Vascular Robotics procurement model based on dynamic programming

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Abstract. There is an increasing demand for vascular robots in the medical field, and different models of vascular robots have different use scenarios. Combining the usage characteristics and training rules of the ABLVR model vascular robot, this paper uses a dynamic programming model to optimize the hospital's short-term purchase decision for 1-8 weeks with the lowest cost as the goal. Considering the attrition of realistic use, the model is modified to derive a long-term purchase decision for hospitals with a 20% loss of robots working each week.

Keywords: Dynamic planning, Vascular robotics, Purchase decisions.

1. Introduction

A hospital uses an ABLVR model vascular robot to meet weekly hospital demand for disease treatment, which consists of two parts, a vessel boat (costing RMB200/ pc) and four operators (costing RMB100/ pc to mount on the vessel boat and replaceable) [1-2]. The new vessel needs to be commissioned for one week (10/pc/week) and the operators are divided into "novice" and "skilled", with the "novice" needing a "skilled" to lead the way through the process. The "novice" needs a "skilled worker" to take the lead and become "skilled" through one week of training before he can use it (training cost including "skilled worker" is 10 RMB/each). Each treatment is fixed for one week, the robot is removed and the operator must be maintained for one week before the vessel can be used continuously [3-4]. All components, on the other hand, must be maintained when not in use. (Operator maintenance is 5 RMB/week; vessel maintenance is 10 RMB/week) [5].

When one "skilled worker" can train ten "novices", how many vessels and operators does a hospital need to buy each week to meet the demand for 1-8 weeks at the lowest cost? In a real-world scenario, how many vessels and operators should a hospital buy each week to meet 1-104 weeks of demand at the lowest cost when the robot has a 20% loss per week (rounded up to the nearest whole number)? What is the corresponding cost?

2. Short-term hospital purchasing decisions without considering wastage

2.1. Pre-study preparation

Phasing of dynamic planning.

Each week requires the number of components to be considered for purchase, so each week is a phase T_i denoted as week i and we will make a decision at the beginning of each week.

State variables of the phase.

Each phase determines the number of robots required in week i, based on the weekly demand, the number of container boats available R_i, the number of operators available S_i, the number of working robots S_i^{on}, the number of working container boats R_i^{on}, the number of robots without working arrangements Soffi, the number of robots dismantled in the last week S_i^{out}, the number of "skilled workers" involved in training Strain. Number of "skilled workers" S_i^{train}, Number of container boats without working arrangements R_i^{off}.

Decision variables.

At the beginning of week i, we have to decide on the number of new container boats X_i and the number of new robots Y_i to be purchased.

2.2. Model building

(1) Objective function analysis

The total cost is the sum of the weekly costs to obtain the objective function:

$$\min C = \sum_1^i minC_T \tag{1}$$

(2) Weekly cost analysis

The weekly cost is divided into the maintenance cost of the robot without work arrangement; the cost of maintenance of the manipulator under disassembly; the cost of training for the "skilled workers" involved in the training; the cost of training for "novices" involved in training; the cost of inspection of newly purchased container boats [6]; maintenance costs for container boat with no work schedule; the cost of purchasing manipulators and containers boat this week:

$$C_T = \left(S_i^{off} + S_i^{out}\right) \times 5 + \left(S_i^{train} + Y_i + X_i + R_i^{off}\right) \times 10 + X_i \times 200 + Y_i \times 100 \tag{2}$$

(3) Analysis of weekly decision constraints

Number of manipulators under disassembly for the next week = number of manipulators working this week, as follow:

$$S_{i+1}^{out} = S_i - S_i^{off} - S_i^{out} - S_i^{train} \tag{3}$$

The number of manipulators that can work this week = manipulators that have no work arrangement in the previous week + "skilled workers" who participated in training in the previous week + "novices" who purchased training in the previous week + manipulators maintained in the previous week, as follow:

$$S_i^{on} = S_{i-1}^{off} + S_{i-1}^{train} + Y_{i-1} + S_{i-1}^{out} \tag{4}$$

Container boats that can work this week = container boats that were inspected last week + mechanical boats that worked last week + mechanical boats that did not work last week, as follow:

$$R_i^{on} = X_i + R_{i-1} \tag{5}$$

Number of manipulators working this week≥ Number of robots needed for work this week ×4, as follow:

$$S_{i-1}^{out} \geq Q_{i-1} \times 4 \tag{6}$$

The number of "skilled workers" participating in training this week× and the number of individual "skilled workers" training can guide ≥ the number of robots purchased this week, as follow:

$$S_i^{train} \times 10 \geq Y_i \tag{7}$$

In summary, we obtain the constraint I of the decision UI for each i week:

$$s.t.\begin{cases} C_T = \left(S_i^{off} + S_i^{out}\right) \times 5 + \left(S_i^{train} + Y_i + X_i + R_i^{off}\right) \times 10 + X_i \times 200 + Y_i \times 100 \\ S_{i+1}^{out} = S_i - S_i^{off} - S_i^{out} - S_i^{train} \\ S_i^{on} = S_{i-1}^{off} + S_{i-1}^{train} + Y_{i-1} + S_{i-1}^{out} \\ R_i^{on} = X_i + R_{i-1} \\ S_{i-1}^{out} \geq Q_{i-1} \times 4 \\ S_i^{train} \times 10 \geq Y_i \end{cases} \tag{8}$$

At the beginning of each week, under the constraints of decision-making conditions, we make the best decision of the week, progressing from the first week to the 8th week, and finally select the overall optimal solution, Dynamic decision-making processes of container boats and operator are shown in figure 1 and figure 2, respectively.

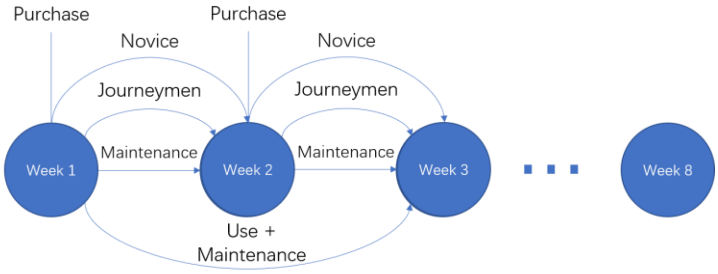

Figure 1. Dynamic decision-making process of container boats

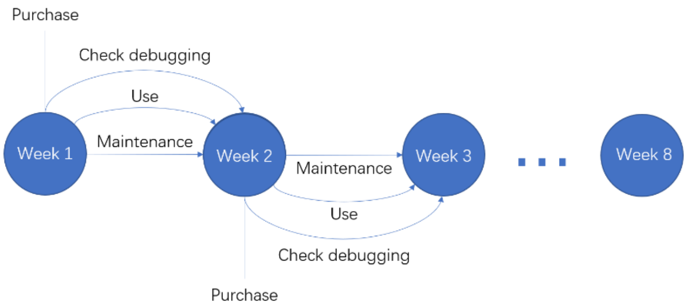

Figure 2. Dynamic decision-making process of the operator

The $\min C_T$ selected in each round can finally make the final objective function:

$$\min C = \sum_1^i \min C_T \tag{9}$$

2.3. Solving the model

Two variables need to be decided-- the number of new container boats purchased X_i and the number of new manipulators Y_i. Because the conditions for the two decisions are different, we calculate the container boats and operators separately [7].

(1) Algorithm of the container boat is shown in figure 3.

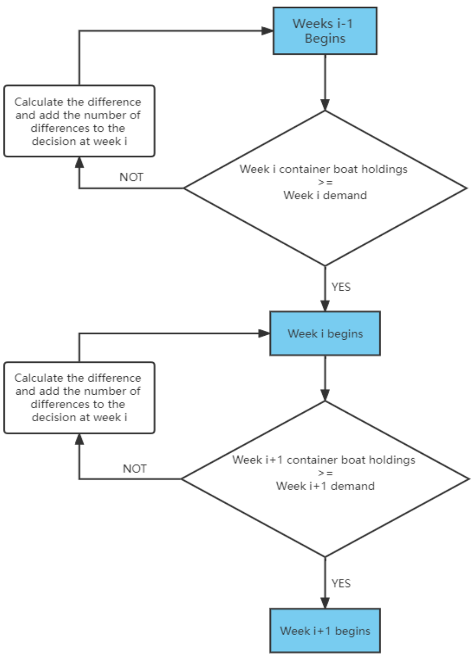

Figure 3. Algorithm idea of a container boat

Steap1: Compare the number of container boats currently in possession with the demand for this week before the start of each week, and if the conditions are met, enter the next week's decision, if not, you need to go to the previous week to make up the shortfall.

Steap2: Calculate the weekly cost of the container boats. The cost is the number of container boats decided to buy every week multiplied by the unit price of 200 yuan per boat. If there are container boats in the maintenance state in the week, the cost also needs to add the maintenance cost of 10 yuan per boat.

The calculation of container boats is relatively simple, repeating the algorithm idea until the 8th week can determine the best decision of the week so that there is the best purchase decision in 8 weeks [8].

(2) Calculation of manipulators, the Algorithm idea of the manipulator is shown in figure 4.

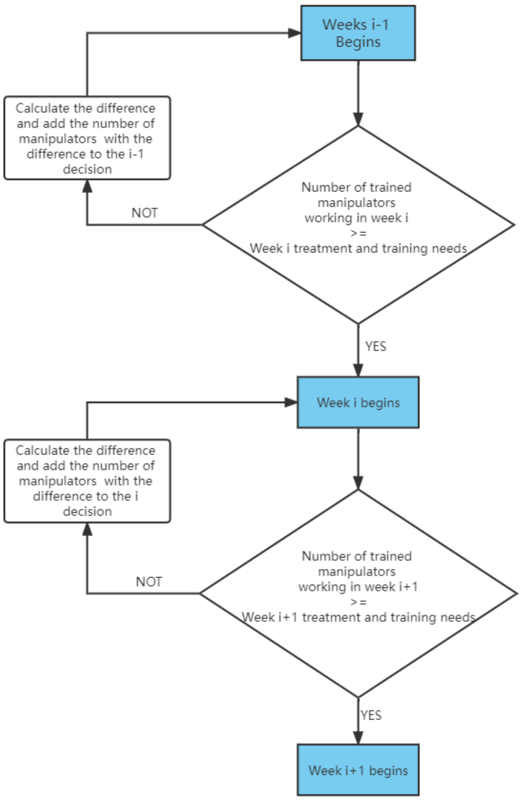

Figure 4. Algorithm idea of a manipulator

The consideration of the manipulator is more complicated because the manipulator must maintain for one week of work, and every 10 "novices" must be trained by a "journeyman", so the complexity of the weekly manipulator decision-making is greatly increased.

We initially set the number of robot purchases per week to 0. Starting from the first week, calculate the number of robots (skilled workers) available for work this week and compare the number of robots required for work and training (skilled workers) during the week. If you can meet the needs of this week's work and training, enter the calculation of next week's work. If the needs of this week's work and training cannot be met, the number of manipulators required to meet the week's work and training is added to the number of manipulators purchased in the previous week and entered in the calculation of last week's work [9].

Among them, due to the addition of the previous week's new manipulators each time, may lead to the need for more "skilled workers" in the previous week to calculate it, and if the number is insufficient and need to return to the week before last to make up for it, the program goes back to the week before last and recycles until the 8th week is determined, the weekly decision is finalized, otherwise, it has been in the process of dynamic change. Based on this idea, the final calculation yields are shown in table 1:

Table 1. Short-term 1-8 week purchase decisions

Number of weeks	Number of container boats purchased	The number of operated lots purchased
1	0	14
2	0	0
3	0	0
4	3	28
5	0	0
6	0	0
7	0	0
8	0	0

Our total cost for 1-8 weeks is 7625 RMB

3. Considering long-term hospital purchasing decisions when using wear and tear

3.1. Research preparation

Phasing of dynamic programming:

To calculate the number of parts purchased per week, so each week is a phase T_i represented as the i week, and we decide at the beginning of each week.

Status variables for the stage:

Each stage is based on the weekly demand. There is a demand for robots Q_i per i week, the weekly damage is W_i, the number of existing container boats R_i, the number of existing operators S_i, the number of manipulators that can work S_i^{on}, the number of working container boats R_i^{on}, the number of manipulators without work arrangement S_i^{off}, the number of manipulators dismantled last week S_i^{out}, the number of "skilled workers" participating in training S_i^{train}, and the number of container boats without work arrangement R_i^{off}.

Decision variables:

At the beginning of every week, we decide on the number of new container boats X_i and the number of new manipulators Y_i.

3.2. Model building

(1) Objective function analysis

The total cost is the sum of the weekly costs to obtain the objective function:

$$\min C = \sum_1^i minC_T \tag{10}$$

(2) Weekly cost analysis

The weekly cost is divided into the maintenance cost of the robot without work arrangement; the cost of maintenance of the manipulator under disassembly; the cost of training for the "skilled workers" involved in the training; the cost of training for "novices" involved in training; Inspection costs for newly purchased container boat; Maintenance costs for vessels with no work schedule; the cost of purchasing a manipulator and container boat this week：

$$C_T = \left(S_i^{off} + S_i^{out}\right) \times 5 + \left(S_i^{train} + Y_i + X_i + R_i^{off}\right) \times 10 + X_i \times 200 + Y_i \times 100 \tag{11}$$

(3) Analysis of constraints

Number of manipulators disassembled in the next week = Number of manipulators working this week - Number of robot damage this week × 4, as follow:

$$\mathrm{S}_{\mathrm{i+1}}^{\mathrm{out}}=\left(\mathrm{S}_{\mathrm{i}}-\mathrm{S}_{\mathrm{i}}^{\mathrm{off}}-\mathrm{S}_{\mathrm{i}}^{\mathrm{out}}-\mathrm{S}_{\mathrm{i}}^{\mathrm{train}}\right)-W_i\times 4 \tag{12}$$

The number of manipulators that can work this week = manipulators that have no work arrangement in the previous week + "skilled workers" who participated in training in the previous week + "novices" who purchased training in the previous week + manipulators maintained in the previous week, as follow:

$$\mathrm{S}_{\mathrm{i}}^{\mathrm{on}}=\mathrm{S}_{\mathrm{i-1}}^{\mathrm{off}}+\mathrm{S}_{\mathrm{i-1}}^{\mathrm{train}}+\mathrm{Y}_{\mathrm{i-1}}+\mathrm{S}_{\mathrm{i-1}}^{\mathrm{out}} \tag{13}$$

Container boat that can work this week = container boat that was inspected last week + mechanical boat that worked last week + mechanical boat that did not work last week - mechanical boat that was damaged by last week's work, as follow:

$$\mathrm{R}_{\mathrm{i}}^{\mathrm{on}}=\mathrm{X}_{\mathrm{i}}+\mathrm{R}_{\mathrm{i-1}}-W_i \tag{14}$$

Number of damaged robots this week = Number of robots in demand this week ×20%

$$w_i = Q_i \times 20\% \tag{15}$$

Number of manipulators working this week≥ Number of robots needed for work this week ×4, as follow:

$$\mathrm{S}_{\mathrm{i-1}}^{\mathrm{out}}\geq \mathrm{Q}_{\mathrm{i-1}}\times 4 \tag{16}$$

The number of "skilled workers" participating in training this week× the number of individual "skilled workers" training can guide ≥ the number of robots purchased this week, as follow:

$$\mathrm{S}_{\mathrm{i}}^{\mathrm{train}}\times 10\geq \mathrm{Y}_{\mathrm{i}} \tag{17}$$

In summary, we get the constraint II of the decision u_i for each i week：

$$s.t.\begin{cases} C_T=\left(\mathrm{S}_i^{off}+\mathrm{S}_i^{out}\right)\times 5+\left(\mathrm{S}_{\mathrm{i}}^{\mathrm{train}}+\mathrm{Y}_{\mathrm{i}}+\mathrm{X}_{\mathrm{i}}+\mathrm{R}_{\mathrm{i}}^{\mathrm{off}}\right)\times 10+X_i\times 200+Y_i\times 100 \\ \mathrm{S}_{\mathrm{i+1}}^{\mathrm{out}}=\left(\mathrm{S}_{\mathrm{i}}-\mathrm{S}_{\mathrm{i}}^{\mathrm{off}}-\mathrm{S}_{\mathrm{i}}^{\mathrm{out}}-\mathrm{S}_{\mathrm{i}}^{\mathrm{train}}\right)-W_i\times 4 \\ \mathrm{S}_{\mathrm{i}}^{\mathrm{on}}=\mathrm{S}_{\mathrm{i-1}}^{\mathrm{off}}+\mathrm{S}_{\mathrm{i-1}}^{\mathrm{train}}+\mathrm{Y}_{\mathrm{i-1}}+\mathrm{S}_{\mathrm{i-1}}^{\mathrm{out}} \\ \mathrm{R}_{\mathrm{i}}^{\mathrm{on}}=\mathrm{X}_{\mathrm{i}}+\mathrm{R}_{\mathrm{i-1}}-W_i \\ w_i=Q_i\times 20\% \\ \mathrm{S}_{\mathrm{i-1}}^{\mathrm{out}}\geq \mathrm{Q}_{\mathrm{i-1}}\times 4 \\ \mathrm{S}_{\mathrm{i}}^{\mathrm{train}}\times 10\geq \mathrm{Y}_{\mathrm{i}} \end{cases} \tag{18}$$

At the beginning of each week, under the constraints of decision conditions, we make the best decision of the week, starting from the first week to week 104, and finally selecting the overall optimal solution. Decision process is shown in figure 5.

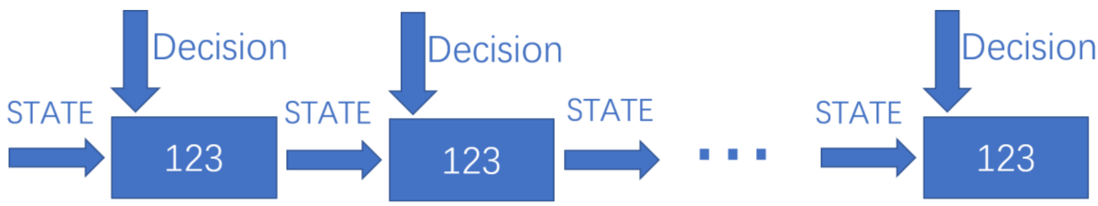

Figure 5. Decision process

The $\min C_T$ selected in each round can finally make the final objective function：

$$\min C=\sum_1^i \min C_T \tag{19}$$

3.3. Solving of the model

The solution can be based on the idea in the previous section, we only need to subtract 20% of the damage of the last week's demand robot before making a weekly decision. The procedure needs to be cycled up to 104 weeks. The final purchase decision is shown in Table 2 below.

Table 2. Long-term purchasing decisions

Week	Number of container boats purchased	Number of manipulators purchased	Number of manipulators under maintenance	Number of container boats under maintenance	Number of trained manipulators (including "skilled man" and "novice")	Total cost (Unit: yuan)
Week 12	5	16	34	1	18	2960
Week 26	0	0	108	9	0	630
Week 52	21	133	72	0	147	19330
Week 78	16	50	177	0	55	9635
Week 101	12	68	317	0	75	11535
Week 102	17	38	348	0	42	9360
Week 103	25	92	316	0	102	16800
Week 104	0	0	314	0	0	1570
Total	879	3904	13864	131	4325	680080

4. Conclusions

For short-term purchasing decisions, given the conditions that a "journeyman" can train 10 "novices", this paper modifies the planning model, due to the difference in the decision-making rules of container boats and operators, so we design calculation ideas respectively to consider them from the first week, and finally obtain 1-8 weeks of purchase results through the cycle, a total of 3 container boats and 42 operators are purchased, with a total cost of 7625 yuan.

When considering that robots working per week are 20% damaged, this article adds constraints and modifies weekly costs. Due to the need to consider the long-term purchase of 1-104 weeks, the number of cycles of the algorithm was increased, and finally the result was obtained, a total of 879 container boats and 3904 operators were purchased, with a total cost of 680080 yuan.

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