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The Multi-period Location-allocation Problem of Engineering Emergency Blood Supply Systems

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Abstract

Unconventional incidents bring great influence to human life, of which the most destructive is earthquake. Blood is a special resource for lives, especially in a big earthquake, in which there will be a sudden increase in demand for blood, therefore sufficient and safe blood supply is a huge challenge. In this paper, we propose an emergency blood supply scheduling model. Providing decision support for the scheduling of engineering emergency blood supply. We propose a multi-period location - allocation model, and give the heuristic algorithm based on Lagrangian relaxation. Finally, give an example case study in the context of Beijing.

Keywords: Multi-period location-allocation; Lagrangian relaxation; Engineering; Emergency blood supply

1. Introduction

Unconventional incidents bring great influence to human life, of which the most destructive is earthquake. From the 2008 WenChuan earthquake and the 2011 Japan earthquake, it can be perceived that the occurrence of unexpected events is a great test to rescue and protection system of human society, in which medical treatment of high-level and high response rate is effective to reduce damages caused by incidents.

In the process of Aid after WenChuan earthquake, the supply and management of blood have a number of problems: 1. China's current laws rule a unified management of blood, a unified blood collection and a unified blood supply. However, there is no specified cross-regional blood scheduling requirements, even in exceptional circumstances, it should be approved by the health authorities, its timeliness can't meet the needs of wounded. 2. The blood sources of the cross-regional scheduling is various, it is hard to ensure the quality of the blood. 3. In the aftermath of the earthquake, citizens will have the unprecedented warmth to denote blood, likely to cause waste, for example, 5.12 Wenchuan earthquake, May 14, the blood inventory reached 20,000 U, caused a great deal of pressure on the reserves, So on May 25, the blood collection is suspended, to digest the blood inventory, the blood scheduling among these collection points is started. "The best place to store the blood is donors 'body, blood centres should find a balance between bloods donate and the inventory, the extensive blood collection will lead to subsequent hematic barren." Because of Wenchuan earthquake, Beijing Olympic Games and other major events in 2008, hematic barren emerged across the country in 2009. Therefore, in any emergency relief stage, we must have

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sufficient blood to ensure the blood needs in medical assistance, but also cherish the blood to avoid the waste caused by excessive storage.

In order to maximize the value of the blood resources within the jurisdiction, it is necessary to develop the scientific program of blood collection, storage, planning and distribution plan. Emergency blood supply process is shown as follows:

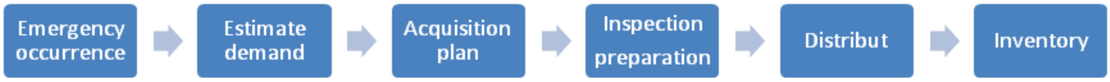

Fig.1 Emergency blood supply process

At different period of the injury, the demand for blood is different, while the temporary facilities can move for the different position of blood donators, so our model is based on the multi-period to meet the needs of disaster relief at different period. Blood collection planning includes how to choose the sitting of temporary blood facilities and how to handle appointment, arrangement and blood volume of the blood donator. According to China's relevant policies, the required blood tests should be done by the Blood Centre, which requires the unity of transportation of the blood obtained by the temporary blood collection points to the Blood Centre. Our goal is to make transport distance minimal, while the cover as much blood donors as possible. This is a multi-period dynamic location problem; the sub-problem is how to distribution problem to meet the demands.

The rest of the article is organized as follows. Section 2 provides a review of disaster management literature with emergency blood supply and dynamic location-allocation aspects. In Section 3, we present multi-period location-allocation model and normalized linear model. In Section 4 we develop a Lagrangean relaxation to get lower bounds on our formulation. Finally, we present a case study for potential earthquakes in Beijing in Section 5.

2. Literature review

For the supply of blood in disaster: Yongming Zhu, etc., Anli Li, etc. [1,2] Some scholars analyzed respectively the blood management system of the United States, Canada and other countries ; based on the 2008 earthquake, Daguo [3] analyzed inventory management during the blood scheduling; Hao Yan [4], Bin Song [5] and other medical workers, witnessed the blood supply in the disaster area, from a practical point of view, they pointed out the shortcomings and deficiencies of blood security in an earthquake, proposed the emergency blood supply method. These articles are the qualitative analysis, summed up the system and experience, no practical solution and the actual situation. And there is no scholars with Quantitative point of view to give a reasonable solution can help decision-making.

Our model is the location - allocation problem essentially, the general form is similar to the P-median problem, first raised by Curry and Skeith [6]. Wesolowsky and Truscott [7] studied the location and distribution problem of the multi-stage, and used the Bender decomposition method to solve the distribution centre location problem. Marianov and Serra D [8] studied multi-service centre location - allocation problem constrained by the wait or queuing time. Luce Brotcorne, Gilbert Laporte and Frederic Semet [9] made a summary of the status the location and distribution problem in the context of ambulance.

There is not only uncertainty, but also dynamics in the real world, so dynamic model is more accurate to reflect the actual problem, of course, taking into account dynamic factors it will inevitably increase the complexity of the model and solving difficulty. Dynamic location problem is the study of the best sitting of service station during some periods of time of the future, in a different period the dynamic model parameter values are different, but in a specific period of time, the model parameters are unique. AJScott [10] studied a multi-stage facility location - allocation problem, and applied myopic algorithm (myopic algorithm) to solve it. CSTapiero [11] studied the dynamic location - allocation model constrained by the cost of transport and the capacity of service stations. Maria [12] studied the dynamics location problem of the incremental facilities. G. Gunawardane [13] created a dynamic set covering problem and the maximum coverage problem model in the study of the sitting of public facilities, taking into account the future coverage of a number of time periods.

For this particular medical supply of blood, its multi-period location - allocation problem, has its own particularity. Our model not only for emergency blood supply, but also can be applied to practical location-allocation problem like prevention, vaccinations etc. with area management features, and multi-period covering issues.

3. A mathematical programming formulation of dynamic multi-period location-distribution problem

In this section we present the formal description of dynamic multi-period location-distribution problem. This model looks for the location and assignment decisions, over a given planning horizon, that lead to the minimization of the total operation costs. The modeling hypotheses T is the set of time periods, indexed by $t \in T$ .Each period t is only include the time of blood collection, the time of temporary blood facilities change between two working periods. The beginning of both periods, the temporary blood facilities have been finished to move. This is in line with the actual situation, some works have working hours during the day, and evening time for moving and equipment installation.

To simplify the mathematical formulation of our problem we use the following notation:

I : set of blood donators, indexed by $i \in I$,

J : set of possible locations of temporary blood facilities, indexed by $j \in J$,

N :set of Blood Centres, $n \in N$

R : matrix for describing the distance between the blood donators and possible locations, indexed by $r_{ij} \in R$,

r : coverage radius of temporary blood facilities, if $r_{ij} \le r$, i is covered by j ,

C_1 : matrix of the cost of transportation from possible locations to Blood Centre, c^t_{jn} is cost of transportation possible locations j to Blood Centre n .

C_2 : matrix of the cost of moving between the possible locations $c_{j_1 j_2}$ is cost of moving from j_1 to j_2 .

C_3 : penalty cost matrix of failing to meet the demands, c is unit penalty cost for failing to meet the demands.

We assume the time period 0 is the origination state, and this time period moving cost matrix is zero, so the temporary blood points in time can be set at any position.

P : total number of temporary blood facilities,

d_0 : the capacity of each blood facilities,

For each period $t \in T$,define：

D^t : total demands at time period t .

For each blood donator groups, define:

d_i : the blood supply volume of blood donator groups i ,.

We define the following decision variables:

$$x^t_{ij} = \begin{cases} 1 & \textit{if blood donator groups i is assigned to possible location } \text{point } j \textit{ at time period } t, \\ 0 & \textit{otherwise,} \end{cases}$$

$$y^t_{j_1 j_2} = \begin{cases} 1 & \textit{if a facility is assigned to } j_1 \textit{ in period } t-1, \textit{and moves to } j_2 \textit{ in period } t, \\ 0 & \textit{otherwise,} \end{cases}$$

d^t_{ij} : possible location point j collect the blood volume from blood donator groups i at period t .

Using these conventions, the mathematical formulation is on the next page.

(1) is the objective function, for minimization of transportation costs, moving costs and the punishment cost or inventory cost. If $D^t - \sum_{i=1}^{I}\sum_{j=1}^{J} x^t_{ij} d^t_{ij}$ is positive, it means costs from inadequate supply. If $D^t - \sum_{i=1}^{I}\sum_{j=1}^{J} x^t_{ij} d^t_{ij}$ is negative, it means costs from the redundancy.first sets of constraints (2) ensure the arrival point at most one point; constraints (3) ensure that the departure point is only, and if and only if there is a facility in the point of departure will occur a facility move. Constraints (4) guarantee that there are always P facilities at work in any period.

Constraint (5) ensures the fact that the blood donors are only assigned to the temporary point has facilities. Constraint (6) is blood donor groups' capacity constraint. Constraint (7) and constraint (8), respectively for blood facilities capacity constraints, while the supply required meeting the plan at each time period. Constraint (9) to meet certain coverage. (10) (11) (12) define the variable.

$$\min \quad \sum_{t=1}^{T}\sum_{j_1=1}^{J}\sum_{j_2=1}^{J}\sum_{n}^{N} y_{j_1j_2}^{t} c_{j_2n} + \sum_{t=2}^{T}\sum_{j_1=1}^{J}\sum_{j_2=1}^{J} y_{j_1j_2}^{t} c_{j_1j_2} + \sum_{t=1}^{T}\left| D^t - \sum_{i=1}^{I}\sum_{j=1}^{J} x_{ij}^{t} d_{ij}^{t} \right| c \qquad (1)$$

$$s.t. \quad \sum_{j_1=1}^{J} y_{j_1j_2}^{t} \le 1 \qquad \forall j_2 \in J, \forall t \in T, \qquad (2)$$

$$\sum_{j_2=1}^{J} y_{j_1j_2}^{t} \le \sum_{j=1}^{J} y_{jj_1}^{t-1} \qquad \forall j_1 \in J, \forall t \in T, \qquad (3)$$

$$\sum_{j_1=1}^{J}\sum_{j_2=1}^{J} y_{j_1j_2}^{t} = P \qquad \forall t \in T, \qquad (4)$$

$$x_{ij}^{t} \le \sum_{j_1=1}^{J} y_{j_1j}^{t} \qquad \forall j_1 \in J, \forall t \in T, \qquad (5)$$

$$x_{ij}^{t} r_{ij} \le r \qquad \forall j \in J, \forall i \in I, \qquad (6)$$

$$\sum_{t=1}^{T}\sum_{j=1}^{J} x_{ij}^{t} d_{ij}^{t} \le d_i \qquad \forall i \in I, \qquad (7)$$

$$\sum_{i=1}^{I} x_{ij}^{t} d_{ij}^{t} \le d_0 \qquad \forall j \in J, \forall t \in T, \qquad (8)$$

$$\sum_{i=1}^{I} \operatorname{sgn}\left(\sum_{t=1}^{T}\sum_{j=1}^{J} d_{ij}^{t}\right) \ge \alpha \left| I \right| \qquad (9)$$

$$x_{ij}^{t} \in \{0,1\} \qquad \forall i \in I, \forall j \in J, \forall t \in T, \qquad (10)$$

$$y_{j_1j_2}^{t} \in \{0,1\} \qquad \forall j_1 \in J, \forall j_2 \in J, \forall t \in T, \qquad (11)$$

$$d_{ij}^{t} \ge 0 \qquad \forall i \in I, \forall j \in J, \forall t \in T. \qquad (12)$$

3.1 Transformed intoa linear programming model

We can see that the original model is non-linear model. We let

$$l_{ij}^{t} = d_{ij}^{t} x_{ij}^{t} \qquad \forall i \in I, \forall j \in J, \forall t \in T$$

Into the original model, the objective function becomes

$$\min \quad \sum_{t=1}^{T}\sum_{j_1=1}^{J}\sum_{j_2=1}^{J}\sum_{n}^{N} y_{j_1j_2}^{t} c_{j_2n} + \sum_{t=2}^{T}\sum_{j_1=1}^{J}\sum_{j_2=1}^{J} y_{j_1j_2}^{t} c_{j_1j_2} + \sum_{t=1}^{T}\left| D^t - \sum_{i=1}^{I}\sum_{j=1}^{J} l_{ij}^{t} \right| c \qquad (13)$$

And original constraint (7) and (8) change to linear constraint:

$$\sum_{t=1}^{T}\sum_{j=1}^{J} l_{ij}^{t} \le d_i \qquad \forall i \in I, \qquad (14)$$

$$\sum_{i=1}^{I} l_{ij}^{t} \le d_0 \qquad \forall j \in J, \forall t \in T, \qquad (15)$$

Further simplify the model, we define two new variables:

$$a_{ij} = \begin{cases} 1, & if \quad r_{ij} \le r \\ 0 & otherwise \end{cases}$$

For the normalized distribution deal to l_{ij}^t, defined

$$z_{ij}^t = l_{ij}^t / d_{ij}^t = (d_{ij}^t / d_i) x_{ij}^t \qquad \forall i \in I, \forall j \in J, \forall t \in T$$

Obviously, if possible location points j has not facilities, $z_{ij}^t = 0$, $z_{ij}^t \in [0,1]$.

We can prove the original problem is equivalent to the following model

$$\min \sum_{t=1}^{T}\sum_{j_1=1}^{J}\sum_{j_2=1}^{J} y_{j_1 j_2}^t c_{j_2} + \sum_{t=2}^{T}\sum_{j_1=1}^{J}\sum_{j_2=1}^{J} y_{j_1 j_2}^t c_{j_1 j_2} + \sum_{t=1}^{T}\left| D^t - \sum_{i=1}^{I}\sum_{j=1}^{J} z_{ij}^t d_i \right| c \tag{16}$$

$$s.t. \quad \sum_{j_1=1}^{J} y_{j_1 j_2}^t \le 1 \qquad \forall j_2 \in J, \forall t \in T, \tag{17}$$

$$\sum_{j_2=1}^{J} y_{j_1 j_2}^t \le \sum_{j=1}^{J} y_{j j_1}^{t-1} \qquad \forall j_1 \in J, \forall t \in T, \tag{18}$$

$$\sum_{j_1=1}^{J}\sum_{j_2=1}^{J} y_{j_1 j_2}^t = P \qquad \forall t \in T, \tag{19}$$

$$z_{ij}^t \le \sum_{j_1=1}^{J} y_{j_1 j}^t \qquad \forall j_1 \in J, \forall t \in T, \tag{20}$$

$$z_{ij}^t \le a_{ij} \qquad \forall j \in J, \forall i \in I, \tag{21}$$

$$\sum_{i=1}^{I} z_{ij}^t d_i \le d_0 \qquad \forall j \in J, \forall t \in T, \tag{22}$$

$$\sum_{t=1}^{T}\sum_{j=1}^{J} z_{ij}^t \le 1 \qquad \forall i \in I, \tag{23}$$

$$\sum_{i=1}^{I} \text{sgn}\left(\sum_{t=1}^{T}\sum_{j=1}^{J} z_{ij}^t\right) \ge \alpha |I| \tag{24}$$

$$y_{j_1 j_2}^t \in \{0, 1\} \qquad \forall j_1 \in J, \forall j_2 \in J, \forall t \in T, \tag{25}$$

$$z_{ij}^t \in [0,1] \qquad \forall i \in I, \forall j \in J, \forall t \in T. \tag{26}$$

Proof.

The constraint (2) (3) (4) (11) do not change in the new model. And constraint (1) (7) (8) according to the definition of l_{ij}^t and z_{ij}^t ,we can know they are equality with (16)(22)(23).

Constraint (5) ensures the fact that the blood donors are only assigned to the temporary point has facilities. If $\sum_{j_1=1}^{J} y_{j_1 j}^t = 0$, $z_{ij}^t = 0$ .Blood donors are not assigned to the point without a facility. If $\sum_{j_1=1}^{J} y_{j_1 j}^t = 1$, $z_{ij}^t \le 1$.Blood donors can be assigned to the point .So (5) is equality with (20).

Constraint (6) is blood donor groups' capacity constraint. For the definition of a_{ij} and z_{ij}^t ,(6) is equality with (21).

$\text{sgn}(\sum_{t=1}^{T}\sum_{j=1}^{J} d_{ij}^t) = \text{sgn}(\sum_{t=1}^{T}\sum_{j=1}^{J} (d_{ij}^t / d_i) x_{ij}^t) = \text{sgn}(\sum_{t=1}^{T}\sum_{j=1}^{J} z_{ij}^t)$, so (9) is equality with (24). □

Whether it is the lack or the excess, the cost is the same, we may wish to make has been in short supply, adding a constraint, then the original problem changes to a linear problem.

4. Lagrangean relaxation

In this section, we consider the Lagrangean relaxation of the problem by relaxing the constraints (32) into the objective function. Let $u_{ij} \ge 0$ denote the non-negative multipliers, and then the relaxed problem, denoted by $L(u)$ is given by:

$$L(u)=\min \sum_{t=1}^{T}\sum_{j_1=1}^{J}\sum_{j_2=1}^{J} y^t_{j_1j_2}c^t_{j_2} + \sum_{t=2}^{T}\sum_{j_1=1}^{J}\sum_{j_2=1}^{J} y^t_{j_1j_2}c_{j_1j_2} + \sum_{t=1}^{T}(D^t-\sum_{i=1}^{I}\sum_{j=1}^{J} z_{ij}d_i)\,c + \sum_{t=1}^{T}\sum_{i=1}^{I}\sum_{j=1}^{J} u^t_{ij}(z^t_{ij}-\sum_{j_1=1}^{J} y^t_{j_1j})$$

$$s.t.\quad (28),(29),(30),(31),(33),(34),(35),(36),(37),(38).$$

After some algebra the objective function turns out to be

$$L(u)=\min \sum_{t=1}^{T}\sum_{j_1=1}^{J}\sum_{j_2=1}^{J}(c_{j_2}+c_{j_1j_2}-\sum_{i=1}^{I}u^t_{ij_2})y^t_{j_1j_2} + \sum_{t=1}^{T}\sum_{i=1}^{I}\sum_{j_2=1}^{J}(u^t_{ij_2}-d_ic\,)z^t_{ij_2} + \sum_{t=1}^{T}D^tc$$

$\sum_{t=1}^{T}D^tc^t$ is a constant variable. This function can be split into two different functions. The first one depends only on the y variables, while the second one only on the variables z. In addition, constraints (29)-(31) and (37) only relate y variables, while constraints (28), (33)-(36) and (38) only relate z variables. Thus $L(u)$ separates into two subproblems. The first problem results to:

$$L_y(u)=\min \sum_{t=1}^{T}\sum_{j_1=1}^{J}\sum_{j_2=1}^{J}(c_{j_2}+c_{j_1j_2}-\sum_{i=1}^{I}u^t_{ij_2})y^t_{j_1j_2} \tag{39}$$

$$s.t.\quad \sum_{j_1=1}^{J}y^t_{j_1j_2}\le 1 \qquad \forall j_2\in J,\forall t\in T, \tag{40}$$

$$\sum_{j_2=1}^{J}y^t_{j_1j_2}\le \sum_{j=1}^{J}y^{t-1}_{jj_1} \qquad \forall j_1\in J,\forall t\in T, \tag{41}$$

$$\sum_{j_1=1}^{J}\sum_{j_2=1}^{J}y^t_{j_1j_2}=P \qquad \forall t\in T, \tag{42}$$

$$y^t_{j_1j_2}\in\{0,1\} \qquad \forall j_1\in J,\forall j_2\in J,\forall t\in T, \tag{43}$$

This problem can be solved as a dispatch problem.

On the other hand, the second problem is

$$L_z(u)=\min \sum_{t=1}^{T}\sum_{i=1}^{I}\sum_{j_2=1}^{J}(u^t_{ij_2}-d_ic)z^t_{ij_2} \tag{44}$$

$$s.t.\quad D^t-\sum_{i=1}^{I}\sum_{j=1}^{J}z^t_{ij}d_i\ge 0 \tag{45}$$

$$z^t_{ij}r^t_{ij}\le r \qquad \forall j\in J,\forall i\in I, \tag{46}$$

$$\sum_{i=1}^{I}z^t_{ij}d_i\le d_0 \qquad \forall j\in J,\forall t\in T, \tag{47}$$

$$\sum_{t=1}^{T}\sum_{j=1}^{J}z^t_{ij}\le 1 \qquad \forall i\in I, \tag{48}$$

$$\sum_{i=1}^{I}\mathrm{sgn}(\sum_{t=1}^{T}\sum_{j=1}^{J}z^t_{ij})\ge \alpha|I| \tag{49}$$

$$z^t_{ij}\in[0,1] \qquad \forall i\in I,\forall j\in J,\forall t\in T. \tag{50}$$

Which can be solved as a distribute problem.

Our Lagrangean approach provides us information to generate upper bounds for our problem.

4.1Upper bounds

Assume that, for a given u, the Lagrangean problem $L(u)$. Then, a feasible solution for our problem can be obtained by the optimal solutions y to $L_y(u)$. If $\sum_{j_1=1}^{J}y^t_{j_1j_2}=1$, $j_2\in J^t(y)$, $J^t(y)$ means the set of all possible points have facilities at period t.

In each period $t\in T$, if $x^t_{ij}=1$ and $j\notin J^t(y)$, then reassign customer i to the point $j\in J^t(y)$ with the minimum cost. Then, an upper bound to our problem.

We can use heuristic algorithm to solve this multi-period problem.

5. Case study

We present a case study to demonstrate our approach to deal with for earthquakes emergency blood supply in some district of Beijing. We only consider the cost of a product does not change with time and only whole blood collected..In this case study, we consider ten possible location and twenty blood donator groups, shown in the Fig.2.In this district, there is only one blood centre. We consider ten temporary blood points in Table 1.Table 1 also includes estimated distance between any two points.

Fig.2 Possible location, blood donator groups and blood center.

distance	1	2	3	4	5
1	0	2469	3382	1503	1751
2	2469	0	1184	1043	3678
3	3382	1184	0	1883	4200
4	1503	1043	1883	0	2646
5	1751	3678	4200	2646	0

Table 1 Distance of temporary blood points.Unit: kilometre

We consider the population density of each blood donator set. We assume that each person can donate blood 200ml (1U) and give number of donators and blood volume in the Table 2.

	1	2	3	4	5	6	7	8	9	10
No.of donators	1080	1672	1432	1432	7000	8000	3500	1100	3482	4320
blood volume	216	334.4	286.4	286.4	1400	1600	700	220	696.4	864
	11	12	13	14	15	16	17	18	19	20
No. of donators	1064	3000	800	1000	3230	1240	4110	2000	2760	3400
blood volume	212.8	600	160	200	646	248	822	400	552	680

Table 2 Number of donators and blood volume in the blood donator sets.

The computational tests have been designed in order to evaluate the structure of the solutions as well as the performance of the solution procedure developed in Section 4.On this account the algorithm was implementation using Visual C++6.0.All computational tests have been performed on a PC with a Pentium IV processor and 2G of RAM. We generate 1000 instances of different demands. Demands were drawn from a normality distribution with 280 of the mean and standard deviation 100. To test the algorithm, the optimal solution shown in Fig.3.The red line is showing the average value. Running 1000 sets of data were run 10s. From the speed and efficiency enhance very much.

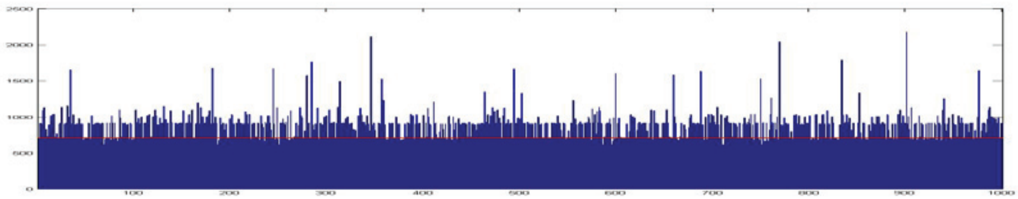

Fig.2 The total cost of the optimal solution for 1000 groups demands

For each candidate location is selected in each period the number of statistical data in Table 3

	1	2	3	4	5	6	7
1	0	0	3	3	3	0	5
2	404	764	786	654	443	251	217
3	216	171	182	313	517	697	693
4	380	65	29	30	36	51	84
5	0	0	0	0	0	1	1

Table 3 Number of being selected for each candidate location in each period of 1000 instances

5 and 1 candidate points were farthest from the blood centre, almost not be selected. This fact reflects the principle of proximity. Paths to the case of 2.3.4 up gradually to a distance forward. That is the principle of site: managers can draw a supply radius of the blood centre f to meet demand. In this range the facilities gradually from near and far move.

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