Research on Design and Dispatching of Circular Shuttle System

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Abstract. The shuttle is also called Rail Guide Vehicle (RGV). It has the characteristics of fast conveying speed, good flexibility, and high degree of automation. The circular RGV system is widely used in logistics network dispatching. The genetic operator of the ordinary partheno genetic algorithm is improved by the single-point transposition operator and the roulette method, and the improved partheno genetic algorithm is obtained. The improved partheno genetic algorithm is used to model and design the circular shuttle system.

1. Introduction
The shuttle is also called RGV (Rail Guide Vehicle, hereinafter referred to as RGV) [1-5]. It is widely used in more and more industries. Early RGV systems mostly used straight-track single (double) RGV reciprocating motion, which was difficult to meet the overall loading, unloading and freight transportation requirements of the system when the number of platforms was large. Therefore, the circular RGV system came into being. The main application of the ring-shaped RGV system is as a link connecting the inbound operation area, the outbound operation area and the three-dimensional warehouse platform of the three-dimensional warehouse, and plays the role of transporting goods. It is the main and important subsystem of the three-dimensional warehouse system [6-11]. Since the circular RGV system adopts a closed circular track, the RGV travels in a one-way circular track in a circle. According to the different track data (straight length, bend length, etc.), RGV operating parameters (straight running speed, bend running speed, etc.), the number and location distribution of loading and unloading stations, and the demand for goods of different project systems, the number of RGV varies greatly. The number of RGVs and the job scheduling of RGVs determine the operating efficiency of the ring RGV system. Therefore, determining a reasonable number of RGVs and RGV scheduling strategies to improve the operating efficiency of the RGV system not only plays an important role in improving the operating efficiency of the warehouse, but also greatly promotes the rapid development of the warehouse.

| Table 1. Symbol Description |
|-----------------------------|
| Symbol | Explain $(i = 1,2,\cdots,4N; k = 1,2,\cdots,N)$ |
| $m_B$ | Total number of ports |
| $p$ | The total number of tasks |
| $T_{task}$ | Time for RGV to complete a handling operation |
| $t_w$ | The total time for RGV to move and walk |
on the entire ring rail

$t_t$  RGV loading or unloading conveying time
$t_o$  RGV communication time and detection time
$T_c$  The number of times the c-th RGV executes compound operations in a scheduling cycle
$B_{c(q)}$  The number of times that the c-th RGV is forced to stop and wait due to the operation of the preceding vehicle in a dispatch cycle
$X_k^1$  The destination platform address of the first lap car k inbound and handling operations
$Y_k^1$  The address of the starting station of the first lap car k out of the warehouse handling operation
$X_k^2$  The destination platform address of car k in the second lap
$Y_k^2$  The address of the starting platform of the second lap car k out of the warehouse and handling operations
$P_i$  The destination platform address of RGV loading from the outbound operation area to unloading in the three-dimensional warehouse is the i-th port
$Q_i$  The starting platform for RGV loading from the warehouse is the i-th port
$F$  Fitness function
$l$  The number of selected individuals whose fitness function value is greater than the average fitness value
$ceil$  Rounded up
$f_{max}$  The largest fitness value among all individuals
$f_{avg}$  Average fitness value
$f_i$  The fitness value of the individual to be transposed
$M$  Fixed the maximum number of times for single point transposition, set to 5
$P_e$  Single point transposition probability
$m$  Number of single-point transpositions
$W$  Maximum site cache
$C$  Accessibility
$n$  Number of RGV
$V_1$  RGV and platform transfer speed
$L_1$  Transfer length between RGV and platform
$t_o$  RGV and station handover response time
$L_2$  Total length of ring rail straight
2. Model assumptions
- The RGV goes around on a closed track to complete a handling task (one inbound or outbound), which is called a single operation. Completing two transport tasks (one inbound transport and one outbound transport) is called a compound operation. Failure to complete any handling tasks is called empty running.
- RGV is assigned tasks and can be executed immediately after the pick-up and unloading stations are stopped, and there is no waiting.
- RGV does not consider acceleration and deceleration when stopping.

3. Model building

3.1. Optimal Scheduling Mathematical Model of Ring RGV System

Research on the "Circular Shuttle Scheduling Problem", the layout diagram of the system is shown in Figure 1.

In the figure, assuming that the number of B-side incoming ports and outgoing ports are the same, one incoming port and one outgoing port constitute a port, and there are a total of ports. Starting from the starting point, sequentially number the port roads as 1, 2, ..., \( m_B \). The scheduling problem of the handling operation of the circular shuttle system can be described as: when the system is running at full capacity, a large number of pallets are in and out of the warehouse, and the set of jobs in a scheduling cycle is \( \text{Task} = \{\text{task}_1, \text{task}_2, \ldots, \text{task}_k, \ldots, \text{task}_p\} \).
A transportation operation of the shuttle includes three processes of loading, transportation, transportation, and unloading. The time to complete a transportation operation is \( T_{\text{task}} = t_w + 2t_t + t_o \).

### 3.2. Establishment of scheduling optimization model

According to the previous description, the following mathematical model can be established:

\[
\begin{align*}
\max & \sum_{c=1}^{N} T_c \\
\min & \sum_{c=1}^{N} B_{c(q)} \\
q &= \begin{cases} 
  (c - 1, c \leq N) \\
  N, c = 1
\end{cases}
\end{align*}
\] (1) (2) (3)

Restrictions:

\[
0 \leq T_c \leq 2 \\
0 \leq B_{c(q)}
\] (4) (5)

### 3.3. Improved partheno genetic algorithm design

The specific design is as follows.

- The specific encoding method is as follows:

\[
X_1^1Y_1^1, X_1^1Y_2^1, \ldots, X_k^1Y_k^1, \ldots, X_N^1Y_N^1, X_2^1Y_2^2, \ldots, X_k^2Y_k^2, \ldots, X_N^2Y_N^2
\] (6)

All genes in the chromosome are represented by two digits. For example, 0309 means that RGV1 accepts the inbound and transportation operation to the 3rd port first, and then goes to the 9th port to perform the warehouse transportation operation. RGV1 completes a compound operation in a circle; 0000 means RGV2 If the job is not completed in one round of the track, it is an empty run.

Note that since the three-dimensional warehouse has \( m_B \) port lanes, there is \( 0 \leq X_k^i \leq Y_k^i \leq m_B \). If \( X_k^i > Y_k^i \), the value \( Y_k^i \) will be directly assigned to 0. For example, when \( X_1^1Y_1^1 = 0903 \), RGV1 will perform 9 lanes inbound and transportation first, and then do 3. For outbound and transportation operations in the lane, because the RGV cannot retreat, it must go around the track again. This is not a compound operation, and \( X_1^1Y_1^1 \) will be modified to 0900, which is a single operation.

- The population size is set to 50. The specific method for the formation of a single chromosome is:

Assume that the warehousing and handling operations are: \( P_1, P_2, \ldots, P_k, \ldots, P_{k+l}, \ldots \)

Outbound handling operations are: \( Q_1, Q_2, \ldots, Q_k, \ldots, Q_{k+l}, \ldots \)

According to the order of inbound handling operations, select \( P_k \) from the inbound handling operations and assign it to \( X_1^i \), randomly select \( Q_k \) from the outbound handling operations and assign it to \( Y_1^i \), and then select \( P_{k+l} \) from the inbound handling operations in order and assign it to \( X_2^i \), from the outbound handling operations. In the handling operation, \( Q_k \) is randomly selected and assigned to \( Y_2^i \), and so on. If \( X_k^i > Y_k^i \), then assign \( Y_k^i \) to zero until a legal chromosome is formed.

### 3.4. Fitness function

The fitness function is a standard for evaluating the merits of individuals. According to the above analysis, the objective function is:

\[
\max \sum_{c=1}^{N} T_c
\] (7)
\[
\min \sum_{c=1}^{N} B_{c(q)}
\]

To solve this dual-objective optimization problem, the fitness function can be expressed as:

\[
F = \max \left( \sum_{c=1}^{N} T_c - \sum_{c=1}^{N} B_{c(q)} \right)
\]

3.5. Genetic operator design

- Selection operator, In this paper, the selection operator adopts a hybrid selection method combining the best part of individuals and the roulette method. The specific steps are as follows: Calculate the fitness of each chromosome in the population and the average fitness of the population, and keep the individuals with fitness greater than the average fitness directly to the next generation. Here we assume that there are a total of \( l \); Perform genetic operations on all chromosomes, and the remaining \( 50 - l \) individuals are selected by the roulette method, and the \( l \) individuals in step 1 form the next generation population.

- Gene recombination operator, At this time, the gene recombination operator adopts a single-point transposition operator to perform \( m \) single-point transpositions on individuals that need genetic manipulation, and \( m \) adopts an adaptive calculation method. The calculation model is as follows:

\[
m = \begin{cases} 
\text{ceil} \left( M \frac{H(f_c - f_{avg})}{f_{max} - f_{avg}} \right), & f_i \geq f_{avg} \\
M, & f_i < f_{avg}
\end{cases}
\]

The single-point transposition operator has separate effects on the genes for inbound handling and outbound handling. Use \( a \) and \( n \) to exchange positions, \( c \) and \( b \) to exchange positions. If \( X^t_k > Y^t_k \) after the exchange, assign \( Y^t_k \) to zero. If there is no operation in or out of the warehouse, it is 0000. Delete this gene string directly, and randomly select an inbound handling operation and an outbound handling operation from the task set to generate a new gene string and place it at the end of the chromosome. \( P_e \) is selected as 0.2.

3.6. Termination condition

When the algorithm runs to meet certain algebraic or time requirements, the algorithm stops.

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Acknowledgments
Development and application of statistical principles courses in the context of big data was supported by Teaching Reform Project of China West Normal University (403543); Application of sampling inference in quality inspection of "one standard and three facts" in public security system was supported by University level scientific research project of China West Normal University (416277).