The Best-Worst Ant System for the Lock Chamber Arrangement Problem

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Abstract. There are many rivers in china, and the inland navigation resources are abundant. 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 safe, convenient, stable and orderly navigation through the ship locks, this paper used a best-worst ant system to solve the lock chamber arrangement optimization problem, established the best-worst ant system for the lock chamber arrangement, implemented corresponding algorithm through further design, and tested the validity of it through the Yangtze Gorges lock chamber arrangement and the Qingyuan Water Conservancy lock chamber arrangement. The calculation results show that the best-worst ant system is effective in application of the lock chamber arrangement.

1. Introduction
There are lots of rivers in our country, and the inland waterway transport resources are very abundant, as the rapid development of the inland waterway transport and the increasing of quantity ships, it has become more and more crowded with the inland ship traffic, especially for the ship locks. So it brings the heavy pressure to the inland river ship locks, and shows the deficiency of the ship lock navigation capacity, the waiting passing ships have become common. Take the Three Gorges ship lock as example, according to the data provided by the Three Gorges navigation administration, the navigation capacity of the Three Gorges ship lock reached 100 million tons in 2011, reaching the design value of shipping standard 19 years ahead of schedule, the average waiting time is 33 hours per ship, the Three Gorges ship lock has become the "blocking" point on the "water highway" of the Yangtze River. The contradiction that between the increasing demand of ship passing through the dam and the insufficient capacity of ship lock has become the main contradiction of navigation in the Three Gorges. Meantime it causes potential safety problems, in addition, the channel's water transport has higher cost and lower efficiency. Therefore, it has very important significance to research and improve the ship locks navigation capability.

In research the ship locks navigation capability, Shang et al. classified the researches associated with the lock throughput capacity and summarized the difference [1]. Other useful research had been done by domestic and foreign scholars on the ship locks navigation capability [2-12]. This paper analyzed the navigation capacity of the ship lock and its main influencing factors, applied the best-worst ant system to the lock chamber arrangement optimization, designed and implemented the corresponding algorithm, and tested the validity of it through the Yangtze Gorges lock chamber arrangement and the Qingyuan Water Conservancy lock chamber arrangement. The calculation results show that the best-worst ant system is effective in application of the lock chamber arrangement.
2. Lock Chamber Arrangement Problem

2.1. Influencing Factors Analysis of the Ship Lock Navigation Capacity
There are many factors that affect the navigation capacity, but it can be analysed through the designed ship lock formula. The calculation formula in the Code for Master Design of Shiplocks (JTJ 305-2001) [1] is shown in equation (1).

\[ P = \left( n - n_0 \right) aNG \frac{1}{b} \]  

(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 navigation 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 navigation 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,

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

(2)

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

2.2. Determination of the Parameter \( G_i \)
The determination of the \( ith \) passing tonnage \( G_i \) with the actual operation of the ship lock also needs to refer to the calculation of the average passing tonnage \( G \) when design the ship lock. At present, the standard ship type coefficient method or the fleet arrangement method is usually used to calculate the average tonnage of once passing lockage.

The standard ship type coefficient method is to multiply the design maximum ship type by a certain coefficient to get the average tonnage of once passing lockage. This method is more random and difficult to determine the coefficient. Obviously, this method is not suitable for determining the parameter \( G_i \), because the waiting vessels are known when the ship lock is actually in operation.

The fleet arrangement method is to determine the average tonnage of once passing lockage by combining different ship types and fleets. However, there are many problems when calculate the average tonnage of once passing lockage, such as the variety of the ship types and the fleet types in actual operation, and the arrival of various ships to the ship lock is random, so it is difficult to reasonably determine the combination of design the ship types and the proportion of design the ship types to pass the ship lock in the whole year.

2.3. The Lock Chamber Arrangement Problem Posing
In order to improve the formula (1) calculation method, some scholars use more operational method to calculate the average tonnage of once passing lockage [1]:

\[ G = g_s \frac{\lambda S}{s(g_s)} \]  

(3)

\( g_s \) is the average tonnage of lockage vessels.
\( s(g_s) \) is the function relation between ship tonnage and ship area.
$S$ is the effective area of the lock chamber.

$\lambda$ is the effective utilization rate of the lock chamber.

This method transforms the calculation of the average tonnage of once passing lockage into the relation between the average tonnage of lockage vessels, the effective area of the lock chamber and the effective utilization rate of the lock chamber.

Combine equations (2), (3) and the idea of the fleet arrangement method, this is actually a problem of arranging as many passing ships (small areas) as possible in a given limited area (the lock chamber), the lock chamber regards as the rectangular, waiting vessels are replaced by an envelope, the envelope is a rectangular region, which defines the minimum circumscribed rectangle of each geometry. So as to improve the navigation capacity, which is called lock chamber arrangement problem (hereinafter called LCAP). The LCAP must meet the following constraints:

- Waiting vessels cannot be overlapped each other.
- Waiting vessels cannot beyond the boundary of the lock chamber.
- Waiting vessels cannot arbitrarily be rotated, vessel head direction is parallel to lock chamber side.

3. Best-Worst Ant System for the Lock Chamber Arrangement Problem

3.1. Ant System

The ant system is an evolutionary simulation algorithm proposed by Dorigo et al [13], which is an abstract simulation of the movement of ant colony. The basic idea of the ant system can be described as follows: artificial ants through mutual cooperation to complete the processing of the designated problem. This kind of cooperation is realized by simulating that ants in the real world leave a certain amount of so-called pheromone material on their path, this substance can be perceived by other ants, and affect the next path of other ants. The higher the pheromone concentration on the path, the greater the probability of other ants passing the path again. The lower the pheromone concentration, the less the probability of other ants passing the path again. Therefore, the group behaviour of a large number of ants shows a positive feedback phenomenon.

3.2. Description of the Best-Worst Ant System for the LCAP

The best-worst ant system [14] was first describes by Cordon O., and has some successful applications in many fields [15-16], it differs from the other ant algorithms in updating pheromone trail. In the best-worst ant system, the pheromone trail of the worst solution in current cycle will be updated except the pheromone trail of the global best solution will be updated after each cycle, the pheromone trail of the components of the global solution is increased, the pheromone trail of the components of the worst solution is reduced, meantime the components are not part of the components of the global solution. In order to avoid algorithm stagnation caused by the pheromone trails of the worst solution are very close to zero and the pheromone trails of the global best solution are very high, the best-worst ant system set all the pheromone trails to initial value when the components between the global solution and the worst solution are lesser than a specific percentage. At the same time, the pheromone trail is diverse by using the pheromone trail mutation to enhance the exploration instead of the exploitation at the later stage. Furtherly, the best-worst ant system will be explained by building the solution of the LCAP.

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 rule (4).

$$
p_{i}^{k}(t) = \begin{cases} 
\frac{[\tau_{j}(t)]^{\alpha}[\eta_{j}]^{\beta}}{\sum_{j \notin \text{tabu}_k} [\tau_{j}(t)]^{\alpha}[\eta_{j}]^{\beta}} & \text{if } i \notin \text{tabu}_k \\
0 & \text{otherwise}
\end{cases}
$$

(4)
where \( i \) and \( j \) are the number of the waiting vessel, \( 1 \leq i \leq n \cdot 1 \leq j \leq n \cdot n \) is the quantity of waiting vessels.

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

\( k \) represents the \( kth \) ant, \( 1 \leq k \leq m \cdot m \) is the quantity of ants.

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

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

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

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

\( tabu_k \) is the 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 rule (5).

\[
\tau_i(t+1) = (1-\rho) \tau_i(t) + \Delta \tau_i
\]

\( \Delta \tau_i \) represents the total increase of the pheromone trail associated with waiting vessel \( i \), it calculated according to equation (6).

\[
\Delta \tau_i = \sum_{k=1}^{m} \Delta \tau_i^k
\]

where \( \Delta \tau_i^k \) represents the increase of the pheromone trail caused by the \( kth \) artificial ant, according to rule (7).

\[
\Delta \tau_i^k = \begin{cases} Q \cdot f(s_{global\_best}) & \text{if } i \in s_{global\_best} \\ 0 & \text{otherwise} \end{cases}
\]

\( Q \) is a parameter. \( f(s_{global\_best}) \) is the utilization rate of the lock chamber effective area that is associated the global best solution.

The pheromone trail of the components of the worst solution but not part of the components of the global solution according to the rule (8).

\[
\tau_i(t+1) = (1-\rho) \tau_i(t)
\]

When the components between the global solution and the worst solution are lesser than a specific percentage, the best-worst ant system set all the pheromone trail to initial value \( \tau_0 \).

At the same time, all the pheromone trails are mutated with probability \( P_m \) as follows:

\[
\tau_i = \begin{cases} \tau_i + \text{mut}(t, \tau_{\text{threshold}}) & \text{if } \sigma = 0 \\ \tau_i - \text{mut}(t, \tau_{\text{threshold}}) & \text{if } \sigma = 1 \end{cases}
\]

\( \tau_{\text{threshold}} \) is the average of the pheromone trail associated to the global solution. \( \sigma \) is a parameter, \( 0 \leq \sigma \leq 1 \).

\( \text{mut}(t, \tau_{\text{threshold}}) \) is calculated according to rule (10).

\[
\text{mut}(t, \tau_{\text{threshold}}) = \frac{t - t_{\text{reset}}}{C - t_{\text{reset}}} \tau_{\text{threshold}}
\]

\( t_{\text{reset}} \) is the number of the last cycle when the components between the global solution and the worst solution are lesser than a specific percentage, \( 1 \leq t_{\text{reset}} \leq C \).

The best-worst ant system for the LCAP is described as follows:
(1) Parameter initialization.
Set $\alpha=1.0$, $\beta=2.0$, $Q=10$, $m=20$.

(2) For all artificial ants
Repeat
Every artificial ant selects the next waiting vessel according to the state transfer rules (4)
Until the lock chamber cannot be arranged
(3) Find out the value of the current worst lock chamber arrangement and the global best lock chamber arrangement, calculates the total increase of the pheromone trail according to (6) and (7).
(4) The corresponding pheromone trail value is updated according to rule (5) and (8).
(5) Mutate all the pheromone trails according to the rule (9) and (10).
(6) Judge whether the components between the global solution and the worst solution are lesser than a specific percentage or not, if lesser, set all the pheromone trail to initial value $\tau_0$.
(7) Judge the convergence condition. If not, continue to repeat. Otherwise, the result of the LCAP is given and the program is finished.

3.3. Computational Results
The best-worst ant system for the LCAP has been designed and implemented with VC++ in Win10. This paper tested the validity of the best-worst ant system for the LCAP through two examples. One is the Three Gorges lock chamber arrangement, the other is the Qingyuan Water Conservancy lock chamber arrangement, the number that showed in the figures is the waiting vessel number.

The first example uses the data which is the 2th instance’s data in Ref. [12]. In the calculation process, the Three Gorges lock chamber regards as the rectangular with 280 meters length and 34 meters width, waiting vessels are replaced by an envelope. The lock chamber utilization rate is 91% by the best-worst ant system for the LCAP, the lock chamber arrangement is shown in figure 1.

![Figure 1. Lock chamber arrangement of 1st example.](image1)

The second example uses the data which is the data of the appendix 4 given in Ref. [10], the ship lock chamber utilization rate can reach 84% and it was recorded in table s of Ref. [10]. The lock chamber utilization rate is 92.67% by the best-worst ant system for the LCAP, the lock chamber regards as the rectangular with 320 meters length and 32 meters width, the lock chamber arrangement is shown in figure 2.

![Figure 2. Lock chamber arrangement of 2nd example.](image2)

4. Conclusions
Based on the existing research work, navigation department scheduling experience and the analysis of the factors influencing of the ship lock navigation capacity, this paper from the angle of improving the once lockage tonnage to improve the ship lock navigation capacity, given the definition of the lock chamber arrangement problem that is actually a problem of arranging as many passing ships (small areas) as possible in a given limited area (the lock chamber) and must meet the constraints, used the best-worst ant system to solve the lock chamber arrangement problem, implemented corresponding algorithm through further design, and tested the validity of it through the Yangtze Gorges lock chamber arrangement and the Qingyuan Water Conservancy lock chamber arrangement. The experimental results
of the above examples show that the best-worst ant system for the LCAP is effective, this paper also provides the idea and method for improving the ship lock practical navigation capacity and solving optimization problems.

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