An Improved Ant System Algorithm for the Ship Lock Arrangement Problem

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Abstract. With the fast development of the inland waterway transport and the increasing of quantity ships, it is obviously exposed the deficiency of inland river ship locks navigation capacity. In order to improve the ship lock navigation capability, to ensure convenient, safe, stable and orderly navigation through the ship locks, this paper established the improved ant system algorithm for the ship lock arrangement, and implemented corresponding algorithm through further design. The calculation results show that the improved ant system algorithm is effective in application of the ship lock arrangement.

1 Introduction

There are many rivers in china, and the inland navigation resources are abundant. With the rapid development of economy, the flow of vessels in the inland rivers is increasing, meantime the ship locks of the inland rivers are facing the heavy pressure, the ship locks navigable capacity is insufficient increasingly. The vessels waiting for passing the ship locks have been become normal. Take the Three Gorges ship locks as an example, the average waiting time has from hours per ship in 2007 rapidly increased to 30 to 60 hours per ship in 2012, the longest 5-7 days even, that does not include special cases such as the bad weather, the Yangtze River flow for excess and the ship locks overhaul. Although the ship lift of the Three Gorges was completed in 2015 and reduces the waiting time for the ship to pass through the dam (about 40 minutes)[1], the vessels detained remain serious, causing potential unsafety factors to the Three Gorges Dam, and meantime, the water transport cost of the whole channel is also high and efficiency is low. Therefore, it is very significance to study the relevant technical issues for improving the navigable capacity, so as to give full play to the comprehensive benefits of the whole country rivers and ensure the rapid development of the economy and society. More and more scholars have done lots of research about the ship lock arrangement optimization [1-9].

2 The ship lock arrangement problem posing

There are many factors that affect the navigable capacity, but it can be analyzed through the designed ship lock formula. The calculation formula in the Code for Master Design of Shiplocks (JTJ 305-2001) is shown in equation (1).
\[ P = \frac{(n - n_0) a NG}{b} \]  

(1)

\( P \) is the annual volume of freight transport passing through the ship lock.  
\( n \) is the average daily number of passing lockage.  
\( n_0 \) is the times of the non-cargo ship passing through the ship lock in the day and night.  
\( a \) is the coefficient of ship loading.  
\( N \) is the annual navigable days.  
\( G \) is the average tonnage of once passing lockage.  
\( b \) is the unbalanced coefficient of monthly traffic volume.  

\( n_0, a \) and \( b \) are determined according to the statistical data of the ship lock in a specific channel. But when the ship lock is actually in operation, obviously these parameters are random. Therefore, when a certain random situation occurs (i.e. the value of parameter \( N, n_0, a \) and \( b \) are given), the navigable capacity can be improved by increasing the average tonnage of once passing lockage and the average daily number of passing lockage. That is the maximum value problem about the average tonnage of once passing lockage, namely,

\[ P_{\text{actual}} = \sum_{i=1}^{n} \max(G_i) \]  

(2)

\( P_{\text{actual}} \) is the actual annual deadweight tonnage of lockage vessels.  
\( G_i \) is the \( i \)th time average tonnage of once passing lockage.

At present, the standard ship type coefficient method or the fleet arrangement method [8] is usually used to calculate the average tonnage of once passing lockage. The idea of the fleet arrangement method is very suitable for determining the parameter \( G_i \), this is actually a problem of arranging as many passing ships (small areas) as possible in a given limited area (the ship lock chamber), so as to improve the navigable capacity, which is called the arrangement problem of the ship lock (SLAP). The SLAP must meet the following constraints:

1) Waiting vessels cannot be overlapped each other.  
2) Waiting vessels cannot beyond the boundary of the ship lock chamber.  
3) Waiting vessels can't arbitrarily be rotated, vessel head direction is parallel to lock chamber side.

### 3 An improved ant system algorithm for the ship lock arrangement

The improved Ant System algorithm [10] is extended from the basic Ant System algorithm[11], the basic Ant System algorithm is a stochastic optimization technique proposed by Dorigo et al. it can be described as the artificial ants indirectly communicate by the pheromone trail, which are a kind of distributed numeric information, and move to explore a search space in order to find the best solution for a particular problem. The improved Ant System algorithm uses the elitist ants strategy and the rank ants strategy relative to the basic Ant System algorithm. The quality of the solutions produced by two strategies could be improved.

The idea of the elitist ants strategy is that the optimal solution is found by a certain number of the so-called elitist ants, and give extra emphasis to some of the pheromone trail intensity after every cycle, namely, the pheromone trail intensity is weighted according to the quantity of the elitist ants.

The idea of the rank ants strategy is that the artificial ants are sorted by the solution found by themselves respectively from large to small, the pheromone trail intensity of the artificial ants in front is updated, namely, the pheromone trail intensity is weighted
according to the rank of the ants, the smaller the order, the greater the contribution of update.

Furtherly, the improved Ant System algorithm will be explained by building the solution of the SLAP.

3.1 Description of the improved ant system algorithm for the SLAP

Initially, m artificial ants randomly chose m waiting vessels. Then, in each construction step, each artificial ant selects a waiting vessel with a probability according to formula (3).

\[
p_i^k(t) = \begin{cases} \frac{\tau_i(t)^\alpha \cdot \eta_j^\beta}{\sum_{j \in \text{tabu}_k} \tau_j(t)^\alpha \cdot \eta_j^\beta} & \text{if } i \notin \text{tabu}_k \\ 0 & \text{otherwise} \end{cases}
\]

where \(i\) and \(j\) are the number of the waiting vessel, \(1 \leq i \leq h, 1 \leq j \leq h, h\) is the total amount of the waiting vessels.

\(t\) is the number of the cycle, \(1 \leq t \leq n, n\) is the total amount of the cycles.

\(k\) is the number of the \(kth\) artificial ant, \(1 \leq k \leq m, m\) is the total amount of the artificial ants.

\(p_i^k(t)\) is the probability that the \(kth\) artificial ant selects waiting vessel \(i\) at the \(t\) times.

\(\tau_i(t)\) is the pheromone trail associated with the waiting vessel \(i\), \(\tau_j(t)\) is the pheromone trail associated with the waiting vessel \(j\).

\(\eta_i\) is the heuristic information associated with the utilization rate of the waiting vessel \(i\) to the ship lock chamber, \(\eta_j\) is the heuristic information associated with the utilization rate of the waiting vessel \(j\) to the ship lock chamber.

\(\alpha\) and \(\beta\) are a parameter that adjust the relative importance between the pheromone trail and the heuristic information, \(\alpha \geq 0, \beta \geq 0\).

\(\text{tabu}_k\) is a set of the waiting vessels which already selected by the \(kth\) ant, all ants cannot select them again.

After every cycle, the pheromone trail updated according to the rule (4).

\[
\tau_i(t + 1) = \rho \tau_i(t) + \Delta \tau_i + \Delta \tau_i^{best}
\]

where \(\rho\) is a coefficient which regulates the reduction of the pheromone trail, \(0 \leq \rho \leq 1\).

\(\Delta \tau_i\) represents the total increase of the pheromone trail associated with waiting vessel \(i\), it calculated according to the formula (5).

\[
\Delta \tau_i = \sum_{r=1}^{e} \Delta \tau_i^r
\]

where \(r\) is the \(rth\) best artificial ant. After all artificial ants have completed one time selecting, the artificial ants are sorted by the solution found by themselves respectively from small to large, the best artificial ant is one of the first artificial ants in the order of small to large, \(r\) can be regarded as order number, \(0 \leq r \leq e\), \(e\) is the quantity of the elitist artificial ants, \(0 \leq e \leq m\).

\(\Delta \tau_i^r\) according to the following formula (6).

\[
\Delta \tau_i^r = \begin{cases} (\sigma - \mu_r) \cdot f(s') & \text{if the } rth \text{best ant selects the waiting vessel } i \\ 0 & \text{otherwise} \end{cases}
\]

where \(\sigma\) is the weight associated with the quantity of the elitist artificial ants.
\[ \mu_r \] is the weight associated with the rank of the \( r \)th best artificial ant.

\[ f(s') \] denotes the solution found by the \( r \)th best artificial ant.

\[ \Delta r_{i}^{best} \] represents the increase of the pheromone trail caused by the elitist artificial ants, it is given by (7).

\[ \Delta r_{i}^{best} = \begin{cases} \alpha \cdot f(s_{\text{best}}) & \text{if the waiting vessel } i \text{ is part of the best solution found so far} \\ 0 & \text{otherwise} \end{cases} \]  

where \( f(s_{\text{best}}) \) the highest utilization rate of the chamber arrangement found so far.

The parameters in the improved Ant System algorithm for the SLAP are chosen as follows:

\[ m=20, \quad e=6, \quad \rho=0.1, \quad \alpha=1.0, \quad \beta=2.0. \]

3.2 Computational results

The Improved Ant System algorithm for the SLAP has been designed and implemented with VC++ in Win10. This paper tests the validity through one example of the Qingyuan Water Conservancy ship lock arrangement. In the calculation process, the ship lock chamber regards as the rectangular, waiting vessels are replaced by an envelope, the envelope is a rectangular region. In the following figures, the number that showed in the figures is the waiting vessel number.

The example uses the data which is the data of the appendix 4 given in [7], the ship lock chamber utilization rate can reach 84% and it was recorded in table 3-4. The ship lock chamber utilization rate is 86.43% by the Improved Ant System algorithm for the SLAP, the ship lock chamber regards as the rectangular with 180 meters length and 23 meters width, the ship lock chamber arrangement is showed in Fig. 1. The ship lock chamber utilization rate is 92.54% by the Improved Ant System algorithm for the SLAP, the ship lock chamber regards as the rectangular with 320 meters length and 32 meters width, the ship lock chamber arrangement is showed in Fig. 2.

![Figure 1](image1.png)

Figure 1. Lock chamber arrangement (180 meters length 23 meters width).

![Figure 2](image2.png)

Figure 2. Lock chamber arrangement (320 meters length 32 meters width).

4 Conclusions

The experimental results of the above examples show that the Improved Ant System algorithm for the SLAP is effective to the ship lock arrangement optimization, this paper also provides the idea and the method for improving the practical navigable capacity and solving the optimization problem.

Authors thank Bullnheimer B and Liu Yuanyuan et al for the related research on the Improved Ant System algorithm and the ship lock arrangement.
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