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Explore the Optimal Design of the Loop Shuttle System and Its Scheduling

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Abstract

With the widely application of the automation technology in the warehouse, shuttle bus system arises at the historic moment, and become an important part in automatic warehouse. The shuttle system due to the access goods are automatically, which greatly save the labor cost. But it is even more crucial, while effectively save the labor cost, also need to ensure that the system efficiency, reduce the completion time. Therefore, in order to solve the problem of the efficiency of completion, according to different scenarios, different goods distribution situation, we need to generate the corresponding automation solution. In this paper, in view of the common ring shuttle car system is analyzed, combining with the actual scene model is established Type, the design algorithm, the idea of combining brute-force algorithm and heuristic algorithm to solve the optimal scheduling system, and according to the parameter optimization design, so as to realize the optimal scheduling of the entire system. At the same time, this article has carried on the simulation experiment and its efficiency evaluation on the plan of the scheduling and error analysis, further revised in this paper, the research results, to ensure its rigor, provides a reference for practical use.

Keywords

Shuttle system; Scheduling optimization; Exhaustive algorithm; Approximate optimal solution.

1. Introduction

Rise and rapid development of modern logistics, puts forward new requirements for automated warehouse. On the one hand, the warehouse system to deal with a lot of cargo handling tasks every day, the goods of blowing up. On the other hand, with the application and popularity of the technology in the logistics industry, people's demands to time efficiency also gradually improve, warehouse system must quickly handle the goods in a limited time, so the shuttle car system also arises at the historic moment, greatly affects the efficiency of warehousing. Shuttle bus system as an important part of automation stereoscopic warehouse, in recent years, the studies of its operation efficiency has attracted much attention. In the shuttle bus transport system In the course of traffic, the circular multi-vehicle mode belongs to one-way circumnavigation, so it is very easy to encounter many problems, such as too long congestion time of shuttle vehicles and unreasonable allocation of vehicle scheduling tasks, which need our attention and analysis, and seek solutions for optimization.

Ring shuttle car system requirements, analysis of its is a circular orbit, shuttle bus, replenish one's stock of port and shipping port. Circular track length of shuttle bus system, such as the number of cars and the average speed parameters affects the efficiency of the whole system, the need for reasonable design and scheduling. Therefore this study under the condition of considering the shuttle actual length, based on the solution to shuttle car congestion and the maximum throughput of the system, analyzes the actual scene and modeling, and algorithm to design, get the general scheduling optimization design scheme, thus minimizing total completion time, improving the efficiency of the shuttle car, to avoid congestion. Finally based on this The system efficiency evaluation and error improvement were carried out from the four aspects of the shuttle's congestion time, the maximum cargo throughput of the system, the shuttle's operating efficiency, and the access efficiency of the inlet and outlet nodes to obtain the final plan.

2. Shuttle System Analysis and Model Construction

2.1. Problem Analysis

From the perspective of system analysis, the shuttle system contains multiple components, as shown in Figure 1. System parameter variables are summarized as shown in Figure 2.

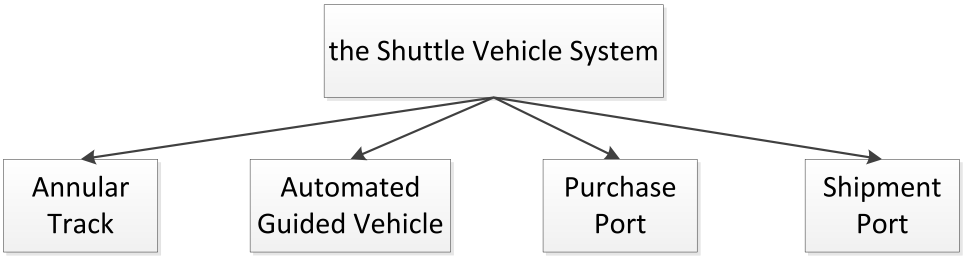

Fig. 1 Component diagram of shuttle system

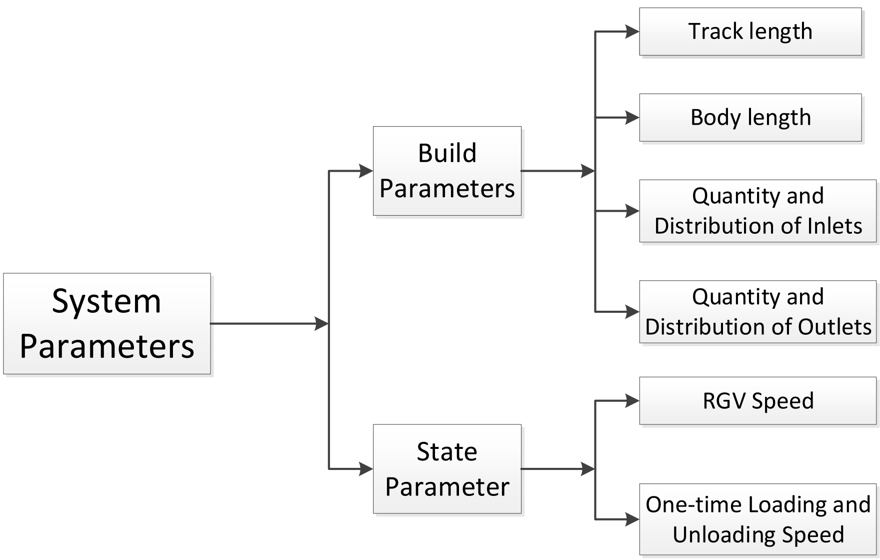

Fig 2. System parameter diagram

The circular shuttle bus system consists of A circular track, N, m A shuttle car purchase and shipment N mouth. Replenish one's stock, each port and shipping port in the sides of the ring rail (linear) for B side, next to A side, as shown in figure 1. A side into the mouth of shipment delivery together, replenish one's stock mouth together; The inlet and outlet on the B side is one incoming port and one outgoing port in turn.

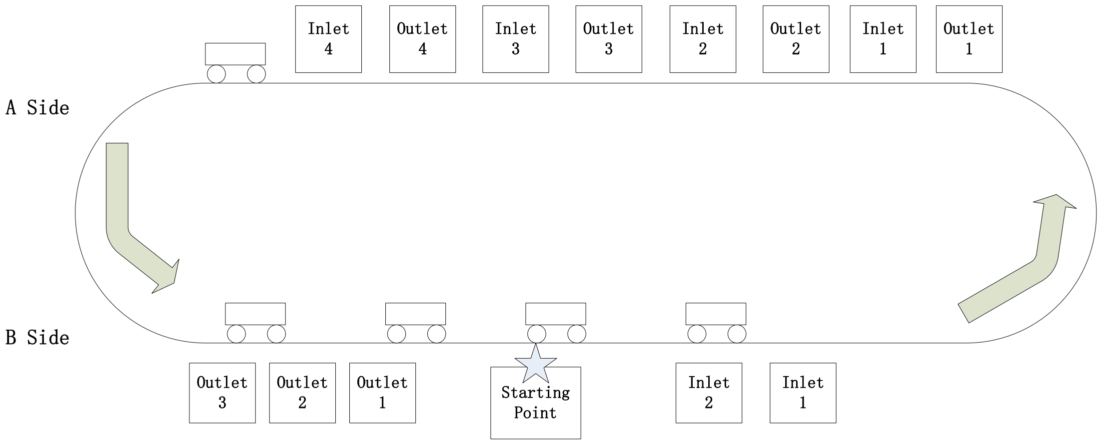

Fig 3. Schematic diagram of circular shuttle system

Side b stock to ship to a side opening a shipment operation process is: the shuttle run to the b side replenish one's stock, shuttle car is parked in the stock mouth loading of the goods until the loading process is complete, in the process of a shuttle car loading, follow behind the car shuttle car may not overtaking and need to stop waiting, then run to a side port of shipment, then stopped at the mouth of the shuttle car delivery goods unloading.

The process of shipment from the inlet of A side to the outlet of B side is the same as that from the inlet of B side to the outlet of A side.

A and b on both sides of the various existing stock mouth have a batch of goods need to be processed respectively, a side purchase of goods transported by the shuttle to b side of the given target port of shipment, b side of the stock of goods transported through the shuttle to a side of any shipment. How much the same shipment into the mouth of goods, according to the rule of first come, first service in order to delivery.

2.2. Model Assumptions

On the premise of considering the actual scenario, in order to simplify the problem and facilitate the solution, the following reasonable assumptions were made in this study:

i. It is assumed that the loading (unloading) time of the shuttle is equal to 10s each time.

ii. Assume that the shuttle travels at a constant speed of 1.5mMS all the time, ignoring the effects of acceleration and track resistance.

iii. Suppose one-way track, when there is a car in front, the car behind can not overtake, need to stop and wait;

iv. Let's say each shuttle can only carry one item at a time;

v. Assuming that the inlet and outlet set on both sides of A and B are evenly distributed on the edge of the track (straight line), the initial set is based on.

vi. Ignore the width of the inlet and outlet itself, assuming as point;

vii. Assume that the starting point of the shuttle is port 2 on side A;

viii. The parameter variables involved in the model are as follows:

N: shuttle car number, m A : A side replenish one's stock, m B : B side replenish one's stock, N A : A side of the port of shipment, N B : B side of the port of shipment, l 1 : straight length (94 m), l 2 : curve length (6 m), l c : shuttle car body length (1.3 m), t L : load time (s), t U : discharge time (s), t b : the shuttle cargo transportation time, t W : wait time, t ci : the I Shuttle bus running time, T cik : the shuttle car I the first k times running time, T: total completion time, Ω: all incoming shipments set tasks, Ω mB : B side purchase task set mouth, seq G : shuttle car G assigned task execution order, R Aj : A side stock j to be processed goods number in the mouth, R Bh : B side purchase mouth to be processed in the h goods number, d Ajk : the first k goods in

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A side purchase mouth j goal in B side port of shipment, the d Bjk : the first k goods in side B stock mouth j goal in A side Shipping port. Cl: The current position of the trolley.

2.3. Model Construction

Due to the system run in real scenarios to consider shuttle car body length, which also increased the next shuttle car additional waiting time for the shuttle car through the node time. Assume that car arrived into (out of) the goods mouth node loading (discharging), namely the rear left into (out of) the goods mouth node, the node to restore the idle state, when a shuttle car after car just to arrive at the node. In addition, due to considering the body length, the shuttle car also line when starting point, so each shuttle bus start location is different. Shuttle car need more driving distance, namely the row in front of the shuttle car body distance.

The unloading stop time of the last loaded shuttle in n shuttles is defined as the total completion time (t).

$$T = MAX\{T_{c1}, T_{c2}, \ldots, T_{cN}\} \tag{1}$$

Since the total completion time is required to be the shortest, the objective function is:

$$\min T = \min MAX\{T_{c1}, T_{c2}, \ldots, T_{cN}\} \tag{2}$$

Among them,

$$T_{ci} = \sum T_{cij}$$

Since the operation process of the shuttle advancing once includes going forward, waiting for (possible occurrence,) loading (possible occurrence), unloading (possible occurrence) and waiting for the congestion time, in the congestion time, the time for the shuttle to complete a task is also increased:

$$T_{cij} = t_M + t_L + t_U + t_W + l_c / v \tag{3}$$

$$t_M = m_{ij} n_{ij} / v \tag{4}$$

t_W Refers to the time that subsequent shuttles have to wait at the node when the node is busy (there is a shuttle at the node currently). This problem requires additional calculation of the time that the previous shuttle passes through the node completely (l_c / v).

For the general scheduling of shuttle system, the following constraints need to be considered:

The probability constraint of taking goods

$$50 < P_b < 100$$

$$20 < P_a < P_b$$

The sequence set constraint of the target task delivery point of the side B inlet:

$$\Omega_{mBi} \in \{n_{A1}, n_{A2}, n_{A3}\},$$

No shuttle can overtake:

$$l_{C(j,j+1)} > 0$$

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The constraint condition model is described as follows:

1) Constraint refers to the probability constraint of taking goods. When the shuttle passes through the inlet on the B side, there is a certain probability P_b When the shuttle passes through the inlet on side A, it is based on the probability P_a Make pickup judgment.

2) constraints (2) the said shipment is b side of the mouth of replenish one's stock list. Therefore, we assume that the scheduling, prior to the start of the b side each stock shipment mouth will generate an ordered list (each shipment which goods are to be shipped to a side mouth), to reduce the shuttle car in a place of discharge of waiting time, should be from b side loading of shuttle car in a side of three shipments of discharging mouth relative "average".

3) Constraint means that the shuttle cannot overtake. When passing a node, it is judged that there are vehicles loading and unloading on the node, then stop and wait, and the queuing model criterion is implemented, as shown in the figure.

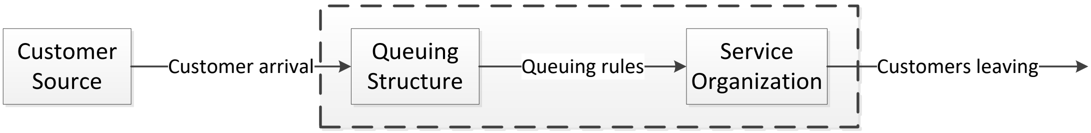

Fig 4. Queuing model criteria

3. Model Solution and Analysis

According to the parameters of the circular shuttle track, the circular track is converted into a linear coordinate system, as shown in the figure.

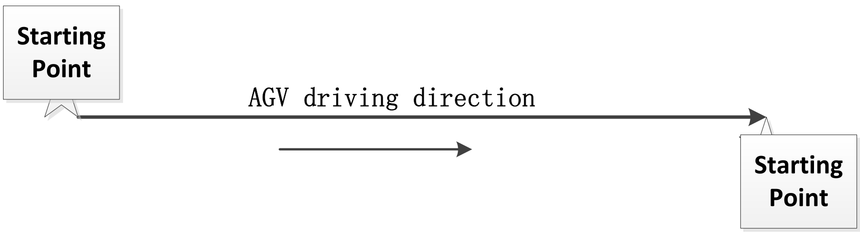

Fig 5. Schematic diagram of the orbital axes

We set the initialization scheme of distribution rule is: the average distribution n shuttle car in a and b on both sides of the six stock mouth. When n < = 6, the largest number of shuttle bus from the starting point mouth 2 take goods receiving, the number of big shuttle bus from a starting point for the first purchase to replenish one's stock is a side opening 1 pickup, and so on. When n > 6, the first shuttle car original pickup location evenly distributed in each stock mouth, when cannot reach the average priority evenly distributed in near the starting point of purchase.

Let's take n=9 for example,1 car load m_{b4} And 2 cars m_{b3} And three cars m_{b2} , 4 truck m_{b1} And five cars m_{b1} And 6 cars m_{a1} And seven cars m_{a1} And eight cars m_{a2} , 9 truck m_{a2} .

The algorithm idea is the combination of exhaustive algorithm and heuristic algorithm. The idea of exhaustive algorithm is applied to list all scheduling situations as far as possible, and then the iteration is combined with heuristic algorithm to obtain the shortest time of these schedules and retain and output the situation and time of this schedule. The algorithm idea is as follows: First, set the number of shuttles and enter the number of iterations.

Randomly generate task lists of four incoming ports on side B (" average "tasks to three outgoing ports on side A with equal probability to generate sequential task lists). At the same time, randomly generate a probability P_b (50< P_b < 100) and probability p_a (20< p_a < P_b), represents the probability that the no-load shuttle will replenish its stock at the inlet.

The shuttle began to move forward.

N shuttle car from the starting point (a side purchase 2) began to walk forward, timing begins. In the first round, the shuttle bus according to the regulations of the beforehand good initial solution (initial destination), traveling to a specified purchase point mouth, completed specified purchase task. After finished the first round of the forward movement, n shuttle car to start the second round of forward movement. Each round forward actions include:

1. Judge whether all nodes have empty tasks. If so, jump out of the cycle and output the shuttle's advance time; If not, enter phase 2.

2. The shuttle moves forward. According to the path node order, change the current position and next target position of the shuttle, and update the travel time (original time + this displacement time).

3. Determine whether to wait. Query the node state, if True, then the node is idle, enter stage 4, the node state is changed to busy; If False, the node is busy and enters stage 7.

If it is True, enter stage 5 to judge. If it is False, then determine whether the destination of your task is the same as the node. If it is the same, then enter stage 9. If it is not at the same location, the shuttle node stores the shuttle time at the current moment, the node state is changed to idle, and the shuttle exits to enter the next cycle and return to stage 1.

5. Judge whether the amount of tasks at the current node is too much (the amount of tasks at the incoming node may be too much, or all the transport has been completed, and the amount of tasks at the outgoing node is always empty). If the node has tasks that can be collected, it will enter stage 6; If there are no tasks left on the node, then the node state is changed to idle, the shuttle leaves and enters the next cycle. The node stores the shuttle's departure time at the current moment and returns to stage 1.

Judge whether the current node is a side node. If it is a side node, randomly generate a number and randomly get the proportion before the cycle starts p_a Make a comparison; If it is the B-side node, the ratio of the randomly generated number to the randomly obtained number before the start of the cycle is calculated P_b If less, then load, enter the stage 8. If more, then do not load, the shuttle will leave and enter the next cycle, the node stores the shuttle time at the current moment, the node state will be changed to idle, and then go back to stage 1.

7. The shuttle waits. Take the time when the last vehicle left from the current node and update the time to the current time to enter Stage 4.

8. Load the shuttle, node task volume -1, update the shuttle time (original base +10s), the node stores the shuttle time at the current time, the shuttle leaves and enters the next cycle, and returns to stage 1.

9. The shuttle will unload, change the shuttle state (make the shuttle state True), update the shuttle time (original basis +10s), store the shuttle time at the current moment on the node, change the node state to idle, and the shuttle will leave to enter the next cycle and return to stage 1.

The model problem is solved according to the above algorithm flow.

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4. Simulation Experiment and Analysis

4.1. Setting of simulation experiment

According to the actual situation, we designed the given fixed parameters as shown in the table:

Table 1. Set the given parameters of shuttle system

Track length		Speed of shuttle	Shuttle length	Number of purchase		Number of shipment		Time of first loading and unloading
straight	curve			A side	B side	A side	B side	
94m	6m	1.5m/秒	1.3m	2	4	3	4	10second

According to the algorithm process we just described in the last section, we continue to perform iterative optimization according to the algorithm mentioned above, and get the final optimization result, as shown in the table.

Table 2. Optimal results table

Number of cars	3	4	5	6	7	8	9
Optimal scheduling time / sec	17689	14287	12348	10376	9624	8606	8038

Code according to the test results, we can conclude, in a limited range (n < = 9), the optimal scheduling time is inversely proportional to the number of shuttle car: the more shuttle car, the less the time it takes to complete the scheduling task. When n increased from 1 to 2, 3, we will find that the optimal scheduling time drop approximate to linear, and in the future, due to the increase in vehicle n, waiting for the shuttle buses will frequently appear in the node, but increase more additional waiting time, thus the optimal scheduling time decline will be more and more slowly, and will be in the n = 9, get the optimal scheduling time. When n > 9, the total completion time began to increase, deviating from the optimal scheduling of time .

4.2. Program Evaluation and Analysis

As shown in the figure, the scheduling optimization scheme is evaluated from the following aspects: the shuttle's congestion time, the maximum cargo throughput of the system, the shuttle's operating efficiency, the node access efficiency, etc.

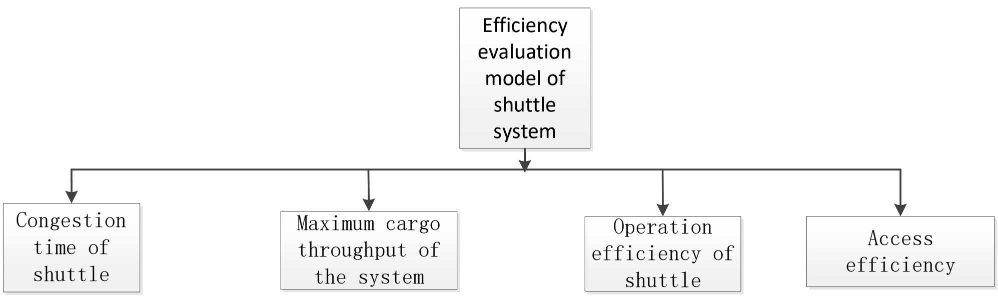

Fig 6. System efficiency evaluation model

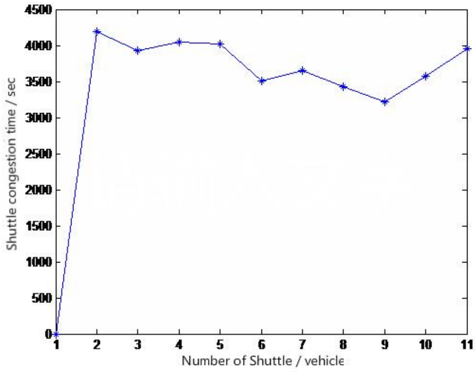

Fig 7. Influence trend based on shuttle congestion time

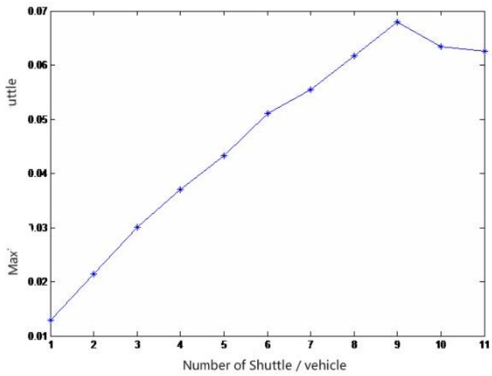

Fig 8. Influence trend based on system maximum cargo throughput

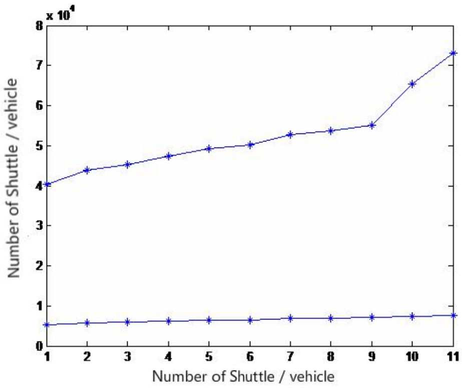

Fig 9. Influence trend of node-based access efficiency

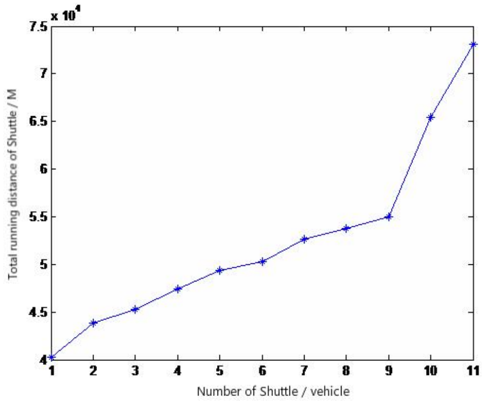

Fig 10. Influence trend of node-based access efficiency

According to the evaluation and analysis of the above, can come to the conclusion that under the condition of the system parameters, with the increase of shuttle car number n, shuttle bus congestion increases after the first time to reduce (minimum when n = 9), shuttle bus system throughput increase (maximum when n = 9), the access efficiency of nodes is reduced, the efficiency of shuttle car.

But in actual production process, with a case, the other most of the time efficiency of evaluation system, and should make the congestion of the shuttle time, the system's maximum cargo throughput, the shuttle car running efficiency, nodes access efficiency such as part of the weight of each item to judge, but according to the requirement of practical production task to change their weight.

4.3. Scheme Improvement

1) Considering the scheduling parameter optimization problem and the queuing theory, the optimization idea is as follows:

Ring rail car model of shuttle car system, due to the close orbit, run anti-clockwise, prone to congestion and in the process of running empty running situation, results in the decrease of system efficiency. In addition, the system of rail length, shuttle car speed and the number of shuttle car, loading and unloading cargo time parameter is closely connected with the efficiency of the whole system. In this circular shuttle car system parameter optimization, this paper USES the queuing theory to analyze the parameters of the mathematical model of the system and optimizing the evaluation.

Assuming that the pallet arrival rule is subject to the Poisson process with the parameter, and the time for the shuttle to enter and ship is 10s. Considering the factors such as task scheduling and the need to wait for the safety and anti-collision of multiple vehicles on the circular track, the overall service efficiency is. Referring to the calculation method of queuing theory M/M/n model, the operating indexes of the system queuing model are:

(1) System service intensity:

$$\rho=\frac{\lambda}{\eta n\mu}$$

(2) The probability that all shuttles in the system are idle:

$$P_0=[\sum_{k=0}^{n-1}\frac{(n\rho)^k}{k!}+\frac{(n\rho)^n}{n!(1-\rho)}]^{-1}$$

(3) The average waiting length of trays in the system is:

$$L_q=\frac{(n\rho)^n\rho}{n!(1-\rho)^2}P_0$$

(4) Average waiting time of trays in the system:

$$W_q=\frac{(n\rho)^{n-1}\rho}{\mu n!(1-\rho)^2}P_0$$

(5) Average number of RGV shuttles under service:

$$L_p=\frac{\lambda}{\eta\mu}$$

According to the queuing theory, the following constraints are established:

(1) The arrival of the shuttle is infinite and independent, and the arrival time is subject to Poisson distribution.

(2) The service process is to deliver multiple goods at the same inlet and outlet in a first-come-first-served order.

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(3) The queuing rule is the waiting system, that is, the shuttle waits in line until the purchase or delivery of goods is completed.

(4) There are a specified number of shuttles on the loop track, that is, there are an equal number of service Windows for service.

(5) The arrival and delivery time, track length and shuttle speed have been specified.

According to the constraint conditions, the system belongs to M/M/n queuing model of multi-service window waiting system, as shown in the figure below.

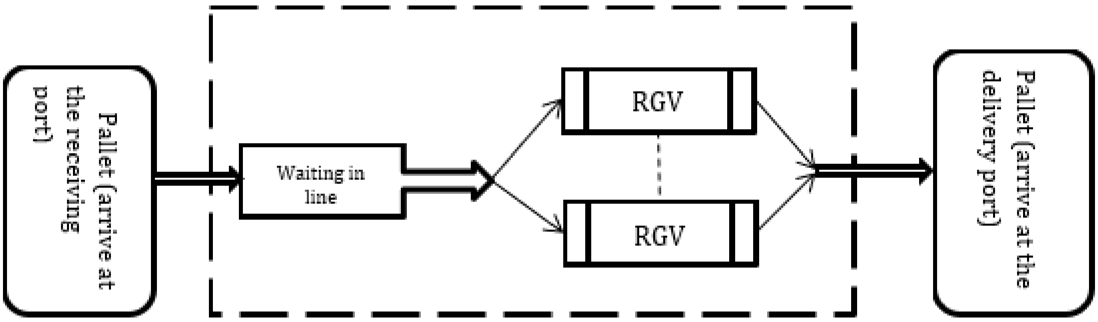

Fig 11. Block diagram of system queuing model

2) For the optimization of system parameters, the optimization ideas are as follows:

Incoming and outgoing ports should be arranged alternately.

From the above solution results, we came to the conclusion that it is easier to deliver the goods when the incoming goods are next to the outgoing ones. Therefore, we took the positions of each incoming goods and outgoing goods on both sides of A and B as variables and optimized them on the previous basis to obtain a shorter total completion time.

In actual solution, we found that the shuttle's relative speed affects the congestion of the shuttle in the node, and the goods shipping time. If you increase the relative speed of the shuttle car while on the basis of the loading and unloading time constant, will increase the congestion problem of nodes, but will improve the efficiency of cargo transport, reduce transportation time. Appropriate increase shuttle car relative speed, will reduce the total completion time.

5. Feasibility Analysis of Optimization Scheme

In view of the proposed scheduling parameter optimization proposal, we carried out a practical analysis. The analysis process is as follows:

According to the relevant parameters provided in practice, the pallet arrival rate is: $\lambda = 1/t_{L/U} = 0.1$ The time for the shuttle to complete one handling service is the sum of the time for the RGV shuttle to travel on the track and the time for pallet handover for four times. Here, the RGV shuttle adopts regular scheduling, which means that the loop track goes in and out of the warehouse twice in one turn, and the time for one cycle is halved in straight and curve $T = \frac{(l1+l2)/v}{4} + 4t_{L/U} = 56.667$ Seconds. The service rate is: $\mu = \frac{1}{T} = 0.0176$ The number of loop-track shuttles n=9, eta = 0.8. Plug the actual data into the above formula and calculate the operating indexes of the queuing model of the loop shuttle system as follows:

(1) System service intensity:

$$\rho = \frac{\lambda}{\eta n \mu} = \frac{0.1}{0.8 \times 9 \times 0.0176} = 0.789$$

(2) The probability that all shuttles in the system are idle:

$$P_0 = [\sum_{k=0}^{n-1}\frac{(n\rho)^k}{k!}+\frac{(n\rho)^n}{n!(1-\rho)}]^{-1} = [\sum_{k=0}^{8}\frac{(9\times 0.789)^k}{k!}+\frac{(9\times 0.789)^9}{9!(1-0.789)}]^{-1} = 0.0007$$

(3) The average waiting length of trays in the system is:

$$L_q = \frac{(n\rho)^n \rho}{n!(1-\rho)^2}P_0 = \frac{(9\times 0.789)^9\times 0.789}{9!(1-0.789)^2}\times 0.0007 = 1.57$$

(4) Average waiting time of trays in the system:

$$W_q = \frac{(n\rho)^{n-1}\rho}{\mu n!(1-\rho)^2}P_0 = \frac{(9\times 0.789)^8\times 0.789}{0.0176\times 9!(1-0.789)^2}\times 0.0007 = 12.56s$$

(5) Average number of RGV shuttles under service:

$$L_p = \frac{\lambda}{\eta\mu} = \frac{0.1}{0.8\times 0.0176} = 7.10$$

(6) Operation efficiency of the queuing model of the circular shuttle system:

$$\delta = \frac{L_p}{n} = \frac{7.10}{9} = 0.789$$

The performance indexes calculated by the queuing theory model of the system are analyzed: The service intensity of the system is 0.789, which is less than 1. The average waiting length of the tray is 1.57, which is less than the average waiting length required when the system is in steady state (its value is half of the maximum value of W cached in the platform: $\frac{W}{2} = \frac{13}{2} = 6.5$), indicating that the system is relatively stable; The average number of shuttle buses in service is 7.10, indicating a low idle rate of RGV shuttle. The average waiting time was 12.56s, 106.67s for the long and small shuttle to go around the ring track, indicating that the average waiting time for the tray was relatively short. The operating efficiency of the system is 78.9%, indicating a high operating efficiency of the system. Through the analysis of the above performance indicators, it is proved that the design of the circular shuttle system is more reasonable and meets the requirements.

6. Conclusion

This study on the circular shuttle car system improvement and optimization of scheduling optimization scheme was put forward and to evaluate it, providing a certain reference value for practical applications, but this research also needs further improvement and research. In the actual system will exist in the process of running the system error, namely because each shuttle car task scheduling is completed by each node (stock), so if the node is the network time delay, will make the shuttle through the node also may produce network delay time to wait for the goods. And the shuttle in the exchange of information between each node and node also need time. Especially when the quantity is relatively large, wear A large number of shuttles will lead to a large number of visits to nodes, which will lead to a large additional time caused by network delay and may lead to a series of chain reactions. In a word, it is imperative to improve the operation efficiency of shuttle system and plays a key role in improving the overall storage efficiency.

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