Designing Allocation Boundary for Organ Transplantation in India

IE 709 Project Report

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Contents

Abstract

Main purpose of our study is to allocate districts to nearest OPOs. Whole study is carried out on hospitals in India which are approved for organ transplantation. Major constraint in model is that a district should be allocated to only one OPO and it should be reachable within available time. Two models are presented: **model 1** is allocating districts to only existing OPOs and **model 2** gives new locations where an OPO can be established in order to optimize our objective value. We used optimization library of python called ***pulp*** for solving both the models. From our model suggested locations for new OPO are observed as East Godavari (A.P.), Sivasagar (Assam), Bhagalpur (Bihar), Janjgir-Champa (Chhatisgarh) and Jaunpur (U.P.).

1 Introduction

Among the different kinds of facility problems, health care location has an important role in maximizing the people benefit or minimizing the cost. There are many studies which deals with allocation of facilities, like *Ghane et.al., 2018* [1] presented a study on stochastic optimization approach to a location and allocation of organ transplant centers. The main contribution of this study was to consider recipient regions as another component of the supply chain; inaddition, importance of transportation time and waiting lists has led to a bi-objective model. And uncertainty of input data has led to consider a stochastic approach. *Rajmohan et.al., 2017* [2] also studied about facility location OPOs in india. Initially, the demand or the population density of organ recipients with respect to particular location is recognized. Then, based on the p-median model, the location of Organ Procurement Organisation (OPO) is effectively identified. Experimental analysis proves that the proposed model performs well in facilitating the location of OPOs. The robustness of the proposed work is validated using a sensitivity analysis of the differences in the selection of OPOs when the estimated demand for organs varies. The study of *Koizumi et.al., 2014* [3] has applied mathematical programming to construct alternative liver allocation boundaries that ensure to achieve more geographic fairness in access to transplants that occurs in any system. *Kong et.al., 2002* [4] considered the effect of region design on total expected intra-regional liver transplants and formulated it as a set partitioning problem in which OPOs were considered as nodes and arc joined two contiguous OPOs. Also the model was designed by considering a decay function (of life of organ) based on distance.
In our study, we worked on data for:

- Hospitals in India which are approved for organ transplantation and
- All districts in india.

And, our aim is to allocate districts to nearest OPO (Here OPO is considered as hospitals which are actually selected in order to throw an optimal result) in order to minimize weighted distance, where weight means population of all districts and assumed that more the population more will be the organ transplantation requirement. Hospitals which are selected as an OPO are considered as node and districts as demand points. Another mathematical model is also given which gives recommendation about where to locate new OPOs in order to have optimal solution. Second model is required because there are some states in which approved hospitals are very few, hence they cannot serve people efficiently.
Following is the data of number of transplantation in from 1980 to 2018 as per [5]:

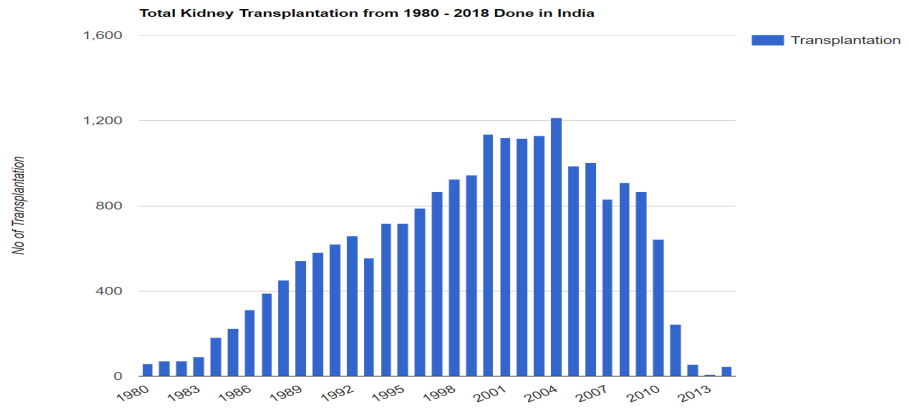

Figure 1: Showing number of kidney transplantation in India between 1980-2018

2 Methodology

Given a set of Transplant Centers (TC) (say n) and set of districts in India (say m) with their population. In our case n = 176 and m = 651. Our main intention is to find group of districts which can be covered by using existing TC in available time (threshold) and their allocation in order to minimize weighted distance[1] between them.
Let I be the set of all districts (demand points) in India and $I = \{1, 2, ..., m\}$ and J be the set of all transplant centers (facilities) and $J = \{1, 2, ..., n\}$.

$$x_j = \begin{cases} 1, & \text{if TC } j \text{ is selected as OPO} \qquad \forall j \in J \\ 0, & \text{otherwise} \end{cases}$$

$$y_{ij} = \begin{cases} 1, & \text{if district } i \text{ is covered by OPO } j \qquad \forall i \in I, j \in J \\ 0, & \text{otherwise} \end{cases}$$

$$Z_{ik} = \begin{cases} 1, & \text{if district } i \text{ belongs to new OPO } k \qquad \forall k \in I \\ 0, & \text{otherwise} \end{cases}$$

$$N_k = \begin{cases} 1, & \text{if location } k \text{ is selected as new OPO} \qquad \forall k \in I \\ 0, & \text{otherwise} \end{cases}$$

$$T_{ij} = \begin{cases} 1, & \text{if } i^{th} \text{ district is reachable from } j^{th} \text{ OPO in available time} \\ 0, & \text{otherwise} \end{cases}$$

$$T_{ik} = \begin{cases} 1, & \text{if } i^{th} \text{ district is reachable from new OPO } k \text{ in available time} \\ 0, & \text{otherwise} \end{cases}$$

W_i = population of district $i \in I$.
D_{ij} = Distance between i^{th} district and j^{th} OPO.
D_{ik} = Distance between i^{th} district and new OPO k.

2.1 Mathematical Models

2.1.1 Assumptions

1. All approved hospitals (for organ transplantation) functions as TC as well as organ retrieval center.

2. We considered transportation only through roadways. And speed of organ transporting vehicle is uniform and equal to 80 *kmph*.

3. Total population [7] of city/district is taken into consideration as weight.

4. Here all transplant centers (Approved Hospitals [8]) are considered as facility and districts as demand points.

[1]We used optimization library of python called ***pulp*** and the distance calculation from one node to other node is done by using python library ***geopy*** (by latitude and longitude [6]).

5. Available time = CIT[2] - (Procurement time + transplantation time). Here CIT of liver [9] is considered, as it is less than CIT of kidney, hence model will work efficiently for both.
6. Every district is covered by any one of the OPO.
7. New OPO should be suggested to build in any of the district only.

2.1.2 Model 1

$$\min \sum_{i \in I} \sum_{j \in J} W_i D_{ij} y_{ij} \tag{1}$$

subjected to

$$\sum_{j \in J} y_{ij} = 1 \qquad \forall i \in I \tag{2}$$

$$y_{ij} - x_j \leq 0 \qquad \forall i \in I, j \in J \tag{3}$$

$$y_{ij} \leq T_{ij} \qquad \forall i \in I, j \in J \tag{4}$$

The above model ensure minimization of distances (weighted) that a patient have to travel in order to get organ transplant. Constraint (2) shows that one district can belong to region of any one OPO only. Constraint (3) make sure that a district should belongs to a hospital which is actually selected as an OPO. Constraint (4) guarantees that if a district belong to any OPO it should be covered in available time.

2.1.3 Model 2

$$\min \sum_{i \in I} \sum_{j \in J} W_i D_{ij} y_{ij} + \sum_{i \in I} \sum_{k \in K} W_i D_{ik} Z_{ik} \tag{5}$$

subjected to

$$\sum_{j \in J} y_{ij} + \sum_{k \in I} Z_{ik} = 1 \qquad \forall\ i \in I \tag{6}$$

$$y_{ij} - x_j \leq 0 \qquad \forall\ i \in I, j \in J \tag{7}$$

$$Z_{ik} - N_k \leq 0 \qquad \forall\ i \in I, k \in I \tag{8}$$

$$y_{ij} \leq T_{ij} \qquad \forall\ i \in I, j \in J \tag{9}$$

$$Z_{ik} \leq T_{ik} \qquad \forall\ i \in I, k \in I \tag{10}$$

$$\sum_{k \in I} N_k = 5 \tag{11}$$

In model 2 also objective function is ensuring minimization of distance (weighted) but also selecting extra five locations (other than already existing hospitals) that can be recommended in order to get more optimal value as compare to optimal value observed in model 1. Constraint (6) make sure that any district should only be covered by exactly any one of the OPO (*i.e.* either by one of the OPO from existing ones or from the new ones). Constraint (7) make sure that a district should belongs to a hospital which is actually selected as an OPO (from existing hospitals). Constraint (8) make sure that a district should belongs to a newly suggested OPO. Constraint (9) guarantees that if a district belong to any existing OPO it should be covered in available time. Constraint (10) guarantees that if a district belong to any new OPO it should be covered in available time. Constraint (11) is for number of new OPOs required.

[2]Time from when blood stops flowing to the donor organ until the time when the recipient's blood starts flowing to it. CIT (in hrs) for Liver is 8 - 12 and for kindey is 24 - 36.

3 Result and discussion

As we discussed earlier that all district are considered as demand points and TCs are considered as facility. In our problem we allocate each district to one transplant center according to the population and distance between them.

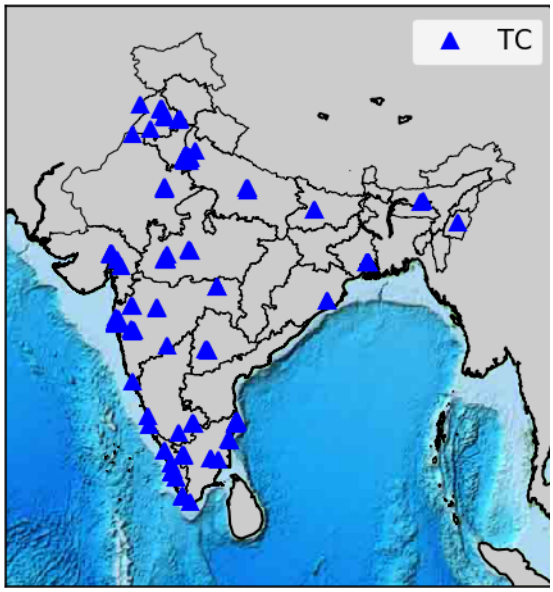

Figure 2: Location of all Approved Hospitals (TCs) in India

Above Figure[2] shows the location of already existing transplant centers in India. We can observe that in states like chhattisgarh, Jharkhand, Andhra Pradesh and most of the North East states are not having transplant centers.
After solving the Model 1, results obtained is as shown in figure[3]. And in figure group of same color of legends represents group of districts belongs to region of any particular OPO.

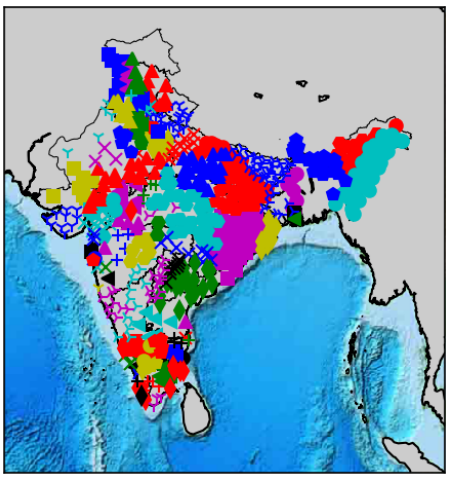

Figure 3: Allocation of district to nearest OPO

Table[1] show some of the OPOs and the districts assigned to it. It is clear that allocation of district to OPO is not uniform *i.e.* some OPOs are assigned with more number of district and some are with less. This imbalance of allocation is due to the reason that some of the states are not having transplant center for *e.g.* Chhattisgarh.

Table 1: Districts covered by OPOs

Hospital Name	**Districts**
Apollo Gleneagles Hospital Ltd Kolkata, West Bengal	Dakshin,Dinajpur,Hooghly,Malda, Murshidabad , Nadia, NorthParganas, ,Pakur
MGM Hospital Aurangabad, Maharashtra	Ahmednagar,Dhule,Jalgaon, Aurangabad
Wockhardt Hospitals Mumbai, Maharashtra	Amreli,Botad,Devbhoomi ,GirSomnath, Jamnagar,Junagadh , Morbi, Porbandar,Rajkot,Surendranagar
Apollo Hospitals Bhubaneswar, Odisha	Srikakulam, Visakhapatnam ,Korba ,Mahasamund , Raigarh , Angul,Boudh,Balangir,Bargar,Debagarh, Dhenkanal ,Ganjam,Gajapati,Jharsuguda,Kendujhar, Kalahandi , Kandhamal , Koraput,Nabarangpur, Nuapada,Nayagarh ,Rayagada,Sambalpur, Subarnapur,Sundergarh,PaschimSinghbhum,Simdega
NIMS Hospital Jaipur,Rajasthan	Churu ,Jaipur,Jhunjhunu,Sikar
SRS Hospital Bhopal, MP	Jhansi(UP),Lalitpur(UP) ,Sagar ,Bhopal,Vidisha , Tikamgarh ,Raisen,Katni,Damoh

To find the optimal location for opening new OPOs in addition to the existing transplant centers, we used **Model 2**.

Results Model 2 are as follows:

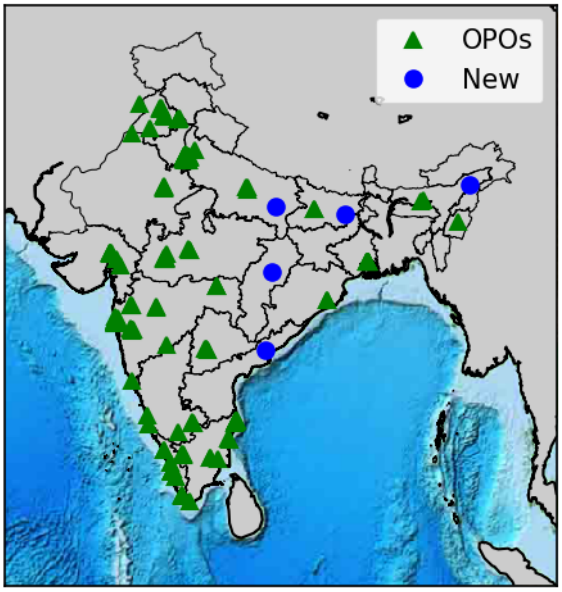

Figure 4: New OPO location with existing system.

Selected districts as the new location for OPO:

1. East Godavari,AP
2. Sivasagar,Assam
3. Bhagalpur,Bihar
4. Janjgir-Champa,Chhatisgarh
5. Jaunpur,UP

The result of Model 2 is intuitive, because as discussed earlier there is no transplant center in Chhatisgarh and A.P. Hence, it is obvious to have a new OPO located in any of the district in these states and other location of new OPO are reasonable because of more population, like in U.P. and Bihar. One can think that district in western Rajasthan should be the potential location for new OPO, but our objective function considers the population of district also, hence because of their low population these districts are not selected for new OPO location .

Objective value with the existing system of OPO (by model 1) is $Z = 138556554318.07944$ (this values show the total weighted distance between the TC and districts). After locating the new OPOs (by Model 2) objective value is $\hat{Z} = 114305208409.3736$. This shows that total weighted distance reduced significantly as clear from the difference of optimal values. $(Z - \hat{Z})$ =24251345908.70584).

Table 2: New location of OPOs and districts covered by them

Location for New OPO	**Districts covered by the new OPO**
East Godavari (AP)	East Godavari, Guntur, Krishna, Srikakulam, Visakhapatnam, West Godavari, Bastar, Bijapur, Bijapur, Dantewada, Kondagaon, Kondagaon, Sukma, Koraput, Malkangiri, Nabarangpur, Bhadradri Kothagudem
Sivasagar (Assam)	East Kameng, Papum Pare, Kurung, Kumey, Lower Subansir, Lower Subansiri, Upper subansiri, West Siang, East Siang, Siang, Lower Dibang Valley, Upper Dibang Valley, Anjaw, Lohit, Namsai,Changlang, Tirap, Longding, Kamle, Biswanath, Dhemaji, Dibrugarh, Golaghat, Jorhat, Karbi Anglong, Lakhimpur, Majuli, Sivasagar, ,Kiphire,Longleng , Mokokchung, Mon , Tuensang, Wokha, Zunheboto ,Zunheboto, Noklak.
Bhagalpur (Bihar)	Araria, Banka, Begusarai, Bhagalpur , Jamui, Khagaria, Kishanganj, Katihar, Lakhisarai, Lakhisarai, Munger, Madhepura , purnia, Saharsa Supaul,East sikkim, north sikkim, south sikkim, west sikkim, darjeeling , uttar dinajpur, jalpaiguri, kalimpong, malda, Dhanbad, Giridih , Bokaro, Deoghar, Godda,Sahibgnaj, Pakur, Jamtara
Janjgir-Champa (Chhatisgarh)	baloda, Balrampur,Bemetara, Bilaspur, Dhamtari, Durg, Gariaband, Janjgir-Champa, Jashpur, Kabirdham, Kanker, Korba, Koriya, Mahasamund,Mungeli ,Raigarh, Raipur, Rajnandgaon, Surajpur, Surguja, Balangir, Bargar, Jharsuguda, Kalahandi,Sambalpur, Sundergarh ,Katn, Shahdol, Anuppur, Dindori,Umaria, Gumla, Simdega
Jaunpur (UP)	Kaimur, Allahabad, Azamgarh, Basti, Chandauli, Chitrakoot, Deoria, Ghazipur, Gorakhpur, Jaunpur, Kaushambi, ,Kushinagar, Mau, Maharajganj,Mirzapur, Pratapgarh, Siddharthnagar, Sonbhadra, Bhadohi, Sultanpur,Varanasi,Khalilabad ,Rewa, Satna, Singrauli, Garhwa

Table [2] shows the districts covered by the new OPOs (that are result from the Model 2). All the districts of Arunachal Pradesh, Nagaland and some districts of Assam covered by the new location Sivasagar (Assam), Janjgir-Champa (Chhatisgarh) covers most of the districts of Chhatisgarh and East Godavari (AP) covers most of the districts of A.P. .

Bibliography

[1] Mahshid Ghane and Reza Tavakkoli-Moghaddam. A stochastic optimization approach to a location-allocation problem of organ transplant centers. *Journal of Optimization in Industrial Engineering*, 11(1):103–111, 2018.

[2] M Rajmohan, C Theophilus, MR Sumalatha, and S Saravanakumar. Facility location of organ procurement organisations in indian health care supply chain management. *South African Journal of Industrial Engineering*, 28(1):90–102, 2017.

[3] Naoru Koizumi, Rajesh Ganesan, Monica Gentili, Chun-Hung Chen, Nigel Waters, Debasree DasGupta, Dennis Nicholas, Amit Patel, Divya Srinivasan, and Keith Melancon. Redesigning organ allocation boundaries for liver transplantation in the united states. In *Proceedings of the International Conference on Health Care Systems Engineering*, pages 15–27. Springer, 2014.

[4] Nan Kong, Steven Shechter, Andrew J Schaefer, and James E Stahl. Organ transplantation regions: The need for optimization. In *IIE Annual Conference. Proceedings*, page 1. Institute of Industrial and Systems Engineers (IISE), 2002.

[5] `http://transplantindia.com/Reports/Fasttrack-TotalTransplantionReport.aspx`, 2018. [Online; accessed 29-April-2018].

[6] For finding out the latitude and longitude of all tc/rc and districts, we used following site. `http://www.latlong.net`. [Online; accessed 18-April-2018].

[7] Population for all city/district are taken from wikipedia (which was as per 2011 census). `https://en.wikipedia.org/wiki/List_of_districts_in_India`. [Online; accessed 18-April-2018].

[8] Approved hospitals list (tc/rc) is taken from site of national organ and tissue transplant organisation(notto).

[9] For cold ischemia time of organs. `https://optn.transplant.hrsa.gov`. [Online; accessed 18-April-2018].