Manufacturing/Remanufacturing Logistics Network Optimization Based on Floyd Algorithm

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Abstract. Manufacturing/remanufacturing logistics network is an integrated network of forward logistics and reverse logistics based on remanufacturing. Optimization of the manufacturing/remanufacturing logistics network is to select a reasonable channel for the flow of each finished product and recycled product to minimize the total operating cost. This paper proposes a manufacturing/remanufacturing logistics network optimization model based on Floyd algorithm, which gives the single-piece operating cost of logistics facilities and the single-piece cost of transportation, and calculates the minimum cost of each distribution channel. Finally, we give an example to illustrate the model.

1. Introduction
Reverse logistics can be divided into remanufacturing, reuse, recycling and disposal methods according to different processing methods and reflow nodes[1]. This paper only discusses remanufacturing type of reverse logistics. Remanufacturing networks are typically targeted at electronic products, automobiles, appliances and other components that have high recycling value. Remanufacturing logistics consists of reverse logistics of transporting used products from the place of consumption to the place of production, as well as forward logistics of remanufactured products from the place of production to the place of consumption, involving the collection, inspection/classification, remanufacturing and redistribution of used products.

Among the various processing methods involved in reverse logistics, research on remanufacturing reverse logistics network is a hot topic, and many scholars have studied the design of remanufacturing reverse logistics network. Lee and Gen et al. [2] presented a three-layer logistics network design model for remanufacturing systems with the goal of minimizing the sum of transportation costs and fixed costs in reverse logistics. In order to solve the model, an improved genetic algorithm based on weight coding and applying new crossover operator is proposed. Zarei et al. [3] studied the reverse logistics network design of the scrapped vehicle remanufacturing under the manufacturer's extended responsibility. He considered the distribution of the new car and the recycling of the scrapped car. It is assumed that the distributor of the new car is also responsible for the recycling of the scrapped car. The network model of minimizing the construction cost and related transportation cost is designed, and a genetic algorithm is designed to solve the model. Alumur et al. [4] studied the design of reverse logistics networks for remanufactured products, including scrapped computers, washing machines, dryers, etc. The authors pointed out that if companies only focus on the extended responsibility of producers, they can outsource reverse logistics to third parties. Wang Shengchi et al. [5] studied the layout of remanufacturing reverse logistics networks of multinational corporations, and considered the dual objectives of logistics network operation revenue and logistics performance indicators. Ma Zujun and Dai Ying et al. [6] studied the integrated optimization design of remanufacturing reverse logistics networks.
and forward logistics network, and established a mixed integer nonlinear programming model, which focuses on integrating manufacturing system and remanufacturing system.

The optimized design of the manufacturing/remanufacturing logistics network is to determine the distribution channels of each finished product and recycling product based on the principle of minimizing the total cost of circulation. This paper proposes a logistics network optimization model based on Floyd algorithm. It can choose a circulation path with the lowest total cost, which minimizes the total circulation cost of the entire logistics network. In addition, the operational capacity constraints of the facility can be addressed by improving logistics management, regardless of capacity or turnover capability, so the capacity limitations of the facility are no longer considered in the model. Compared with the integer linear programming model, the model is simple, the algorithm is clear, and it can be programmed into the existing logistics information system, allowing the system to make choices automatically.

2. Model Description

2.1. Model Assumptions

Only consider recycling and re-manufacturing a product, and recycling through the recycling center, the forward/reverse logistics sharing facility. That is, the same production enterprise can produce new products and recycling products, the new product distribution center is also a recycling center for used products, and the end distribution center of new products can be a used product recycling point.

The operating costs of each facility and the transportation costs between facilities are determined and known.

Different manufacturers can remanufacture recycled products, that is, the products produced in the A production area are recycled to the B production area for remanufacturing.

Do not consider the supply of raw materials.

2.2. Algorithm Description

We simplify the expression of the entire manufacturing / remanufacturing system with a diagram. In the diagram, the nodes represent the facilities, the connections between the nodes represent the logistics, and the values on the links represent the cost of a single piece of transportation between the two facilities.

We use the improved Floyd algorithm [7] to calculate the minimum operational and transportation costs between all facility vertices in a manufacturing/remanufacturing closed-loop logistics network. The Floyd algorithm is a dynamic programming algorithm based on iterative ideas. In this paper, the operating costs of the facilities (such as the production cost of the enterprise and the turnover cost of the distribution center) are added, and the algorithm is improved accordingly. The main parts of the algorithm are as follows:

Declare and initialize the cost matrix $C^{(0)}[i][j]$, the forward logistics facility operating cost array $F[k]$, and the reverse logistics facility operating cost array $R[k]$.

```
for(i=1;i=G.vnum();i++)
    for(j=1;j=G.vnum();j++)
        if(i==j) { C[i][j].cost=0; }
        if(j>i) { C[i][j].cost= R[i]+C[i][j]+R[j]; }
        C[i][j].cost= F[i]+C[i][j]+F[j];  // $C^{(0)}[i][j]$ Initialize
        for(k=0;k<G.vnum();k++)
            for(i=0;i<G.vnum();i++)
                for(j=0;j<G.vnum();j++)
                    if(C[i][j].cost>C[i][k].cost + C[k][j].cost+ F[k])
                        { C[i][j].cost= C[i][k].cost+ C[k][j].cost+ F[k];
                          C[i][j].pre=k; }  // Forward logistics part
                    for(j=i;;j++)
                        if(C[i][j].cost>C[i][k].cost + C[k][j].cost+ R[k])
                            { C[i][j].cost= C[i][k].cost+ C[k][j].cost+ R[k];
```
C[i][j].pre=k;}  // Reverse logistics part

Where G.vnum() is the node number function, \( C[i][j].cost \) is the transportation cost between node \( V_i \) and node \( V_j \), and \( C[i][j].pre \) stores predecessor node (hop node) of node \( V_j \) between them.

According to the model operation results, the minimum total cost between all node pairs (two facilities) can be obtained, the total cost of the various possible paths of a cycle (forward/reverse logistics is completed) can be calculated, the minimum cost path and the order of the facility nodes of this cycle can be known by comparing.

3. Model Simulation

A manufacturer has built a manufacturing/ remanufacturing integrated logistics network, and now needs to optimize the distribution channels of existing networks. It is known that there are two production sites, three logistics centers/recycling centers (forward/reverse logistics sharing), three consumer distribution centers/recycling points (forward/reverse logistics sharing), and their operating costs and sign representations are shown in Table 1. The integrated logistics network is shown in Figure 1.

![Figure 1. The integrated logistics network](image)

| Facilities          | Signs | Forward/Reverse Logistics (F/R) | Single Piece Operating Cost |
|---------------------|-------|---------------------------------|-----------------------------|
| Production site 1   | V1    | F                               | 5                           |
| Production site 2   | V2    | F                               | 4.5                         |
| Logistics center 1  | V3    | F                               | 2                           |
| Logistics center 2  | V4    | F                               | 1                           |
| Logistics center 3  | V5    | F                               | 1                           |
| Distribution center 1 | V6    | F                               | 1                           |
| Distribution center 2 | V7    | F                               | 1                           |
| Distribution center 3 | V8    | F                               | 1                           |
| Production site 1   | V1    | R                               | 4                           |
| Production site 2   | V2    | R                               | 3                           |
| Recycling center 1  | V3    | R                               | 1.5                         |
| Recycling center 2  | V4    | R                               | 0.5                         |
| Recycling center 3  | V5    | R                               | 1                           |
| Recycling point 1   | V6    | R                               | 2                           |
| Recycling point 2   | V7    | R                               | 2                           |
| Recycling point 3   | V8    | R                               | 2.5                         |
In Figure 1, the connection between nodes indicates transportation. The cost of single-piece transportation is marked on the connecting line. The unsigned line indicates that the costs of two-way transportation are the same. The directed line indicates that the costs of two-way transportation are different. The number outside the parentheses indicates the cost of forward logistics, and the number in parentheses indicates the cost of reverse logistics.

Let's optimize the integrated network.

Step 1 According to the Floyd algorithm, we can give the initial cost matrix $C(i,j)$ (Table 2), the predecessor node matrix $P(i,j)$ (Table 3), and the forward logistics facility operation cost array $F[i] = \{5, 4.5, 2, 1, 1, 1, 1\}$, reverse logistics facility operating cost array $R[i] = \{4.3, 1.5, 0.5, 1.2, 2, 2.5\}$. Wherein, the single piece cost of $VI \rightarrow V3$ is the sum of the forward transportation cost and the forward logistics facility cost of the two nodes $VI$ and $V3$, namely: $5 + 3 = 10$; The single piece cost of $V3 \rightarrow V1$ is the sum of the reverse transportation cost and the reverse logistics facility cost of the two nodes $V1$ and $V3$, namely: $1.5 + 3 = 8.5$; No displacement occurs between the same nodes, and the cost is 0; According to the meaning of the question, there is no connection between the nodes of the same layer, so the transportation cost between them is infinite, such as $VI \rightarrow V2$, which is represented by the symbol “$\propto$”; the transportation cost between nodes that are not directly connected is temporarily unreachable, such as $VI \rightarrow V6$, which is represented by the symbol “$\infty$”.

**Table 2. $C(i,j)$**

| $C(i,j)$ | $V1$ | $V2$ | $V3$ | $V4$ | $V5$ | $V6$ | $V7$ | $V8$ |
|----------|------|------|------|------|------|------|------|------|
| $V1$     | 0    | $\infty$ | 10  | 10  | 8    | $\infty$ | $\infty$ | $\infty$ |
| $V2$     | $\infty$ | 0    | 10.5 | 7.5 | 8.5  | $\infty$ | $\infty$ | $\infty$ |
| $V3$     | 8.5  | 8.5  | 0    | $\infty$ | $\infty$ | 7    | 6    | 8    |
| $V4$     | 8.5  | 5.5  | 7    | $\infty$ | $\infty$ | 7    | 6    | 5    |
| $V5$     | 7    | 7    | $\infty$ | 0    | 5.5  | 7    | 6    | 5    |
| $V6$     | $\infty$ | 6.5  | 6.5  | 7    | 0    | $\infty$ | $\infty$ | $\infty$ |
| $V7$     | $\infty$ | 7.5  | 5.5  | 7    | $\infty$ | 0    | $\infty$ | $\infty$ |
| $V8$     | $\infty$ | 7.5  | 7    | 7.5  | 7    | $\infty$ | 0    | $\infty$ |

**Table 3. $P(i,j)$**

| $P(i,j)$ | $V1$ | $V2$ | $V3$ | $V4$ | $V5$ | $V6$ | $V7$ | $V8$ |
|----------|------|------|------|------|------|------|------|------|
| $V1$     | 1    | 1    | $\infty$ | $\infty$ | $\infty$ | $\infty$ | $\infty$ | $\infty$ |
| $V2$     | 2    | 2    | 2    | 2    | 2    | 2    | 2    | 2    |
| $V3$     | 3    | 3    | 3    | 3    | 3    | 3    | 3    | 3    |
| $V4$     | 4    | 4    | 4    | 4    | 4    | 4    | 4    | 4    |
| $V5$     | 5    | 5    | 5    | 5    | 5    | 5    | 5    | 5    |
| $V6$     | 6    | 6    | 6    | 6    | 6    | 6    | 6    | 6    |
| $V7$     | 7    | 7    | 7    | 7    | 7    | 7    | 7    | 7    |
| $V8$     | 8    | 8    | 8    | 8    | 8    | 8    | 8    | 8    |

Step 2 According to the algorithm, the two matrices should be updated starting from the $VI$ node. In this example, since $VI$, $V2$, and $V6$, $V7$, $V8$ are the starting and ending nodes of the network, there is no connection between the nodes in the same layer, and the nodes between the non-adjacent layers are not connected (consistent with the actual logistics system). Therefore, it is only necessary to consider updating the matrix from the intermediate layer nodes $V3$, $V4$, and $V5$. After $C(i,j)$ and $P(i,j)$ are updated through $V3$, a single piece cost matrix $C(i,j)$ (Table 4) and a predecessor node matrix $P(i,j)$ (Table 5) are obtained.

**Table 4. $C(i,j)$**

| $C(i,j)$ | $V1$ | $V2$ | $V3$ | $V4$ | $V5$ | $V6$ | $V7$ | $V8$ |
|----------|------|------|------|------|------|------|------|------|
| $V1$     | 0    | $\infty$ | 10  | $\infty$ | 10  | 8    | 15   | 14   |
| $V2$     | $\infty$ | 0    | 10.5 | 7.5 | 8.5  | $\infty$ | 14.5 | 16.5 |
| $V3$     | 8.5  | 8.5  | 0    | $\infty$ | $\infty$ | 7    | 6    | 8    |
| $V4$     | 8.5  | 5.5  | 7    | $\infty$ | $\infty$ | 7    | 6    | 5    |
| $V5$     | 7    | 7    | $\infty$ | 0    | 5.5  | 7    | 6    | 5    |
| $V6$     | 13.5 | 13.5 | 6.5  | 6.5  | 7    | 0    | $\infty$ | $\infty$ |
| $V7$     | 14.5 | 11.5 | 7.5  | 5.5  | 7    | $\infty$ | 0    | $\infty$ |
| $V8$     | 13   | 13   | 7.5  | 7.5  | 7    | $\infty$ | 0    | $\infty$ |

**Table 5. $P(i,j)$**

| $P(i,j)$ | $V1$ | $V2$ | $V3$ | $V4$ | $V5$ | $V6$ | $V7$ | $V8$ |
|----------|------|------|------|------|------|------|------|------|
| $V1$     | 1    | 1    | 1    | 1    | 1    | 3    | 3    | 3    |
| $V2$     | 2    | 2    | 2    | 2    | 2    | 3    | 3    | 3    |
| $V3$     | 3    | 3    | 3    | 3    | 3    | 3    | 3    | 3    |
| $V4$     | 4    | 4    | 4    | 4    | 4    | 4    | 4    | 4    |
| $V5$     | 5    | 5    | 5    | 5    | 5    | 5    | 5    | 5    |
| $V6$     | 6    | 6    | 6    | 6    | 6    | 6    | 6    | 6    |
| $V7$     | 7    | 7    | 7    | 7    | 7    | 7    | 7    | 7    |
| $V8$     | 8    | 8    | 8    | 8    | 8    | 8    | 8    | 8    |

Wherein, the value of $VI \rightarrow V6$ is updated to 15 in $C(i,j)$, because that $C[1][6].cost > C[1][3].cost + C[3][6].cost - F[3]$ (the operating cost of $V3$ is more than once), that is, $\infty > (10 + 7 - 2)$. At the same time, the predecessor node from $VI$ to $V6$ is marked as 3 in $P(i,j)$, that is, the route from $VI$ to $V6$ passes through $V3$. Similarly, the value of $V6 \rightarrow VI$ is updated to 13.5 in $C3(i,j)$, because that $C[6][1].cost >$
The network optimization results are $C[6][3].cost + C[3][1].cost - R[3]$ (the operating cost of $V3$ is more than once). At the same time, the predecessor node from $V6$ to $V1$ is marked as 3 in $P^3(i,j)$.

Step 3. The matrix $C^4(i,j)$ (Table 6) and matrix $P^4(i,j)$ (Table 7) are updated by comparing whether to pass through the hop node $V4$. Wherein, the value of $V1→V8$ is updated to 14 in $C^4(i,j)$, because that the value of $V1→V4→V8$ is less than the value of $V1→V3→V8$. At the same time, the predecessor node from $V1$ to $V8$ is marked as 4 in $P^4(i,j)$.

**Table 6. $C^4(i,j)$**

| $C^4(i,j)$ | $V1$ | $V2$ | $V3$ | $V4$ | $V5$ | $V6$ | $V7$ | $V8$ |
|------------|------|------|------|------|------|------|------|------|
| $V1$       | 0    | 10   | 10   | 8    | 15   | 14   | 14   | 14   |
| $V2$       | ∞    | 0    | 10.5 | 7.5  | 8.5  | 13.5 | 12.5 | 11.5 |
| $V3$       | 8.5  | 8.5  | 0    | ∞    | 7    | 6    | 8    | 8    |
| $V4$       | 8.5  | 5.5  | 0    | 0    | ∞    | 7    | 6    | 5    |
| $V5$       | 7    | 7    | 0    | ∞    | 0    | 5.5  | 5    | 5    |
| $V6$       | 13.5 | 11.5 | 6.5  | 6.5  | 7    | 0    | ∞    | ∞    |
| $V7$       | 12   | 11.5 | 7.5  | 5.5  | 7    | 0    | ∞    | ∞    |
| $V8$       | 13   | 13   | 7.5  | 7    | 7    | 7.5  | ∞    | ∞    |

**Table 7. $P^4(i,j)$**

| $P^4(i,j)$ | $V1$ | $V2$ | $V3$ | $V4$ | $V5$ | $V6$ | $V7$ | $V8$ |
|------------|------|------|------|------|------|------|------|------|
| $V1$       | 1    | 1    | 1    | 1    | 1    | 3    | 3    | 4    |
| $V2$       | 2    | 2    | 2    | 2    | 2    | 4    | 4    | 4    |
| $V3$       | 3    | 3    | 3    | 3    | 3    | 3    | 3    | 3    |
| $V4$       | 4    | 4    | 4    | 4    | 4    | 4    | 4    | 4    |
| $V5$       | 5    | 5    | 5    | 5    | 5    | 5    | 5    | 5    |
| $V6$       | 3    | 4    | 6    | 6    | 6    | 6    | 6    | 6    |
| $V7$       | 4    | 3    | 7    | 7    | 7    | 7    | 7    | 7    |
| $V8$       | 3    | 3    | 8    | 8    | 8    | 8    | 8    | 8    |

Step 4. The matrix $C^5(i,j)$ (Table 8) and matrix $P^5(i,j)$ (Table 9) are updated by comparing whether to pass through the hop node $V5$. Wherein, the value of $V1→V6$ is updated to 12.5 in $C^5(i,j)$, because that the value of $V1→V5→V6$ is less than the value of $V1→V3→V6$. At the same time, the predecessor node from $V1$ to $V6$ is marked as 5 in $P^5(i,j)$. The value of $V6→V1$ is updated to 13 in $C^5(i,j)$, because that the value of $V6→V5→V1$ is less than the value of $V6→V3→V1$. At the same time, the predecessor node from $V6$ to $V1$ is marked as 5 in $P^5(i,j)$.

**Table 8. $C^5(i,j)$**

| $C^5(i,j)$ | $V1$ | $V2$ | $V3$ | $V4$ | $V5$ | $V6$ | $V7$ | $V8$ |
|------------|------|------|------|------|------|------|------|------|
| $V1$       | 0    | 10   | 10   | 8    | 12.5 | 14   | 12   | 12   |
| $V2$       | ∞    | 0    | 10.5 | 7.5  | 8.5  | 13   | 12.5 | 11.5 |
| $V3$       | 8.5  | 8.5  | 0    | ∞    | 7    | 6    | 8    | 8    |
| $V4$       | 8.5  | 5.5  | 0    | 0    | ∞    | 7    | 6    | 5    |
| $V5$       | 7    | 7    | 0    | ∞    | 0    | 5.5  | 5    | 5    |
| $V6$       | 13   | 11.5 | 6.5  | 6.5  | 7    | 0    | ∞    | ∞    |
| $V7$       | 12   | 11.5 | 7.5  | 5.5  | 7    | 0    | ∞    | ∞    |
| $V8$       | 13   | 13   | 7.5  | 7    | 7.5  | 0    | ∞    | ∞    |

**Table 9. $P^5(i,j)$**

| $P^5(i,j)$ | $V1$ | $V2$ | $V3$ | $V4$ | $V5$ | $V6$ | $V7$ | $V8$ |
|------------|------|------|------|------|------|------|------|------|
| $V1$       | 1    | 1    | 1    | 1    | 1    | 5    | 3    | 5    |
| $V2$       | 2    | 2    | 2    | 2    | 2    | 5    | 4    | 4    |
| $V3$       | 3    | 3    | 3    | 3    | 3    | 3    | 3    | 3    |
| $V4$       | 4    | 4    | 4    | 4    | 4    | 4    | 4    | 4    |
| $V5$       | 5    | 5    | 5    | 5    | 5    | 5    | 5    | 5    |
| $V6$       | 5    | 4    | 6    | 6    | 6    | 6    | 6    | 6    |
| $V7$       | 4    | 3    | 7    | 7    | 7    | 7    | 7    | 7    |
| $V8$       | 3    | 3    | 8    | 8    | 8    | 8    | 8    | 8    |

We can do the following analysis. For instance, the value of $V1→V6$ is 12.5, the value of $V2→V6$ is 13, so in $V6$, the optimal single piece cost is 12.5 and the route is $V1→V5→V6$. Similarly, the optimal value of $V6→V2$ is 11.5 and the route is $V6→V4→V2$. So in $V6$, optimization result is that products produced by production site 1($V1$) are distributed to distribution center 1($V6$) through logistics center 3 ($V5$), used products recycled by recycling point 1($V6$) are distributed to production site 2 ($V2$) through recycling center 2 ($V4$), and the total single piece cost is 24. The network optimization results are shown in Table 10.
Table 10. The network optimization results

| Facilities          | Forward/Reverse logistics (F/R) | Routes          | Optimal Single Piece Cost |
|---------------------|---------------------------------|-----------------|---------------------------|
| Distribution center V6 | F                              | V1→V5→V6       | 12.5                      |
| Distribution center V7 | F                              | V2→V4→V7       | 12.5                      |
| Distribution center V8 | F                              | V2→V4→V8       | 11.5                      |
| Recycling point V6    | R                              | V6→V4→V2       | 11.5                      |
| Recycling point V7    | R                              | V7→V3→V2       | 11.5                      |
| Recycling point V8    | R                              | V8→V3→V2 Or V8→V3→V1 | 13                      |

4. Conclusion

If the manufacturing/remanufacturing network has been constructed, the limit of the facility capacity can be overcome by management. The purpose of network optimization is to select the optimal distribution channel based on a certain factor. The manufacturing/remanufacturing network optimization based on the Floyd algorithm can be done based on cost or time factor. We can choose the fastest route in a manufacturing/remanufacturing network if we optimize it by Floyd algorithm based on time factor. Note that Floyd algorithm can be used to solve a fully connected graph, that is, we can use it to solve more complex manufacturing/remanufacturing logistics networks.

5. References

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