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Ordering Problem of Vascular Robot Based on Time Series Prediction

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Abstract: The vascular robot is used to treat diseases related to blood vessels. The vascular robot can carry drugs into blood vessels to treat diseases related to blood vessels. At the same time, the operator needs a week of maintenance before he can continue to work. If the robot is not scheduled to work, it also needs maintenance, which will incur corresponding costs. This paper studies how to determine the number of vessels and manipulators to be purchased in vascular robots under different constraints. Firstly, this paper establishes a multi-step decision-making model and analyzes the best time to purchase the container boat and the operator. Then using the least squares curve fitting to analyze the data, through multivariate linear programming, multi-step decision, integer programming and other methods to solve, finally determine the optimal number of ordering vascular robots.

1. Introduction

Vascular robots are robots in blood vessels, because of the physiological limitations of blood vessels[1]. A vascular robot is also an important branch of micro-robot. Vascular robots can be used to treat diseases related to blood vessels at fixed points. Vascular interventional robots are essentially the organic combination of surgical robots and vascular interventional technology. Robot manipulates interventional surgical instruments, which can work in an unfavourable environment for doctors, accurately locate concerning medical images, perform continuous actions without a tremor, quickly and accurately pass through complex trajectories, accurately locate and reach target blood vessels, and finally complete vascular interventional surgery under the command of doctors or autonomously.

However, the operator needs a week of maintenance before he can continue to work[2]. If the robot is not scheduled to work, it will also need maintenance, which will incur corresponding costs. How to determine the optimal number of vascular robots to be ordered is a problem.

First of all, because the vascular robot needs the vessel and the manipulator to run at the same time, we use integer programming to solve the problem. Then the objective function of the model is modified and optimized, the quantity relationship of each week in the constraint conditions is adjusted, and the constraint conditions are increased. Because there are different preferential policies for container boats and operators when the purchased quantity is different, the price difference between the maintenance cost and the purchase preferential policy is compared and analyzed. Through the loop solution, we find out when to buy the best, on the premise of meeting the treatment, choose the right time to buy combined with preferential policies to make the cost lowest, and finally determine the best number of vascular robots to order.

2. Model establishment and solution

2.1 Determination of robot demand based on a multi-step decision

How to purchase the number of operators and container boats to meet the treatment while minimizing the operating costs[3]. The optimization model can be established and solved by purchasing the number of container boats and operators of the vascular robot. As shown in formula (1).

$$Z = 110 s_i + 10\left[\frac{s_i}{10}\right] + 200 t_i + 5\left(10 + \sum_{k=1}^{i-1} s_k - a_i - \left[\frac{s_i}{10}\right]\right) + 10\left(13 + \sum_{k=1}^{i-1} t_k - b_i\right) \tag{1}$$

The objective function is the minimum cost under the premise of satisfying the treatment.The decision variables are the number of purchased operators and the number of purchased container boats.The constraint condition is that the number of operators maintained every week should be greater than or equal to the amount used in the previous week, and the number of original and purchased container boats[4] should be greater than or equal to the amount used every week, As shown in formula (2).

$$\begin{aligned} &\min \quad Z = 110 s_i + 10\left[\frac{s_i}{10}\right] + 200 t_i + 5\left(10 + \sum_{k=1}^{i-1} s_k - a_i - \left[\frac{s_i}{10}\right]\right) + 10\left(13 + \sum_{k=1}^{i-1} t_k - b_i\right) \\ &\text{s.t.} \begin{cases} 50 + \sum_{k=1}^{i-1} s_k - a_i - \left[\frac{s_i}{10}\right] \ge a_{i-1} \\ 13 + \sum_{k=1}^{i-1} t_k \ge b_i \end{cases} \end{aligned} \tag{2}$$

Where s_i is the operator purchased in week i, t_k is the container boat purchased in week k,

Due to the particularity of the program, it can be solved by writing the program through the algorithm, and the data of the first to eighth weeks can be solved as shown in the following Table1.

Table 1: Relevant result data for question one

Week	Number of container boats purchased	Number of operators purchased	Number of operators serviced	Number of vessel boats maintained	Number of operators participating in the training	Total cost (Unit: yuan)
Week 1	0	14	4	2	16	1600
Week 2	0	0	44	8	0	300
Week 3	0	0	48	9	0	330
Week 4	3	28	33	6	31	3950
Week 5	0	0	28	0	0	140
Week 6	0	0	68	10	0	440
Week 7	0	0	72	11	0	470
Week 8	0	0	64	9	0	410

The minimum cost for weeks 1-8 is 7640 yuan.

2.2 Add robot loss analysis

Vascular robots work in the blood vessels of patients at risk, once they encounter macrophages[5], if they can not avoid them, they will be completely destroyed. At this time, 20% of the vascular robots are damaged every week (the number of damages is rounded up). On this basis, the modification and optimization of the objective function and constraints based on model 2.1 can not only meet the treatment, but also minimize the operation cost. As shown in formula (3).

$$Z=110s_i+10\left\lceil\frac{s_i}{10}\right\rceil+200t_i+5\left(50+\sum_{k=1}^{i-1}s_k-a_i-\left\lceil\frac{s_i}{10}\right\rceil-0.2\sum_{k=1}^{i-1}a_k\right)+10\left(13+\sum_{k=1}^{i-1}t_k-b_i-0.2\sum_{k=1}^{i-1}b_k\right) \quad (3)$$

The objective function is to minimize the operation cost under the premise of satisfying the treatment.The decision variables are the number of purchased operators and the number of purchased container boats.The constraint condition is that the number of operators maintained in each week should be more than 80% of the number of operators used in the previous week, and the number of original and purchased container boats should be more than or equal to the number used and damaged. As shown in formula (4).

$$\min\ Z=110s_i+10\left\lceil\frac{s_i}{10}\right\rceil+200t_i+5\left(50+\sum_{k=1}^{i-1}s_k-a_i-\left\lceil\frac{s_i}{10}\right\rceil-0.2\sum_{k=1}^{i-1}a_k\right)+10*\left(13+\sum_{k=1}^{i-1}t_k-b_i-0.2\sum_{k=1}^{i-1}b_k\right)$$

$$s.t.\begin{cases}50+\sum_{k=1}^{i-1}s_k-a_i-\left\lceil\frac{s_i}{10}\right\rceil-0.2\sum_{k=1}^{i-1}a_k\ge 0.8a_{i-1}\\ 13+\sum_{k=1}^{i-1}t_k\ge b_i+0.2\sum_{k=1}^{i-1}b_k\end{cases} \quad (4)$$

Where s_i is the operator purchased in week i, t_k is the container boat purchased in week k.

Due to the special nature of the program, the solution can be solved by writing a program through the algorithm, and the results are shown in Table 2 below.

Table 2: Result data related to Model 2

Week	Number of container boats purchased	Number of operators purchased	Number of operators serviced	Number of vessel boats maintained	Number of operators participating in the training	Total cost (Unit: yuan)
Week 12	5	20	26	1	22	3360
Week 26	0	0	100	9	0	590
Week 52	21	128	59	0	141	18705
Week 78	16	40	172	0	44	8500
Week 101	12	80	308	0	88	12820
Week 102	17	36	344	0	40	9120
Week 103	0	92	306	0	102	11750
Week 104	0	0	308	0	0	1540
1-104 weeks total	854	3826	13102	131	4234	662560

Since that numb of vascular robots to be used is not given at 105, we consider 104 weeks to be the last week

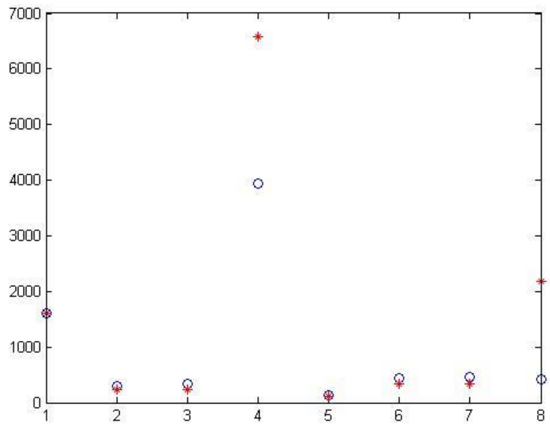

Figure 1: Cost Comparison for Weeks 1-8 of Model 2.1 and Model 2.2

The data of the 8th week obtained in model 2.2 is obtained through the overall analysis, as shown in Figure 1, while the data of the 8th week obtained in model 2.1 is not supported by the data of the 9th week, so we mainly compare the data of first 7 weeks.The difference between the first week and the eighth week was obtained by MATLAB data comparison. The main factor causing the difference was the number of operators (including "skilled workers" and "novices") who participated in the training in the fourth week? Because there is damage every week, after damage, you need to consider when to buy to minimize the cost. The biggest difference between the two problems is the number of damaged vessels and operators, and then we need to consider when the purchase cost is the smallest[6].

2.3 Modeling under additional constraints

Based on Model 2.2, adjust the maximum number of skilled operators that can guide new operators, reduce the percentage of damage to 10%, and solve how to buy to minimize operating costs. As shown in formula (5).

$$Z = 110s_i + 10\left[\frac{s_i}{20}\right] + 200t_i + 5\left(50 + \sum_{k=1}^{i-1} s_k - a_i - \left[\frac{s_i}{20}\right] - 0.1\sum_{k=1}^{i-1} a_k\right) + 10\left(13 + \sum_{k=1}^{i-1} t_k - b_i - 0.1\sum_{k=1}^{i-1} b_k\right) \tag{5}$$

The objective function is the minimum operation cost under the premise of satisfying the treatment.The decision variables are the number of purchased operators and the number of purchased container boats. The constraint condition is that the number of maintenance operators in each week must be greater than or equal to 0.9 times the number of operators used in the previous week, and the number of original and purchased container boats must be greater than or equal to the number used and damaged in each week. As shown in formula (6).

$$\begin{aligned} &\min\ Z = 110s_i + 10\left[\frac{s_i}{20}\right] + 200t_i + 5\left(50 + \sum_{k=1}^{i-1} s_k - a_i - \left[\frac{s_i}{20}\right] - 0.1\sum_{k=1}^{i-1} a_k\right) + 10\left(13 + \sum_{k=1}^{i-1} t_k - b_i - 0.1\sum_{k=1}^{i-1} b_k\right) \\ &s.t. \begin{cases} 50 + \sum_{k=1}^{i-1} s_k - a_i - \left[\frac{x_i}{20}\right] - 0.1\sum_{k=1}^{i-1} a_k \ge 0.9a_{i-1} \\ 13 + \sum_{k=1}^{i-1} t_k \ge b_i + 0.1\sum_{k=1}^{i-1} b_k \end{cases} \end{aligned} \tag{6}$$

Where s_i is the operator purchased in week i, t_k is the container boat purchased in week k.

Due to the particularity of the program, it can be solved by writing the program through the algorithm, and the results are shown in Table 3.

Table 3: Relevant result data for Model 2.3

Week	Number of container boats purchased	Number of operators purchased	Number of operators serviced	Number of vessel boats maintained	Number of operators participating in the training	Total cost (Unit: yuan)
Week 12	3	12	35	3	13	2135
Week 26	0	0	116	11	0	690
Week 52	18	116	78	0	122	16810
Week 78	10	20	195	1	21	5195
Week 101	1	40	354	0	42	6390
Week 102	7	0	392	0	0	3360
Week 103	0	44	361	0	47	6675
Week 104	0	0	344	0	0	1720
1-104 weeks (total)	482	2338	15485	281	2474	436540

Since that numb of vascular robots to be used is not given in week 105, we consider week 104 to be the last week.

2.4 Purchase volume analysis based on loop solving

Table 4: Relevant result data

Week	Number of container boats purchased	Number of operators purchased	Number of operators serviced	Number of vessel boats maintained	Number of operators participating in the training	Total cost (Unit: yuan)
Week 12	3	12	36	3	13	2140
Week 26	0	0	116	11	0	690
Week 52	0	168	84	18	177	16410
Week 78	26	20	196	1	21	7660
Week 101	0	0	40	1	0	210
Week 102	23	0	392	0	0	5940
Week 103	0	44	364	16	47	6570
Week 104	0	0	344	0	0	1720
1-104 weeks (total)	498	2338	13566	466	2470	388990

Based on model 2.3, the purchased quantity of container boats and operators has different unit prices at different times. It is necessary to consider the number of operators and container boats purchased per week, to achieve the purpose of treatment and minimize the cost. At this time, it is necessary to analyze the purchased quantity each week, determine under which preferential policy the purchased quantity can make the cost lowest, and consider the maintenance cost of the purchased operator. The purchase amount of each week is analyzed[7] under different policies, the constraints are limited, and the cost is calculated, to meet the treatment and achieve the lowest cost.

Preferential policies for container boats $\begin{cases} 200s_i, & 0 < s_i \le 5; \\ 1000 + 180s_i, & 5 < s_i \le 10; \\ 1900 + 160s_i, 10 < s_i. \end{cases}$

Preferential policies for operators $\begin{cases} 100t_i, & 0 < t_i \le 20 \\ 2000 + 90t_i, 20 < t_i \le 40 \\ 3800 + 80t_i, & 40 < t_i \end{cases}$

Under this preferential policy, data processing can be carried out to obtain the most purchase quantity.In this preferential policy, The available data are shown in Table 4.

2.5 Time series prediction model based on curve fitting

Firstly, the data of 105-112 weeks is predicted by fitting the data of 1-104 weeks. Secondly, the first scheme should consider the training cost and training time of the operator, as well as the influence of the learning time of the container boat on the cost after 105 weeks, and predict the purchase number of 105-112 weeks through the time series prediction model. The second scheme is based on the overall consideration of the fourth problem, and the purchase volume of 105-112 weeks is also predicted by the time series prediction model[8].As shown in Table 5.

Table 5: Predicted number of vascular robots needed for weeks 105-112

Number of weeks	105	106	107	108	109	110	111	112
Predicted number	112	114	116	118	121	123	125	127

Analyze the vascular robot data required in the first 104 weeks, and fit and predict the function curve through MATLAB to obtain the following figure 2.

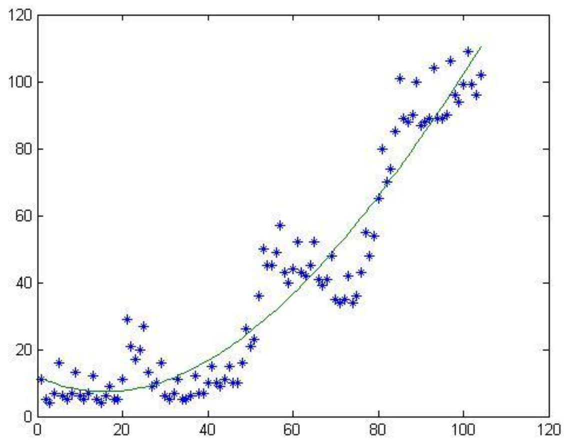

Figure 2: Plot of curve fitting and prediction data

3. Conclusions

This problem can be programmed by MATLAB and LINGO to calculate the optimal result, that is, the minimum operating cost. In model 2.1, debugging and learning are carried out according to the needs of the vessel boat and the operator, and related models are established by a mutual contact. When the number of container boats and operators purchased is different, the minimum cost is also changed, to solve it. The minimum operating cost is predicted under two scenarios based on the available data. If the usage suddenly changes greatly in a week, the data forecast will change greatly, resulting in inaccurate forecast data. The time series forecasting method is better than the long-term forecasting method for short-term and medium-term forecasting.

From a practical point of view, the model established in this paper and the results obtained can explain how hospitals purchase container boats and operators of vascular robots and when they operate. This kind of model can be used as a reference for similar problems such as cost optimization in goods procurement.

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