Analysis of vascular robot optimization scheme based on dynamic planning and ARIMA model

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Abstract. The study of vascular robots has become a new research hotspot in the interdisciplinary field and is of pivotal importance to the field of minimally invasive therapy. In this paper, we focus on the development of the ordering scheme of vascular robot, establish the optimal ordering model of vascular robot based on the idea of dynamic programming, calculate the minimum operating cost of the ordering scheme through LINGO software programming, and provide a specific weekly ordering scheme for the hospital to order vascular robot. Firstly, the optimal ordering model of the vascular robot is established based on the idea of bottom-up solution of dynamic programming in order to solve the specific to weekly ordering scheme. Second, a mind map format is adopted to sort out the problem, which allows a clearer analysis of the topic conditions. Then, the correctness of the model solution is checked by using segmented programming verification, which enhances the persuasive power of the model. Finally, the principles of machine learning are combined to build.

Keywords: Vascular robot ordering, dynamic planning, Auto ARIMA prediction, optimization, segmentation testing.

1. Introduction

Nowadays, High-intensity work environment and poor lifestyle habits have increased the probability of cardiovascular disease, and traditional surgical treatment methods are risky. For this reason, we have invented the "vascular robot" using micro-electro-mechanical systems, which are gradually being researched in depth - through external control, we are able to enter the tiny tissues in the human body and use its tiny nature to achieve a number of functions in the vascular environment, such as targeted drug delivery, cutting gout stones, unblocking blood vessels, and monitoring blood conditions. It can also be used to remove bacteria and parasites from inside the blood vessels, clot blood quickly, clean wounds, crush stones, and reactivate cellular energy, which not only solves patients' disease problems but also improves people's quality of life [1-3].

The vascular robot consists of a powered vessel and four operators with a biological brain and a robotic arm, which is capable of controlling the arm but does not have the ability to replicate information. Therefore, the "novices" need to undergo a week of biological learning in a simulated vessel by "skilled workers" before they can officially enter the vascular work, until the "novices" reach the level of "skilled workers"[4-5]. The "novice" will be required to undergo a week of biological learning in the simulated vessel as a "skilled worker" until the "novice" reaches the "skilled worker" level. In addition, the "skilled worker" should be removed from the patient after one week of work, and if work is required after removal, the operator must undergo another week of maintenance, while the vessel can continue to work; if no work is required, both the operator and vessel should be in a continuous state of maintenance [6-7].

With 13 boats and 50 skilled operators, the newly purchased boats and operators are required to arrive at the beginning of each week and are inspected and commissioned and biologically learned immediately upon arrival. Where the associated costs are given along with the number of vessel machines required per week. The following problems are solved by developing a mathematical model [7-8].

Question 1: Considering only weeks 1-8, how many vessels and operators would need to be purchased each week in order to minimize operating costs, given that each "skilled worker" can instruct 10 "novices" in biological learning?

Question 2: Based on question 1, considering weeks 1-104, and with 20% of the vascular robots destroyed each week, what is the total number of vessels and operators that would need to be purchased each week in order to minimize operating costs? Please fill in Table 1 with the relevant results and analyze the results data for weeks 1-8 of questions one and two for comparison [9-10].

2. Data Analysis

2.1. Introduction of dynamic programming ideas

We need to programmatically solve for the number of vessel boats and operators purchased for each of weeks 1-104. The amount of data is extremely large and places a slight demand on the computing power of the programming software. In order to ensure that the model created can be solved smoothly, we need to use the idea of dynamic programming for modeling.

In this case, we solve for the optimal ordering solution for the first week and the total cost of the ordering solution for the previous week by using the initial conditions and the remaining constraints, and then solve for the optimal ordering solution for the first two weeks and the total cost of the ordering solution for the previous two weeks by combining the optimal ordering solution for the first week, and so on. In the process of solving the optimal ordering scheme for weeks 1-104, we can find the ordering scheme for any week and the total cost up to that week.

2.2. Optimal ordering model for vascular robots

In order to give a weekly purchase plan for vessel boats and operators for weeks 1-8, we build an optimal ordering model for vessel robots based on the idea of dynamic programming. Two requirements for the problem are.

① Satisfy the treatment

② Minimal operating cost

We consider the costs associated with the vascular robot and whether the purchase of vessel boats and manipulators can meet the number of vascular robots used in the first 1-8 weeks, and specify the ordering plan for the hospital to purchase manipulators and vessel boats.

The specific factors affecting the ordering of vascular robots are analyzed and sorted out as shown in Figure 1.

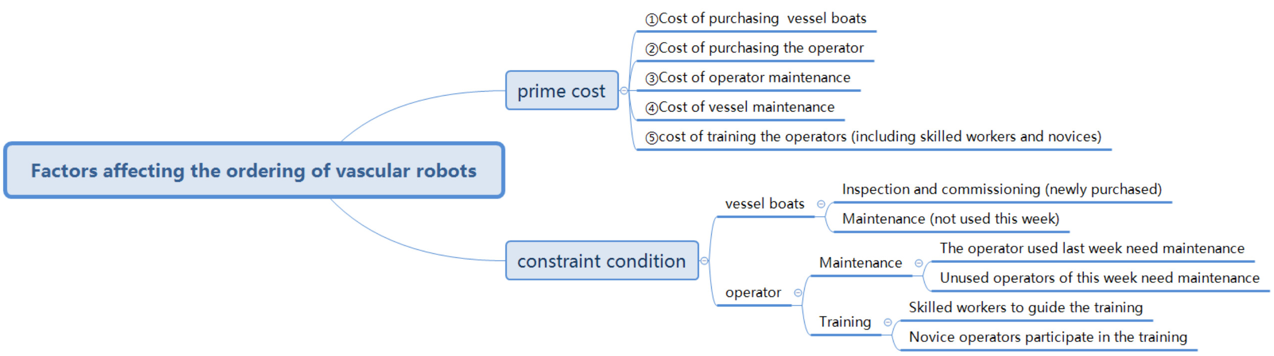

Figure 1 Analysis of the factors affecting the ordering of vascular robots in question 1

2.3. Operating Costs

First of all it is necessary to express the operating costs based on the minimum principles. The operating costs consist of the following five aspects.

①The cost of purchasing vessel boats

②The cost of purchasing operators

③The cost of operator maintenance

④The cost of vessel maintenance

⑤ Cost of operator training (including skilled and novice operators)

From the symbols, the number of vessel boats demanded by the hospital in week i = the number of vascular robots demanded by the hospital in week i is n_i, the number of operators demanded by the hospital in week i is $4n_i$, the number of vessel boats to be maintained in week i is $f_i - n_i$, the number of operators to be maintained in week i is $g_i - 4n_i - y_i - \left\lceil \frac{y_i}{10} \right\rceil$. Combined with the relevant data in Annex 1, the operating cost for the first 8 weeks can be expressed as:

$$\min z = 200\sum_{i=1}^{8} x_i + 100\sum_{i=1}^{8} y_i + 10\sum_{i=1}^{8}(f_i - n_i) + 5\sum_{i=1}^{8}\left(g_i - 4n_i - y_i - \left\lceil \frac{y_i}{10} \right\rceil\right) + 10\sum_{i=1}^{8}\left(y_i + \left\lceil \frac{y_i}{10} \right\rceil\right) \quad (1)$$

Notes: $\left\lceil \frac{y_i}{10} \right\rceil$ is rounded upward and x_i, y_i, f_i, n_i, g_i are integers.

2.4. Analysis and determination of new constraints

Considering that a vascular robot working in the patient's vasculature may destroy the vascular robot due to avoidance if it encounters macrophages, the specific number of destroyed vascular robots is 20% of the vascular robots destroyed per week (the number of destroyed robots is rounded to the nearest whole number). This will result in a change in the relationship between the total number of vessel boats currently owned and the number of new vessel boats purchased, and the relationship between the total number of operators currently owned and the number of new operators purchased in question 1.

The specific factors and changes affecting the ordering of vessel robots are analyzed and sorted out as shown in Figure 2 (the changes are in orange).

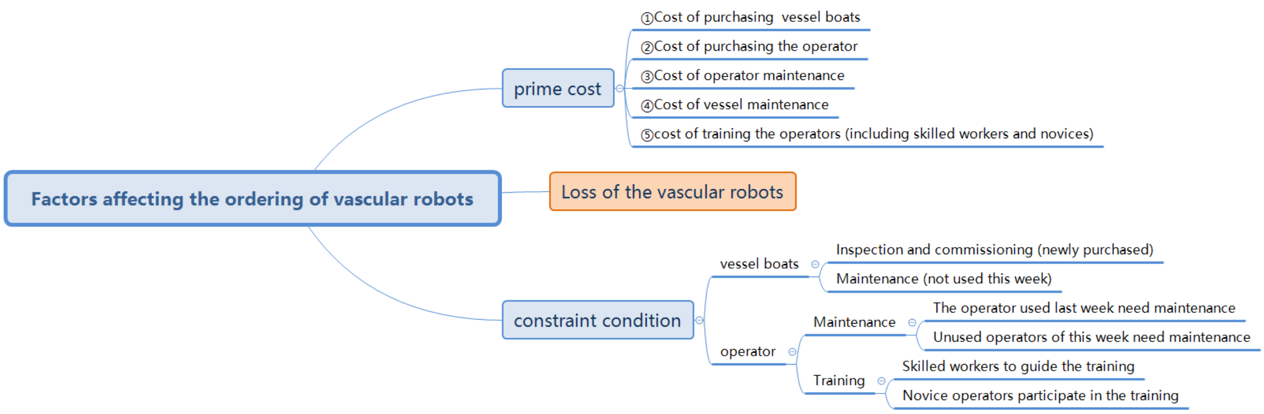

Figure 2 Analysis of factors affecting vascular robot ordering in question 2

The number of container boats owned in week i, f_i = the number of container boats owned in the previous week, $f_{(i-1)}$ + the number of new container boats purchased this week, x_i - the number of container boats destroyed last week, [$0.2 \times f_{(i-1)}$] ([ ]: indicates rounding to the nearest whole number), i.e.

$$f_i = f_{i-1} + x_i + [0.2 \times f_{i-1}] \quad (2)$$

The number of operators owned in week i g_i = the number of operators owned in the previous week $g_{(i-1)}$ + the number of newly purchased operators in this week y_i - the number of operators destroyed last week [$0.2 \times 4 \times f_{(i-1)}$] (the destruction of a vascular robot is equivalent to the destruction of 1 vessel boat and 4 operators), that is

$$g_i = g_{i-1} + y_i + [0.8 \times f_{i-1}] \quad (3)$$

2.5. Testing of the model

When running the LINGO code, it was found that there might be programming errors due to the large amount of work directly solving for weeks 1-104. In order to ensure the correctness of the model, we used the method of reducing the order of solving, i.e., we checked the results by programming the solution in segments, i.e., we first calculated the minimum operating cost for weeks 1-26, and then used the data of week 26 as the initial value to calculate the minimum operating cost for weeks 27-52. The results of the model were found to be the same as the results of programming, and the model was solved correctly.

3. Model Construction

3.1. Objective function construction

The objective function is the minimum value of the operating costs for the first 8 weeks, i.e.

$$\min z = 200\sum_{i=1}^{8} x_i + 100\sum_{i=1}^{8} y_i + 10\sum_{i=1}^{8}(f_i - n_i) + 5\sum_{i=1}^{8}\left(g_i - 4n_i - y_i - \left\lceil\frac{y_i}{10}\right\rceil\right) + 10\sum_{i=1}^{8}\left(y_i + \left\lceil\frac{y_i}{10}\right\rceil\right) \tag{4}$$

3.2. Auto ARIMA modeling

In order to predict more accurate data, we use the Auto ARIMA model, which is similar to the principle of machine learning, and automatically iterates through all common autoregressive coefficients p, moving average order q, and difference order d, and finds the optimal ARIMA prediction model that corresponds to the model with the smallest AIC value based on the value of the information criterion AIC. We can get the most suitable prediction result by making prediction based on the most suitable ARIMA model.

Considering that: $g_i \geq 4n_i + 4n_{(i+1)} + y_i + \lceil y_i/10 \rceil$ in g_i and n_i are second order, so in the Auto ARIMA model, in order to make the prediction model fit the model established earlier. We can fix the difference order d as 2 and apply the Auto ARIMA model for prediction on this basis.

4. Model solving

4.1. Creation and solution of the original solution model

Using LINGO programming to solve for the following.

The total number of container boats purchased in weeks 1-104 is 438, the total number of operators is 2310, and the optimal cost for container boats and operators to be able to meet the treatment is: ￥271,500.

Table 1 Related results data

Week	Number of vessel boats purchased	Number of operators purchased	Number of operators maintained	Number of vessel boats maintained	Number of operators participating in training	Total Cost (Unit: Yuan)
week12	0	1	153	7	1	8205
week26	0	0	126	12	0	24135
week52	21	8	396	21	8	57200
week78	8	1	471	10	1	257395
week101	0	0	492	0	0	259855
week102	6	4	489	6	4	264000
week103	15	0	466	15	0	269780
week104	0	0	404	0	0	271500
week1-104 (total)	438	2310	25832	1051	2417	271500

4.2. Modeling and solving of the new scheme

The new scenario is based on the optimal results for Weeks 1-104, with the addition of the ability to directly purchase directly usable container boats and proficiency at a high cost. This results in a change in the total cost of purchasing container boats and operators, the total cost of operators involved in training, and the total cost of operator maintenance compared to before (the rest of the total costs are the same as before). By notational assumption, the number of container boats purchased in week *i* is x_i and the number of operators purchased in week *i* is y_i. The price of the container boats purchased in week *i* is ￥300x_i and the price of the operators purchased in week *i* is ￥150y_i. By the problem assumption, the purchase of novice operators is not considered, so there is no operator involved in training, i.e., the total cost of operator involved in training is ￥0. In summary, the objective function is adjusted acknowledgements:

$$min\, z = 300\sum_{i=1}^{8} x_i + 150\sum_{i=1}^{8} y_i + 10\sum_{i=1}^{8}(f_i - n_i) + 5\sum_{i=1}^{8}(g_i - 4n_i) \quad (5)$$

Change in the relationship between the total number of operators currently used and the number of operators required by the hospital:

$$f_i + x_i \geq n_i + n_{i+1} \quad (6)$$

This will result in a change in the relationship between the total number of currently owned container boats purchased and the number of container boats required by the hospital, as follows.

$$g_i + y_i \geq 4n_i + 4n_{i-1} \quad (7)$$

In summary, the optimal ordering model for the new solution can be determined.
Objective function:

$$min\, z = 300\sum_{i=105}^{112} x_i + 150\sum_{i=105}^{112} y_i + 10\sum_{i=105}^{112}(f_i - n_i) + 5\sum_{i=105}^{112}(g_i - 4n_i) \quad (8)$$

Constraints:

$$\begin{cases} f_i = f_{i-1} + x_i - [0.1 \times f_{i-1}] \\ f_i + x_i \geq n_i + n_{i+1} \\ g_i = g_{i-1} + y_i - [0.4 \times f_{i-1}] \\ g_i + y_i \geq 4n_i + 4n_{i-1} \\ x_{104} = 15, y_{104} = 0, f_{104} = 111\ , g_{104} = 850 \\ n_{105} = 105, n_{106} = 103, n_{107} = 109, n_{108} = 105 \\ , n_{109} = 110, n_{110} = 106, n_{111} = 111, n_{112} = 107 \\ x_i, y_i, f_i, n_i, g_i is\ integer, 0 \leq\ i \leq 8 \end{cases} \tag{9}$$

5. Conclusion

The model uses a hierarchical analysis of the factors affecting the ordering of vascular robots in the form of a mind map during the modeling process to ensure that the model can consider the various constraints comprehensively and that it is easy to test the correctness of the modeling.

The model uses the idea of dynamic planning, starting from the first week and specifying the ordering scheme from the bottom up, which can directly obtain the total cost and ordering scheme for any week in between [5].

In the process of programming to solve the model, in addition to directly solving the ordering scheme for weeks 1-104, a segmented programming test is used to provide a double guarantee for the correctness of the model solution.

When solving the ordering scheme for too many weeks at once, such as directly solving the ordering scheme for weeks 1-104, the program takes much longer to run than the desired run time, i.e., the time to find the optimal solution is too long. This may put the correctness of the solution in doubt and requires a segmented programming approach to verify the accuracy of the model solution.

For that, the algorithm used in the Auto ARIMA prediction model is advanced and the prediction results of the model are more accurate. The model, based on the machine learning principle, traverses all common autoregressive coefficients p, moving average order q, and difference order d, and finds the optimal ARIMA prediction model based on the value of the information criterion AIC, and predicts the number of vascular robots used in the model for the next 105-112 weeks based on this.

The Auto ARIMA prediction model not only has a complete process of model building, model solving, and model validation, but also is able to import data directly on the specialized online data analysis software SPSSAU to achieve prediction of short-term future data.

This model is not suitable for large sample forecasting. If the question is to predict the demand for vascular robots in the next few tens of weeks, the error of using this model is so large that the model can only be replaced by other models.

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