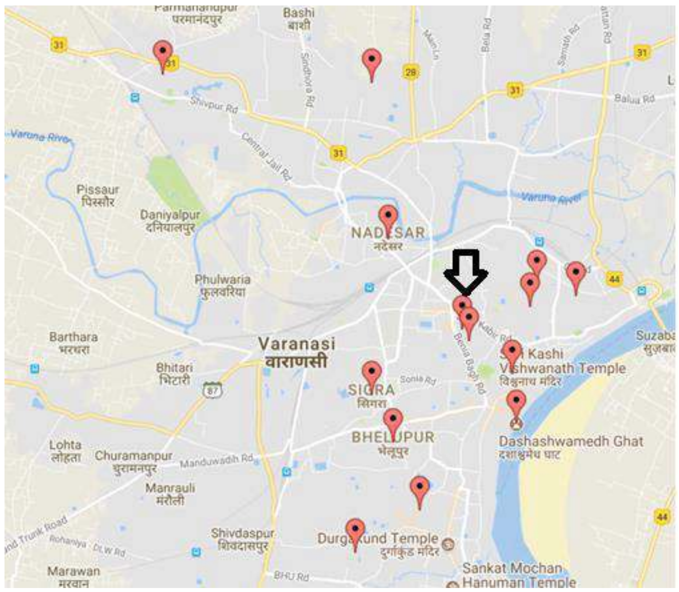

Figure 4. 3: Coordinates of Location and Central Facility

From the above figure, we can infer that the central facility for the diabetes management should be planned near Chetganj at Beniabag road connecting Vidyapeeth to Kashi Vishwanath Temple. The straight line distance between Chetganj and the optimal solution is 0.23 Kilo Meter only. Hence, we have shifted the central facility at Chetganj and removed the corresponding node. Table-4.12 below lists the distance between various nodes and a central facility for further calculation of Milk-Run.

Table 4. 12: Distance Matrix for Various Nodes

D\S	Chetganj	Dashashwamedh	Sigra	Kotwali	Chowk	Bhelupur	Khojwa	Nagwa	Sikraul	Shivpur	Nadesar	Adampura	Jaitpura
Chetganj	0	3	3.7	2	9.3	4.7	6	6.3	6.6	6.5	2.4	3	2.5
Dashashwamedh	2.1	0	3	2.3	1	3.2	3.3	5.5	8.5	10	4.2	3	2.9
Sigra	2.6	3	0	4.6	2.7	1.6	3.4	5.2	8	9.3	3.3	6.4	6.4
Kotwali	2	2.3	4.6	0	1.6	4.5	4.9	7.1	7.3	8.9	3.6	0.95	0.75
Chowk	1.8	1	2.7	1.6	0	3	3.4	5.7	8.1	9.7	3.9	2.2	2.2
Bhelupur	3.1	2.7	1.6	5.7	3	0	2.6	5.2	9	9.7	4.4	7.4	7.4
Khojwa	3.9	3.3	3.4	4.9	3.4	2.6	0	1.5	10.5	11.1	5.8	8.9	7.6
Nagwa	5.2	5.5	5.2	7.1	5.7	5.2	1.5	0	13	13.6	8.3	11.4	11.4
Sikraul	5.8	8.5	9.5	7.3	8.1	9	10.5	12.9	0	5.2	4.9	8.2	8.2
Shivpur	7.5	10	9.3	8.9	9.7	10.3	11.1	13.6	5.2	0	6.3	9.8	9.8
Nadesar	2.4	4.2	3.3	3.6	3.9	4.4	5.8	9.5	4.9	4.9	0	4.5	4.6
Adampura	2.6	3	6.4	0.95	2.2	7.4	5.7	12.6	8.2	9.7	4.4	0	0.9
Jaitpura	2.5	2.9	6.4	0.95	2.2	7.4	7.6	11.3	8.2	9.8	4.4	0.9	0

Solving the Travelling Salesman Problem (equation 4.9.1 to 4.9.8) we get the following sequence of the nodes: 1-4-13-12-5-2-8-7-6-3-11-10-9.

Sequence of the nodes traveled during Milk-Run: Chetganj-Kotwali-Jaitpura-Adampura-Chowk- Dashashwamedh-Nagwa-Khojwan-Bhelupur-Sigra-Nadesar-Shivpur-Sikraul

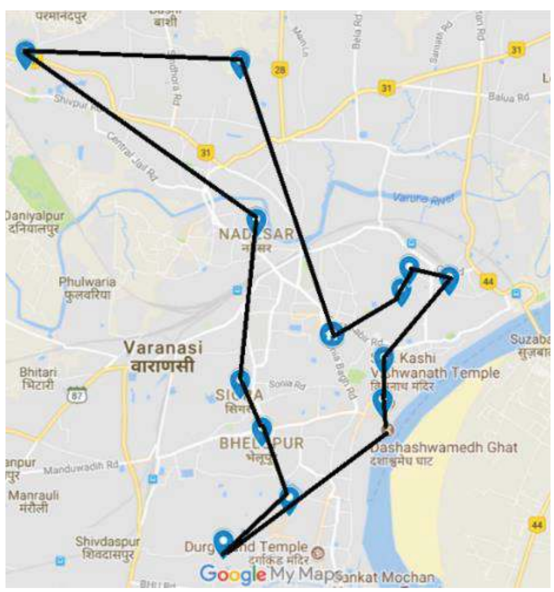

Figure 4. 4: Milk-Run Route for Vehicle

The figure-4.4 depicts the Milk-Run route for the vehicle connecting central facility with remote locations.

4.3 Conclusion

There is evidence of diabetes becoming a major healthcare challenge in India. The chronic nature of the disease makes the economic burden of disease humongous. Since the diabetes is a state having a risk of multiple complications, its management has various components like doctor's consultation, exercise, diet consultation, foot care, eye care, diabetes education, lab investigation, and medical prescription. Providing all these components of diabetes management at every location increases the cost of care.

This study classifies the components of diabetes management in two categories namely "central facility only" and "remote facility". There is an assumption that this classification will result in better utilization of resources hence reduced the cost of care. To make these facilities available to the residents of the city study identifies a central facility and then plan a Mil-Run to connect central facility with remote locations (nodes).This research is first of its kind and provides an approach for facility planning in case of a chronic disease like diabetes. Although the study is done for diabetes management it can be easily adapted for other chronic care like respiratory disease, HIV, and Tuberculosis.

4.4 Future Directions

This study discusses the decentralization of the diabetes care but doesn't talk about the agility of this remote facility in managing the emergencies or referring the patients to the central facility. There is also need of prioritizing the resources allocation for the critical components of diabetes care. The next chapter discusses the selection of supply chain strategy for different supply categories of diabetes care.