Efficient Predictive Regulation Algorithms for AGV System in Industrial Internet

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Abstract

In recent years, the industrial Internet has developed rapidly. In order to improve the reliability, real-time, and economy, Automated Guided Vehicle (AGV) in intelligent manufacturing system becomes an indispensable technology. However, the current AGV system relies too much on the fixed network bandwidth environment in information transmission and management. When the traffic demand changes frequently, this form of network configuration lacks network resource management mechanism. Further, it leads to the problems of delay, waste of network flow, and inability to dynamically allocate network resources. So it is vital to improve the AGV system. Therefore, this paper proposes three predictive control algorithms and a Network Cable Scheduling algorithm to manage the network resources. They are Markov Chain Linear Programming Regulation (MCLPR) algorithm, Prophet Linear Programming Regulation (PLPR) algorithm, and Machine Learning Linear Programming Regulation (MLLPR) algorithm. The experimental results show that PLPR and MLLPR algorithm have high efficiency in the aspect of regulation. MLLPR algorithm has the lowest cost. MLLPR algorithm has the strongest leakage limitation ability, followed by PLPR algorithm. The balance regulation efficiency of MLLPR in none "4 + 1" mode is the highest in different network cable modes.

Keywords: Balance regulation, Machine learning, AGV, Resource management mechanism

1 Introduction

With the rapid development of the economy, the industrial Internet has gradually shifted from Industry 4.0 to Industry 5.0. Industry 5.0 refers to all advanced information technology, artificial intelligence, augmented reality, and robots used in daily life, industry, medical care, and other fields of human activities. It contributes to the digitalization, networking, and intelligent development of manufacturing industry. It makes the production process faster, safer, and more economical [1]. At the same time, in order to realize automatic transportation, automated guided vehicle (AGV) material handling system has become an important part of modern intelligent manufacturing system. As typical intelligent transportation equipment, AGV is widely used in all kinds of production workshops [2]. In order to improve reliability and efficiency, many researchers study AGV path planning, cost reduction, and AGV scheduling, etc. However, the existing research topics don't mention the lack of network resource management mechanism in AGV system. The current AGV system is equipped with a fixed network bandwidth. It includes 4G and 5G bandwidths. When bandwidth is 4G, the AGV system will delay the information transmission. When bandwidth is 5G, AGV system will waste traffic. AGV system cannot dynamically control the allocation of bandwidth. It will affect the production efficiency of the workshop. Network resource management mechanism is an indispensable part. Therefore, this paper studies the network resource scheduling of AGV system without considering the security factor. To facilitate understanding, the examples are given to illustrate.

Nowadays, more electronic manufacturing enterprises use AGV to transport materials in the process of realizing automatic production [3]. Figure 1 describes the operation flow of AGV system. First, the AGV waits for the AGV control system to send task information in the standby area. When goods are offline at the finished product transmission port, the AGV control system will assign transportation tasks according to the location of each AGV [4]. Subsequently, the AGV control system send task information. After receiving the task, the AGV goes to the loading area. After that, it waits for the goods and loads the goods automatically. Then, the AGV carries the goods back to the warehouse along the route planned by the AGV control system. After arriving at the warehouse, AGV locates the shelf position of goods by sensing the RFID tag on the ground [5]. As long as reaching the shelf, AGV puts the goods into the shelf and reads the information card of the shelf. AGV feedbacks the reading information to the AGV control system and records the storage location of the goods. After the goods are put on the shelf, the AGV exits the shelf and proceeds to the next task. If there is no transportation task, it will return to the standby area.

The operation process of AGV system shows that the system has the problem of lack of network resource management mechanism. It includes the following aspects:

(1) If the fixed bandwidth of the AGV system is 4G, insufficient bandwidth causes transmission delay. First, when multiple finished product transmission ports need to

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DOI: 10.53106/160792642024052503005

take off-line goods, the AGV system will have insufficient bandwidth due to frequent information transmission, which makes the AGV control system unable to capture information in time. Further, the task of transporting goods cannot be allocated in time, which affects the timely warehousing of goods. Second, in the process of transporting goods, AGV needs to constantly sense the route, obstacles, and shelf positions through RFID technology. Insufficient network resources will affect the perceived efficiency of AGV. Furthermore, it will affect the timely warehousing of goods.

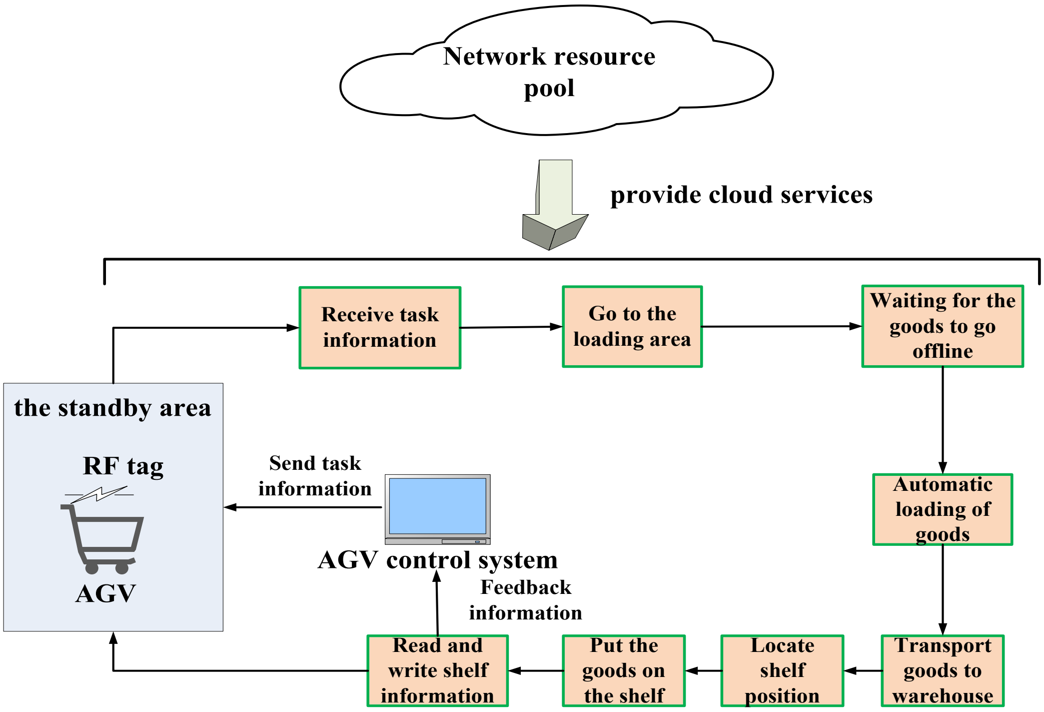


Figure 1. AGV system flow chart

(2) If the fixed bandwidth of the AGV system is 5G, more bandwidth leads to waste of network flow. When the AGV waits for tasks in the standby area and goods at the finished product transmission port, it consumes less traffic. At this time, the traffic resources of the AGV corresponding network cable are idle. It results in a waste of some network resources.

(3) The traditional fixed bandwidth method of AGV system makes the network resources not dynamically adjustable according to the specific situation. In the above two aspects, the AGV system needs to balance the network resources in the system. When some AGVs perform tasks, a large amount of traffic passes through the network cable. However, the network cable is overloaded with bandwidth. It can easily lead to data transmission errors and network latency. When other AGVs are idle, a small amount of traffic passes through the network cable, which causes a waste of traffic. Therefore, AGV systems need to dynamically adjust network resources to suit different operating conditions.

Therefore, this paper explores the above problems. Figure 2 shows the research process. In AGV logistics system, the current network supply adopts 4G network cable. When the machines in the workshop are busy work, the AGV system is easy to run out of network flow and then delay the data transmission. This doesn't carry out the production activities smoothly and enhance the production efficiency. 5G network cables are also used for network supply. When the workshop machines are not busy work, 5G network cable can cause a lot of waste of network resources, which increases the cost of ineffective communication in the enterprises. Therefore, "4G+extension" model which is proposed in this article contains the advantages of industrial internet and cloud services. It can dynamically adjust the supply of the network while the workshop machines are working. Based on this idea, this article develops three predictive control methods to realize the management of network resources of AGV system. First, the AGV system uses markov chain, prophet, and machine learning methods to predict traffic. Then, the AGV system uses the newly proposed scheduling algorithm to schedule. Finally, the AGV system can achieve seamless operation of AGV, no waste of traffic, and dynamic control of network resources.

The contributions of this paper are summarized as the following three parts.

(1) This paper achieves the idea of "4G+Extension" which uses linear planning and cloud services to control network resources of AGV system. It can improve the efficiency of AGV system under a single network in both 4G and 5G.

(2) This paper establishes the intelligent resource

management mechanism, and develops three predictive control algorithms to effectively allocate network resources of AGV system.

(3) The three predictive control algorithms proposed in this paper are compared experimentally. The experimental results show that MLLPR algorithm has the highest balance regulation efficiency.

The rest of this article is organized as follows. Section 2 represents related works. Then, section 3 is the problem description. And, the system methods are introduced in section 4. Furthermore, section 5 mentions experimental results and analysis. Finally, the conclusion is in section 6.

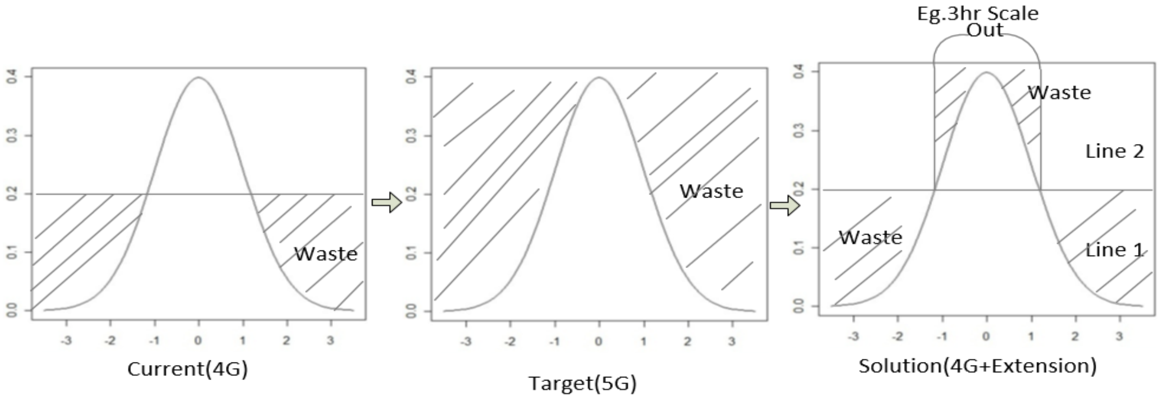


Figure 2. “4G + extension” model

2 Related Works

Industrial Internet closely integrates equipment, production lines, and factories through an open and global industrial network platform, which helps to improve the productivity of factories. At the same time, with the characteristics of high efficiency, flexibility, versatility, and security, AGV plays an increasingly important role in intelligent manufacturing [6]. More and more enterprises use AGV to transport materials in the workshop. However, there are still many problems in AGV system. Based on the advantages of industrial Internet, improving AGV system is a major challenge. Many researchers study AGV system from many aspects to make it better applied in the industrial Internet. The joint development of many aspects enables AGV to better improve the production efficiency of the workshop.

There are many researches on AGV scheduling. [7] developed a mathematical model with new objective function and proposed an improved harmony search algorithm to solve the scheduling problem of AGV. [8] presented a method which is based on hormone regulation to schedule AGV online in distributed system. Compared with the most advanced online and offline methods, this method improves the quality of scheduling. In order to solve the problem of joint vehicle scheduling and storage allocation, [9] proposed two mixed integer linear programming models, and developed a three-stage decomposition method called particle swarm optimization to solve the optimal scheduling scheme. [10] mentioned that the commonly used task scheduling methods of AGV do not fully consider the influence of factors such as power consumption and workshop environment, resulting in a gap between the scheduling methods and practical applications. After modification, this scheduling algorithm can meet the model and algorithm of factory real-time application, so as to solve the scheduling problem of AGV.

The above research is to develop new mathematical models and new algorithms to maximize AGV efficiency. However, these methods do not consider the impact of network bandwidth. The network bandwidth also has a great impact on the AGV system. Therefore, with the help of industrial Internet and cloud services, this paper develops a novel scheduling algorithm based on network bandwidth. Before scheduling, predicting the traffic of each network cable can avoid problems such as delay and waste of network traffic. However, the existing research on AGV system lacks this part. Inspired by some website traffic prediction methods, this paper develops several classic prediction methods to predict the traffic of AGV system. It includes markov chain prediction, prophet prediction, and machine learning prediction. Their applications in other fields are shown below.

Markov chain prediction is applied in various fields. [11] proposed a Markov chain prediction algorithm with speed constraint to predict and control the vehicle speed, which has reached the maximum utilization of vehicle fuel. [12] proposed a Markov chain location prediction model based on multi-dimensional correction to predict the passenger flow density in intelligent transportation, so as to make corresponding adjustments in time and make the traffic smooth. [13] developed Markov chain models based on continuous time and discrete time to accurately predict computing resources in cloud computing, so that computing resources can be fully utilized in cloud computing. [14] proposed a Markov Chain Prediction (MCP) model for routing in DTNs to mine the movements of nodes property with historical contact information and use this model to improve the delivery ratio of message transferring within the network.

Prophet is a prediction method based on time series. Its application fields are also very wide. [15] proposed to use prophet and Autoregressive Integrated Moving Average model (ARIMA) to predict bitcoin. The performance indexes of prophet and ARIMA methods are compared on the same data set. The final results show that the prophet prediction method is more accurate. [16] proposed a user traffic prediction method based on Prophet and Gaussian process regression. The proposed method first employs discrete wavelet transform to decompose the user traffic time series to high-frequency component and low-frequency component. Then Prophet model and Gaussian process regression are applied to predict the two components respectively based on the characteristics of the two components. [17] applied the facebook prophet prediction framework to the Microsoft azure virtual machine workload to predict the future resource utilization required to run tasks. This enables substantial improvement in cost-effective resource management.

Machine learning is divided into supervised learning, semi supervised learning, and unsupervised learning. They are applied to prediction and classification in various fields. [18] proposed a supervised learning method to accurately and effectively predict cardiac related hospitalizations according to the specific medical history of existing patients. [19] proposed a new active semi supervised learning method to predict software defects. Experiments show that this method has the potential to be applied to industrial practice. [20] proposed a prediction method based on unsupervised learning to predict the degree of air pollution, so that users can know the extreme weather conditions in time.

These methods are all classical prediction methods. They have significant prediction effects in other fields. Due to the lack of network resource management mechanism in the existing AGV system, this paper proposes a method of prediction first and then scheduling to manage network resources. Previous studies have not predicted the flow of each line in AGV system, so this paper applies these classical prediction algorithms to AGV system. In addition, the new scheduling algorithm proposed in this paper increases the efficiency of the AGV system and reduces the waste of traffic.

3 Problem Description

This section gives a formal description of the problem and then explains its correlative concepts. For convenience, the symbols that will be used and their corresponding descriptions are shown in Table 1.

A. Symbol definition

Table 1. Symbol table

Signs	Description
n	number of network cables
m_j	Number of trolleys for network cable *j*
Δ	Target tag set for network cable *j*
car	Trolley set
car_j	Trolley set of network cable *j*
car_j^i	-th trolley of network cable *j*
μ	General flow set of AGV
μ_j^i	Normal flow value of trolley of network cable *j*
s_j^r	Status of network cable *j round r*
ε_j^{rScale}	Flow to be divided in the round of network cable *j*
σ_j^r	Final divided flow in the round of network cable *j*
ξ	Network cable set
λ_i	Network cable *i*
x	Initial size of trafficable flow
y	Predicted flow
z	Flow waste after regulation
Θ_r^i	Bandwidth utilization of the *r*-th round of network cable *i* before regulation
Γ_r^i	Bandwidth utilization of the *r*-th round of network cable *i* after regulation
Γ^i	Bandwidth utilization of network cable *i*after regulation
S	State group of possible states
p	Balance valve
$Time^{(*\rightarrow \mathrm{balance} \rightarrow *)}$	Balancing times in the process of network cable *j* dynamic regulation
BRR	Network cable balance regulation rate
SBRR	System equilibrium regulation rate
z'	Flow waste before regulation
ϖ	Reserve bandwidth for other network cables
$\zeta(r)$	temporary change elimination mechanism
σ	Flow transfer in set
θ	Network cable bandwidth
β_{mm}	Probability matrix
r	Number of control rounds
ψ	Target network cable set
T_{final}	Final balance regulation times
$\mathrm{T}_{\mathrm{first}}$	First balance regulation times

B. Problem description

Problem Description: the AGV system have n $(n \in N_+)$ network cables, and there are m_j trolleys on each network line. Target tag set for network cable j: $\Delta = \{\Delta_i \mid i \in [1, n], i \neq j, \Delta_i \in \{1,0\}\}$. When the value of Δ_i is 1, network cable j is the target scheduling object of network line i at the next time. When the value of Δ_i is 0, network cable j is not the target scheduling object of network line i at the next time. Trolley car = $\{ car_j^i \mid j \in [1, n], i \in \{1, m_j\}\}$. car is i-th trolley of network cable j. When the value of car_j^i is 1, car_j^i is a dispatchable trolley. When the value of car_j^i is 0, car_j^i is not a dispatchable trolley. $\mu = \{\mu_j^i \mid j \in [1, n], i \in [1, car_j]\}$.is the conventional flow set of AGV. μ_j^i represents the normal flow value of the trolley i of the network cable j. Before the r-th of dynamic regulation, the network resource management mechanism predicts the state s_j^r of network cable j. The target tag set of network cable j Δ is obtained by Network Cable Scheduling algorithm. At this time, the AGV system calculates the flow ε_j^{rScale} to be divided in the r-th round of network cable j according to the scale in and scale out rules. Further, the final divided flow σ_j^r of the r-th round of network cable j is calculated through formula (1).

$$\sigma_j^r = \begin{cases} \sum_{i=1}^{m_j} car_j^i * \mu_j^i, \ \varepsilon_j^{rScale} > \sum_{i=1}^{m_j} car_j^i * \mu_j^i, \ \varepsilon_j^{rScale} < \sum_{i=1}^{m_j} car_j^i * \mu_j^i \\ \varepsilon_j^{rScale}, \qquad \varepsilon_j^{rScale} = \sum_{i=1}^{m_j} car_j^i * \mu_j^i \end{cases}. \tag{1}$$

(1) Definition 1: Bandwidth utilization: the network cable set is $\xi = \{\lambda_1, \ldots, \lambda_i\}$and λ_i represents network cable i ($i \in [1, n]$). The initial size of the trafficable traffic of network cable i is x (x has no effect on the regulation efficiency), the predicted traffic is y, and the flow waste after regulation is z. Therefore, the bandwidth utilization Θ_r^i of the r-th round of network cable i before regulation is (2). The bandwidth utilization Θ_r^i of the r-th round of network cable i after regulation is (3). For the convenience of research, x returns to the initial value before the prediction at the next time.

$$\Theta_r^i = \frac{y}{x} * 100\%. \tag{2}$$

$$\Gamma_r^i = \frac{x-z}{x} * 100\%. \tag{3}$$

Definition 2: Balance Regulation Rate (BRR): $S = \{ s_j^r \mid j \in [1, n], r \in N_+\}$, which represents the state group composed of the possible states of the r-th round of network cable j. The desirable values of state variable s_j^r are "positive", "balance", and "negative" (representing bandwidth overload, balance, and bandwidth excess respectively). p is the balance valve. The balance times in the process of network cable j dynamic regulation is $Time^{(*\to balance\to *)}$. Therefore, BRR can be expressed as (4). The system balance regulation rate (SBRR) is (5).

$$BRR = \log_{10} = \frac{Time_j^{(*\to balance\to *)} + 1)}{(T_{final} - T_{first} + 1)}. \tag{4}$$

$$SBRR = \log_{10} \sum_{j=1}^{n} \left(\frac{\left(Time_j^{(*\to balance\to *)} + 1 \right)}{\left(T_{final} - T_{first} + 1 \right)} \right). \tag{5}$$

Definition 3: Flow waste after regulation (z): the flow waste before regulation is z′, When the bandwidth is overloaded, according to the scale out balance rule, the bandwidth division amount of the r-th round of network cable j is σ_j^r($j \in [1, n]$). Meanwhile, the network cable j is set as other network cables, and the requested reserved bandwidth is yes ϖ. $\zeta(r)$ is temporary change optimization mechanism, which can reduce the size of trafficable traffic according to σ_j^r and eliminate the impact of temporary bandwidth changes. Therefore, z of network cable j meets (6).

$$\frac{z}{(z' + \sigma_j^r + \varpi)\zeta(r)} = 1. \tag{6}$$

Definition 4: network cable model. The configuration mode of the network cable is "b + 1". The b represents b 4G network cables and 1 represents one 5G network cable.

C. Objective function

Therefore, the algorithm designed in this paper needs to achieve three goals. First, bandwidth utilization is higher. Second, the waste of network traffic is less. Third, System equilibrium regulation rate is higher. The objective function is shown in (7).

$$F = \left\{ \max\left(\frac{1}{n} \sum_{i=1}^{n} \Gamma^i\right), \min(z), \max(SBRR) \right\}. \tag{7}$$

4 The Proposed Approaches

In order to solve the problems mentioned in the introduction, three predictive control algorithms are developed in this paper. This section describes the proposed method in detail, including system architecture, Network Cable Scheduling algorithm, and three system methods.

A. System architecture

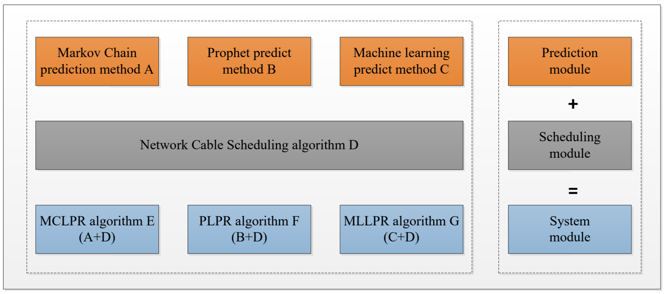


Figure 3. Architecture with its methods

Figure 3 shows the system architecture of the predictive control method. The architecture consists of three layers. The first layer is the prediction module, which is mainly used to predict the network cable status of AGV system in real time. The second layer is the scheduling module, which is used to schedule the network cable of AGV system according to specific rules. The third layer is the system regulation module, which is used to dynamically regulate the network resources of AGV system to realize the reasonable arrangement of network resources. It is composed of a prediction module in the first layer and a scheduling module in the second layer. E, F, and G of this layer are respectively composed of A, B, and C of prediction module and D of scheduling module. The following is an overview of each sub-module.

(1) Based on the idea of "4G + extension", the Network Cable Scheduling algorithm regulates the network cable of AGV system with the help of linear programming and cloud services. This can improve the situation of excess flow and flow overload of each network cable.

(2) Markov Chain has high efficiency in predicting long-term state [21]. It is often used in stock market analysis, manpower planning, and many other fields. Therefore, sub-module A is combined with sub-module D to ensure the continuity of sub-module E.

(3) Prophet prediction method is a large-scale prediction method combined with configurable model, which can effectively realize the reliable and practical prediction of business time series. It has the characteristics of both high reliability and quality [22]. Then, sub-module B is combined with sub-module D to make sub-module F more stable.

(4) Machine learning is able to use computers to simulate or realize human learning activities. It can automatically learn new patterns to update the model automatically. Therefore, the combination of sub-module C and sub-module D can improve the accuracy and adaptability of sub-module G [23].

B. Network Cable Scheduling algorithm

In order to improve the situation of excess flow and bandwidth overload of network cable, this section proposes a Network Cable Scheduling algorithm. Based on the idea of "4G + extension", the algorithm regulates the network resources of AGV system with the help of linear programming and cloud services.

Next, this paper describes the core steps of Network Cable Scheduling algorithm. Lines 4 and 14 indicate that the system needs to calculate the traffic to be divided in the next round of the current network cable according to the rules of Scale in and Scale out. The addition of the concept of resource balance in cloud computing realizes the balanced division of traffic and improves the reliability of the system. In addition, lines 5 and 15 seek the target scheduling object by setting the objective function. The universality of linear programming can improve the adaptability of the algorithm. Line 9 receives the traffic to be divided with the help of 5G network cable and 4G network cable. The advantages of 5G technology in high speed and low delay are applied to AGV system to improve the efficiency of AGV system. Line 10 indicates the dynamic application for bandwidth from the cloud service provider to realize on-demand application and improve resource utilization. Line 18, 20, and 23 indicate the free switching of network cables and adjustment of parameters with the help of cloud services, which increases the flexibility and automation of the system.

Algorithm 1. Network cable scheduling algorithm (λ_j)

```
$\psi = \xi - \lambda_j$; r = 1
Input:
    $\lambda_j' s$ flow transfer in set: $\sigma = \{ \sigma_i^r \mid i \in [1, n], i \neq j, \sigma_i \geq 0, r \in N_+ \}$
    Δ: A set of network cables that can participate in traffic control in the next round
    S: A collection of the status of each network cable in the next round
Output: $\sigma_j^r$ ; $\Delta_j$
1:  while |S|≠0 do
2:      if $\Theta_r^j > p$ then
3:          $s_j^r$ = "positive"
4:          Calculate the flow to be distributed according to the scale out rule
5:          Use linear programming in $\psi$ to confirm target network cable
6:          if find the optimal solution then
7:              Prepare to divide the flow
8:          else
9:              Mobilize 5G network cable
10:             Apply for network bandwidth cloud service
11:         end if
12:     else if $\Theta_r^j < p$ then
13:         $s_j^r$ = "negative"
14:         Calculate the flow to be distributed according to the scale in rule
15:         Use linear programming in $\psi$ to confirm target network cable
16:         if find the optimal solution then
17:             Prepare to divide the flow
18:             Ready to revoke $\lambda_j$
19:         else
20:             Call cloud computing service and adjust round r $\lambda_j'$'s network speed
21:         end if
22:     end if
23:     Combine Δ and $\sigma$, reserve bandwidth through cloud service application $\varpi$
24:     Execute round r scheduling
25:     r + 1
26:     Restore the initial setting of the network cable
27: end while
```

C. MCLPR algorithm

Markov Chain is a stochastic process that transitions from one state to another in state space. As a statistical model of actual process, it has many applications.

Therefore, considering the simplicity and flexibility of Markov Chain, this paper proposes a Markov chain based MCLPR algorithm for AGV system. The algorithm is described in detail as follows.

Algorithm 2. MCLPR algorithm

```
Output: S
1: while true do
2:     Selection probability matrix $\beta_{mm} = \{a_{ij} | a_{ij} > 0, \sum_{j=1}^{m} a_{ij} = 1\}$
3:     Realize n-step transformation according to Markov property ($n \in N^*$)
4:     Start the network cable scheduling job according to the network cable scheduling algorithm
5: end while
```

Next, this paper describes the core steps of MCLPR algorithm. Line 2 is the network line state transition probability matrix, which will have a great impact on the accuracy of network line state prediction results. Line 3 represents n-step conversion based on Markov property to predict the next time state of the current network line. This method has a good effect on the state prediction of the process, and it can even be used to predict the dangerous state of the production site.

D. PLPR algorithm

Time series prediction is to arrange the data in time series, and then infer the possible level in the future by analyzing its change direction and degree. The basic idea of time series prediction is to take the time series as the sample of random variables and use the method of probability and statistics to reduce the influence of accidental factors as much as possible. Among them, the time series is a line measurement of a variable or a group of variables X(t) of the objective process. At time t1 < t2 < ... < tn, the discrete ordered set X(t1), X(t2), …, X(tn) with time t as the independent variable. Among them, the independent variable t can have different physical meanings, such as length, temperature, or other physical quantities. The fluctuation of time series is the result of many factors. The effects include long-term trend, seasonal variation, cyclic variation, and random variation. If T, S, C, and I are used to represent the values of long-term trend, seasonal variation, cyclic variation, and random variation respectively, there are two types of models most commonly used for time series YT: yt = T × S × C × I and yt = T + S + C + I.

Combined with Prophet prediction method and Network Cable Scheduling algorithm, this paper implements the PLPR algorithm for AGV logistics system.

Algorithm 3. PLPR algorithm

```
θ: The bandwidth of $\lambda_i$
Input: A known dataset in the form of {timestamp value}
Output: S
1:  while true do
2:      Initialize data
3:      Set the length of the predicted time series
4:      Calculate the future trend of time series
5:      Get the predicted value, upper bound, and lower bound
6:      Calculate network cable status according to θ
7:      Start network resource management according to Network Cable Scheduling algorithm
8:  end while
```

The core steps of PLPR algorithm are line 5 and line 6. Line 5 indicates that the next time traffic of the corresponding network line is predicted through the time series prediction algorithm. It can find out the characteristics, trend, and development law of variable change from time series, and effectively predict the future change of variables. Line 6 introduces that the load of the corresponding network cable is calculated based on the traffic and bandwidth to provide necessary parameters for the scheduling of the network cable.

E. MLLPR algorithm

Machine learning is a branch of artificial intelligence. It is a method to automatically analyze and obtain laws from data and use laws to predict unknown data. At present, machine learning has been widely used in many fields. At the same time, it can be divided into the following categories: 1) supervised learning. 2) Unsupervised learning. 3) Semi supervised learning. 4) Enhance learning. In order to achieve the goal, the machine gradually adjusts its behavior with the changes of the environment, and evaluates whether the feedback of each action is positive or negative.

To sum up, due to the rapid and efficient development of machine learning, this paper uses it to develop MLLPR algorithm. In addition, combined with the problems studied, this paper adopts the regression of supervised learning.

The core steps of MLLPR algorithm are described as follows. Row 1 indicates that the data set is preprocessed by normalization, standardization, and missing value processing. This is the foundation of the later training work, and it has a great impact on the accuracy of the training mode. Row 5 represents the training data set to mine the corresponding fitting model. Line 7 indicates that the obtained model is optimized to improve the prediction accuracy of unknown data. Rows 10 and 11 provide the necessary parameters for the scheduling of the current network cable in the next round. Line 15 can realize the regular update of the model to avoid the loss of generalization ability of the model.

Algorithm 4. MLLPR algorithm

```
T: Model optimization cycle; count = 0
Input: data set
Output: S
1:  Preprocess the traffic data set of each network line in AGV system
2:  Divide the data set into training set and test set
3:  Use feature engineering to obtain the characteristics of data
4:  Filter valid features
5:  Compare the performance of different machine learning algorithms
6:  Select the optimal machine learning algorithm
7:  Train the model with the training set
8:  Estimate the obtained model.
9:  Optimize the parameters of the model
10: while true do
11:     if count < T then
12:         Obtain the predicted value for a period of time in the future
13:         Calculate the network cable balance state value
14:         Start the network cable scheduling job according to the network cable scheduling algorithm
15:         count+1
16:     else
17:         Add new data training and optimization model
18:     end if
19: end while
```

5 Experimental Results and Analysis

This section verifies and compares the effectiveness of the three methods proposed in this paper in the following three aspects: 1) Dynamic adjustment ability of network resources. 2) Seamless operation of the trolley. 3) Reduction of wasted network resources.

A. Experimental environment

Table 2 introduces the hardware environment and software environment of this experiment.

Table 2. Experimental environment

Hardware environment	Software environment
Intel(R) Core(TM) i5-8250U CPU @ 1.60GHz 1.80 GHz	PyCharm Community Edition 2020.2.3

B. Experimental results

The experiment uses “4 + 1” mode. The initialization parameters of the experiment include: 1) The number of balance regulation is set to 15 rounds. 2) The number of network cables is initialized to 4. 3) The number of AGVs is 8, and one network cable connects two AGVs. In addition, in order to improve the simplicity of the chart, the balance control state values “positive”, “balance”, and “negative” are converted to 1, 0, and -1 respectively. RD indicates the number of control rounds. The traffic of each network cable is recorded as OT, TT, ST and FT respectively. In order to follow the core idea of on-demand distribution of cloud services, the parameters are set to ensure the continuous operation of the AGV. Moreover, in order to ensure the continuity of the image, the cancellation of the network cable and the speed limit of the network cable mean that the flow waste of the network cable is 0. All experiments recognize the accuracy of the prediction algorithm.

1) MCLPR algorithm (analog data)

The bandwidth utilization of the four network cables is initialized to positive, negative, balance, and positive.

(a) Dynamic adjustment ability of network resources.

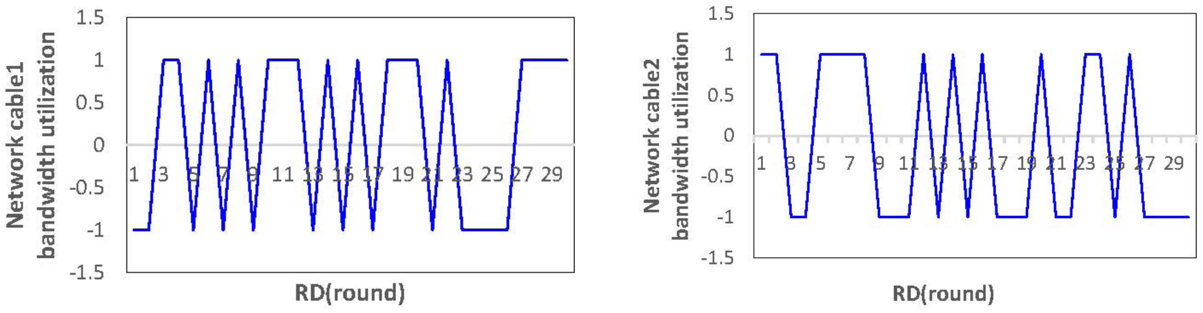
Figure 4 shows the dynamic balance control diagram of each network cable for MCLPR algorithm. Next, the process of balance adjustment will be described by taking the network cable 2 as an example. In Figure 4(b), a negative prediction state in the second round indicates that a large amount of bandwidth is wasted in the network cable 2. Therefore, the AGV system adjusts the bandwidth of the network cable 2 through the scheduling algorithm. After successful regulation, the state of network cable 2 changes to positive. Similarly, during the third round of regulation, the predicted state of the network cable is negative. AGV system adjusts the network cable according to the scale in rule through the Network Cable Scheduling algorithm. After successful regulation, the state of network cable 2 changes to positive. It can be seen that under the network resource management mechanism, network cable 2 fluctuates up and down around the balance valve during the working process, which can achieve a continuous balance change. Through further calculation of the balance efficiency, the balance regulation efficiency of network cable 1, 2, 3, and 4 are $\log_{10} 0.3$, $\log_{10} 0.7$, $\log_{10} 0.6$, and $\log_{10} 0.53$. Therefore, in this experiment, the balance sensitivity of network cable 2 is the highest.

(b) Seamless operation of the trolley.

Figure 5 is a flow state diagram for the MCLPR algorithm. It depicts the flow change curve of the four network cables. To simplify the chart, “*true*” means that the AGV system uses 5G cable, and “*false*” means that the AGV system does not use 5G cable. The traffic of each network cable is recorded as OT, TT, ST, and FT respectively. During the 15 rounds of monitoring, the traffic of network lines 1, 2, 3, and 4 continuously and dynamically changes. During this process, 4G and 5G network cables are used interchangeably. This means that the AGV car runs seamlessly on the network cable. During the balance adjustment process, while using 4G network cables, the traffic difference between the four network cables is relatively small. Four 5G network cables generate a significant difference as the total network traffic is increasing. So the 4G and 5G network cables work well together, and then improve the operational efficiency of the AGV system.

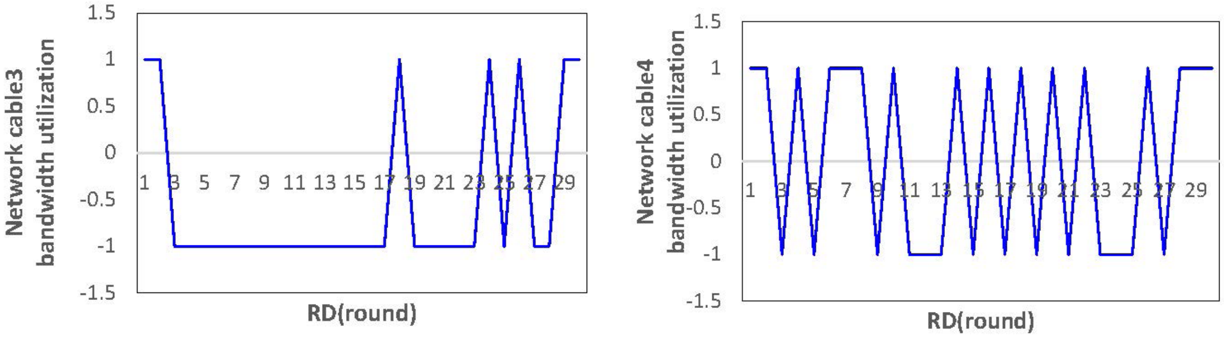
(c) Reduction of wasted network resources.

Figure 6 shows a comparison of the waste of traffic on each network cable before and after scheduling. Figure 6(a) to Figure 6(d) show a comparison of traffic waste for network cables 1, 2, 3, and 4, respectively. Orange represents the situation after scheduling. Blue represents the situation before scheduling. It is from the Figure 6 that the flow resources wasted by network cable 1, 2, 3, and 4 are reduced by 21764286.5B, 62197608.25B, 46377890B, and 41326394B. Therefore, the bandwidth leakage rates of network cable 1, 2, 3, and 4 are 21.21%, 62.81%, 56.70%, and 46.24%. In 15 rounds of balance regulation, the flow waste of network cable 2 is least.



(a) Network cable 1

(b) Network cable 2



(c) Network cable 3

(d) Network cable 4

Figure 4. Dynamic balance control diagram of MCLPR algorithm network cable

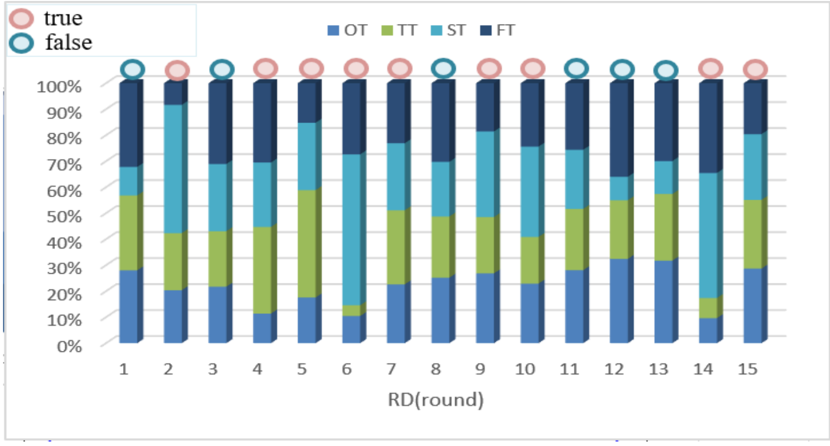
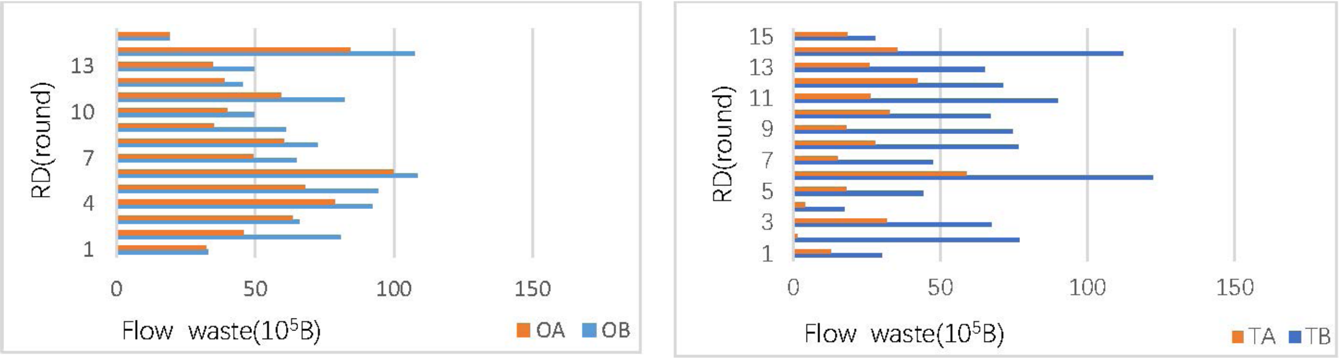
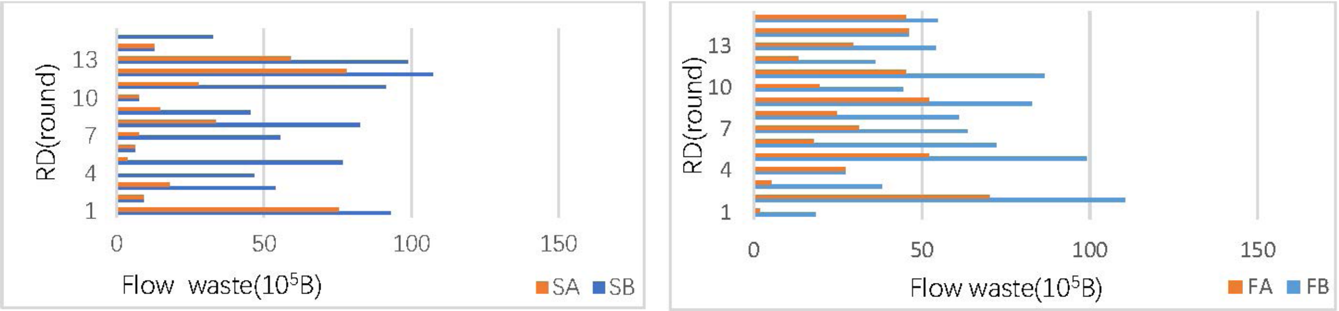


Figure 5. Flow state diagram of MCLPR algorithm



(a) Network cable 1

(b) Network cable 2



(c) Network cable 3

(d) Network cable 4

Figure 6. Comparison of flow waste before and after scheduling of MCLPR algorithm

2) PLPR algorithm (real data)

This section uses real data. In order to preserve the characteristics of real data, the experiment is set to be executed once a day.

(a) Dynamic adjustment ability of network resources.

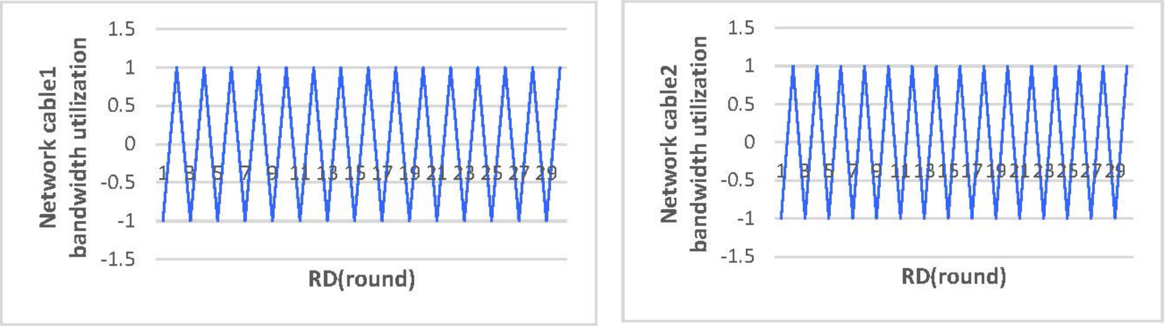
Figure 7 shows the balance regulation diagram of four network cables in AGV system. Next, the process of balance adjustment will be described by taking the network cable 1 as an example. In Figure 7(a), a negative prediction state in the first round indicates that a large amount of bandwidth is wasted in the network cable 1. Therefore, the network cable is adjusted according to the scale in rule through the Network Cable Scheduling algorithm. After successful regulation, the state of network cable 1 changes to positive. Similarly, during the second round of regulation, the predicted state of the network cable is negative. The AGV system adjusts the network cable according to the scale in rule through the Network Cable Scheduling algorithm. After successful regulation, the state of network cable 1 changes to positive. It can be seen that under the network resource management mechanism, network cable 1 fluctuates up and down around the balance valve during the working process, which can achieve a continuous balance change. According to the calculation of the balance efficiency, the balance regulation efficiency of the four network cables are: log^{1}_{10}, $log^{0.93}_{10}$, log^{1}_{10} and log^{1}_{10}. It can be seen that the other three network cables except the network cable 2 have good balance adjustment sensitivity. In addition, compared with MCLPR algorithm, the balance regulation efficiency of PLPR algorithm is generally at a higher level. It can be seen that PLPR algorithm has more advantages than MCLPR algorithm in dynamic balance ability.

(b) Seamless operation of the trolley.

Figure 8 shows the flow changes of four network cables during 15 rounds of balance regulation. As shown in Figure 8, four network cables can meet 15 rounds of continuous traffic transmission. At the same time, the comparison value between 5G network cable and 4G network cable for PLPR algorithm is 0.07, which is less than MCLPR algorithm. At this time, 5G network cable is used as an auxiliary to coordinate the work of 4G network cable. This reduces the network cable switching cost of balanced regulation and improves the economy of AGV system.

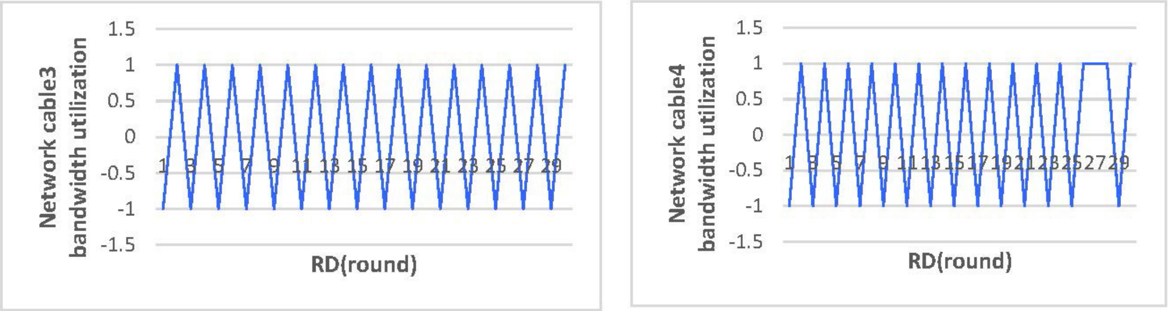
(c) Reduction of wasted network resources.

Figure 9 shows a comparison of the waste of traffic on each network cable before and after scheduling. Figure 9(a) to Figure 9(d) show a comparison of traffic waste for network cables 1, 2, 3, and 4, respectively. Orange represents the situation after scheduling. Blue represents the situation before scheduling. The flow waste status will be described by taking the network cable 2 as an example. That network cable 2 continues to be regulated by Network Cable Scheduling algorithm. From the first round to the 13th round, the flow waste of network cable 2 is reduced to 0 to a certain extent. At the same time, in the 14th round, due to the problem of prediction accuracy, the network cable balance regulation algorithm made a mistake. Therefore, the reduced flow waste in round 14 is not obvious enough. However, in the 15th round, the flow waste of network cable 2 is greatly reduced within a certain limit. Through further observation and calculation, the bandwidth leakage rates of these network cables are 100%, 94.97%, 100%, and 100%, respectively. In addition to network cable 2, network cables 1, 3, and 4 all show excellent bandwidth protection capability. Moreover, the bandwidth protection capability of PLPR algorithm is significantly higher than that of MCLPR algorithm.



(a) Network cable 1

(b) Network cable 2



(c) Network cable 3

(d) Network cable 4

Figure 7. Balance regulation state diagram of PLPR algorithm

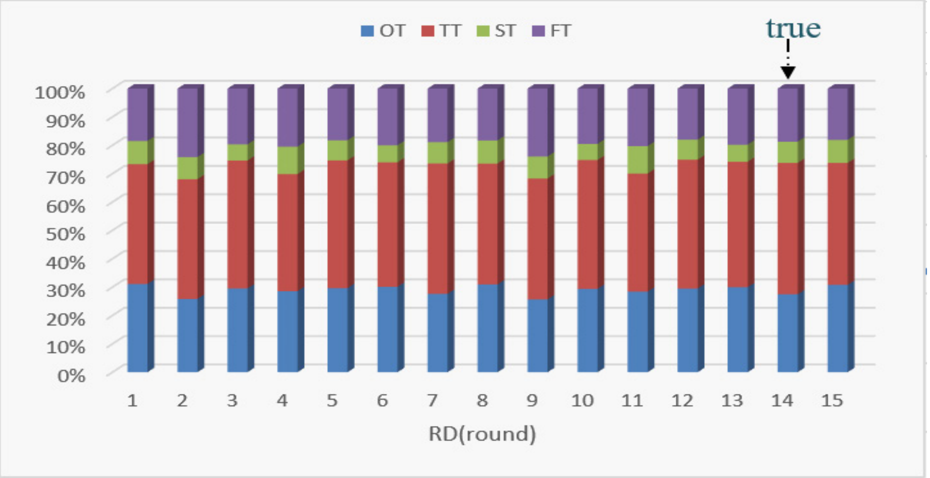
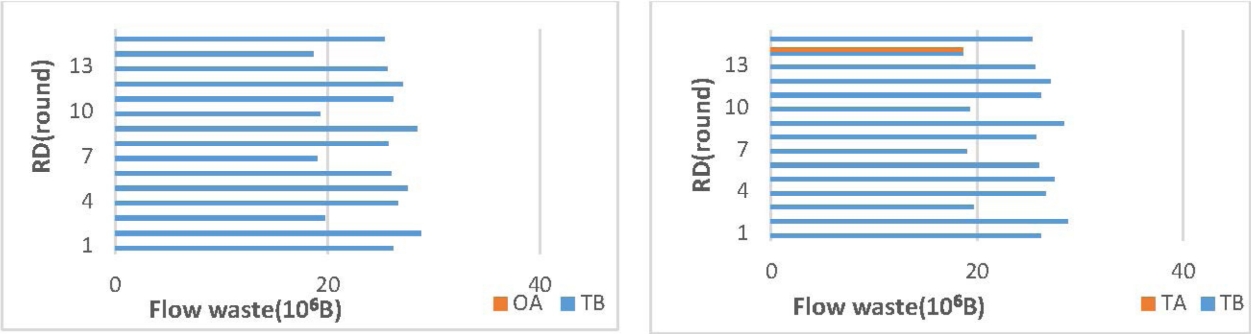
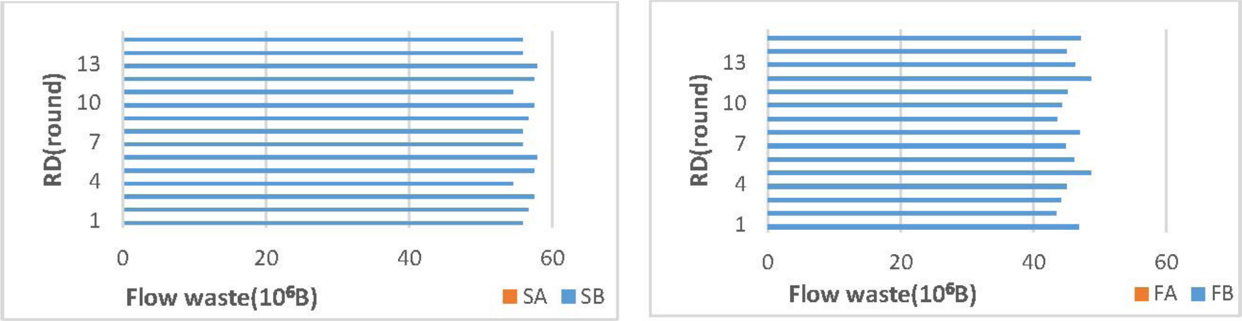


Figure 8. Traffic variation diagram of PLPR algorithm



(a) Network cable 1

(b) Network cable 2



(c) Network cable 3

(d) Network cable 4

Figure 9. Comparison of flow waste of PLPR algorithm before and after scheduling

3) MLLPR algorithm (real data)

This section uses real data to validate the MLLPR algorithm. The task of the experiment is to allocate the best bandwidth for the four network cables.

(a) Dynamic adjustment ability of network resources.

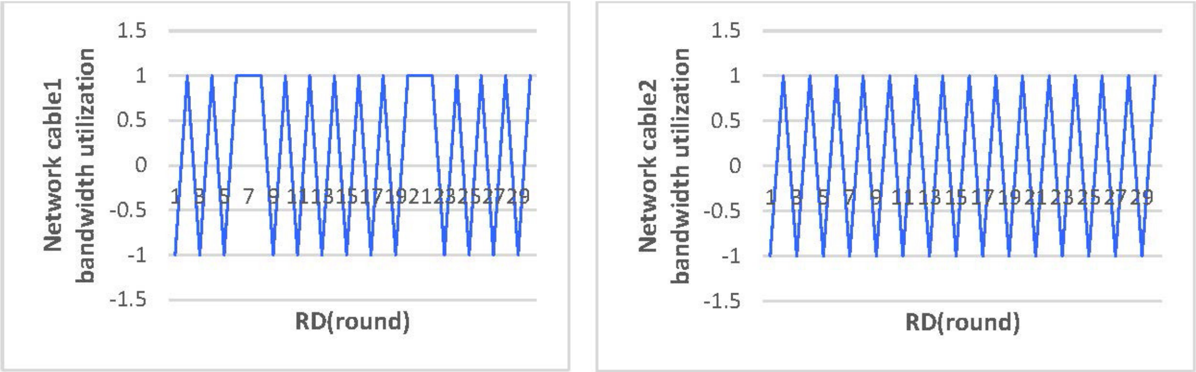
Figure 10 is a broken line diagram of balance regulation of each network line. Next, the process of balance adjustment will be described by taking the network cable 2 as an example. In Figure 10(b), a negative prediction state in the first round indicates that a large amount of bandwidth is wasted in the network cable 1. Therefore, the network cable is adjusted according to the scale in rule through the Network Cable Scheduling algorithm. After successful regulation, the state of network cable 2 changes to positive. Similarly, during the second round of regulation, the predicted state of the network cable is negative. The AGV system adjusts the network cable according to the scale in rule through the Network Cable Scheduling algorithm. After successful regulation, the state of network cable 2 changes to positive. It can be seen that under the management of the Network Cable Balance Control algorithm, network cable 2 fluctuates up and down around the balance valve during the working process, which can realize continuous balance change. Through further calculation of the balance efficiency, the balance efficiency of network cable 1 is $\log_{10}^{0.87}$, $\log_{10}^{1}$, $\log_{10}^{1}$, and $\log_{10}^{1}$, while the balance efficiency of network cables 2, 3, and 4 is 100%. This shows that MLLPR algorithm is equal to PLPR algorithm in balancing regulation efficiency, and they can replace each other. What's more, the balance regulation ability of the two algorithms is better than that of MCLPR algorithm.

(b) Seamless operation of the trolley.

In this section, the predicted flow values are transformed to increase the consistency of the experiment. Figure 11 shows the flow distribution during the operation of AGV system. 4G network cable runs well in the whole process and can ensure normal traffic transmission. On the contrary, 5G network cable was not involved in balance regulation in this experiment. Therefore, based on the above two algorithms, MLLPR algorithm further reduces the network cable switching cost of AGV system. Therefore, the algorithm not only ensures the normal operation of AGV system, but also increases the economic benefit. This is more conducive to the creation of economic and energy-saving factories.

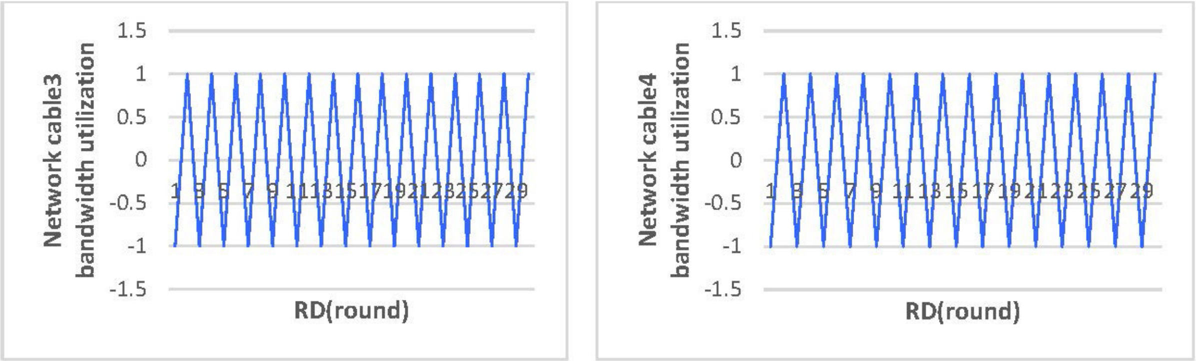
(c) Reduction of wasted network resources.

Figure 12 shows a comparison of the waste of traffic on each network cable before and after scheduling. Figure 12(a) to Figure 12(d) show a comparison of traffic waste for network cables 1, 2, 3, and 4, respectively. Orange represents the situation after scheduling. Blue represents the situation before scheduling. Next, the flow waste status will be described by taking the network cable 1 as an example. Then, the network cable 1 continues to be regulated by Network Cable Scheduling algorithm. From the first round to the third round, the flow waste of network cable 1 is reduced to 0 to a certain extent. In the fourth round, only part of the flow waste is reduced due to the efficiency of the Network Cable Balance Control algorithm. Then, from 5 to 10 rounds, the flow waste of network cable 1 is greatly reduced again within a certain limit. At the same time, the flow waste in the 11th round is limited by the efficiency of Network Cable Balance Control algorithm, which is only reduced by a part. However, from 12 to 15 rounds, the flow waste of the network cable is reduced to 0 within a certain limit. According to the chart, the bandwidth leakage rate of the four network cables can be calculated as 97.12%, 100%, 100%, and 100%, respectively. Therefore, the bandwidth protection capability of network line 1 for MLLPR algorithm is slightly inferior to that of PLPR algorithm, while the bandwidth protection capability of network line 2 for MLLPR algorithm is better than that of PLPR algorithm. Overall, compared with PLPR algorithm, MLLPR algorithm can reduce flow waste.



(a) Network cable 1

(b) Network cable 2



(c) Network cable 3

(d) Network cable 4

Figure 10. Network cable balance regulation efficiency diagram of MLLPR algorithm

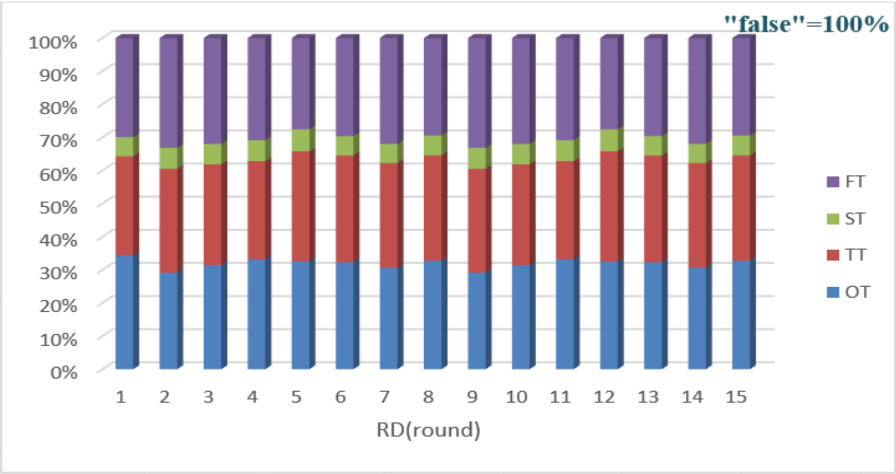
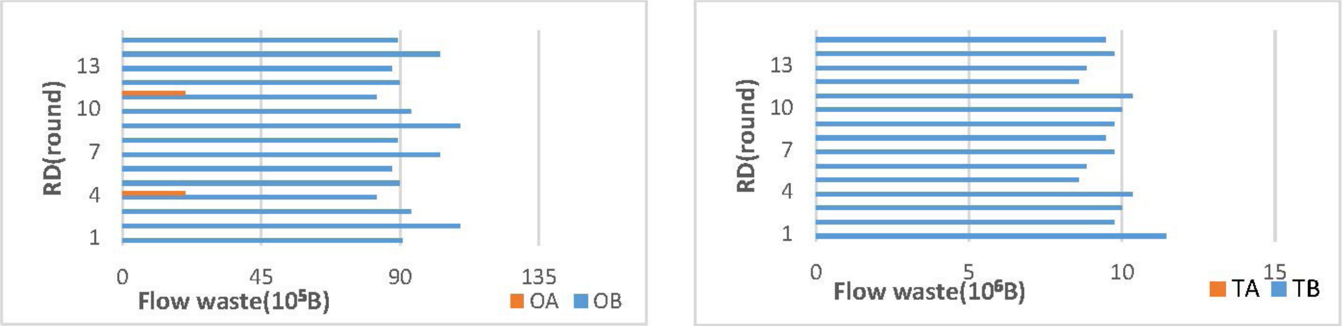
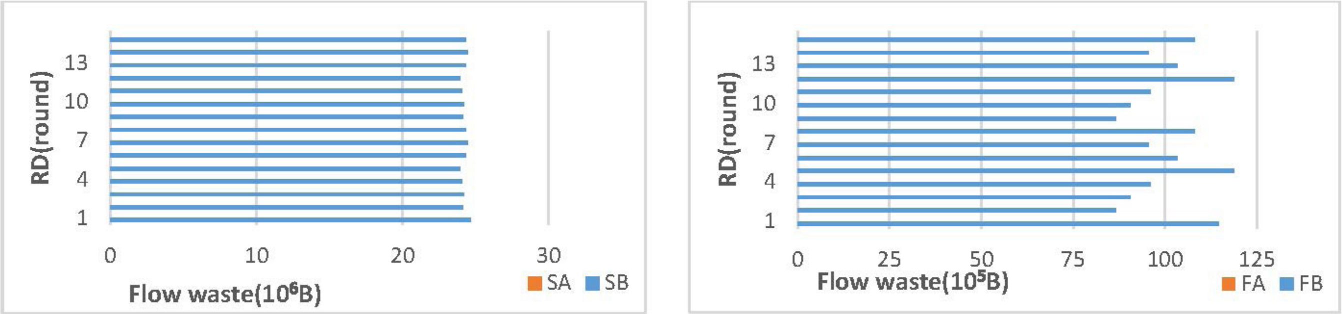


Figure 11. Flow change diagram of MLLPR algorithm



(a) Network cable 1 (b) Network cable 2

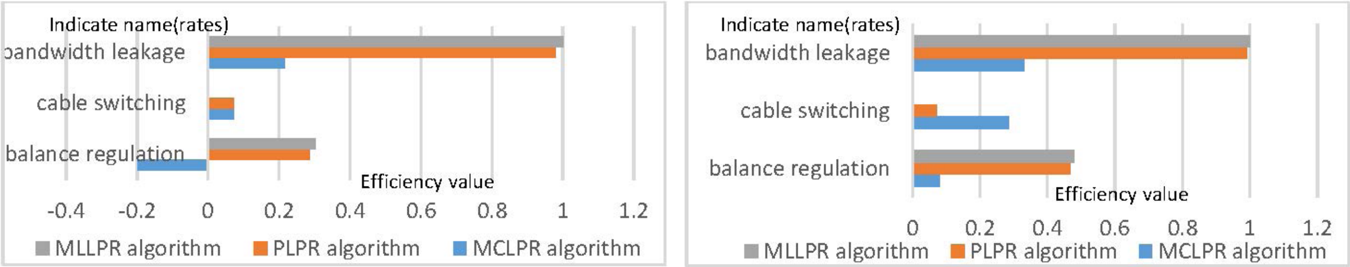


(c) Network cable 3 (d) Network cable 4

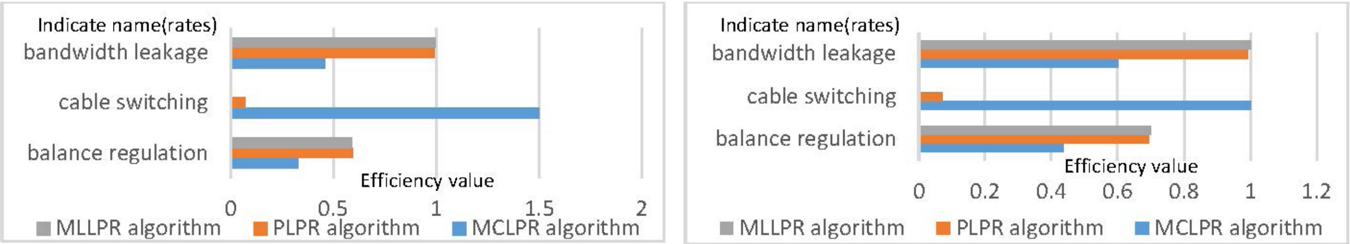
Figure 12. Comparison of flow waste of MLLPR algorithm before and after scheduling

C. Comparison of three methods

In this section, MLLPR, PLPR, and MCLPR algorithms are used for experiments in different network cable modes, as shown in Figure 13. There are "2+1", "3+1", "4+1", and "5+1" network cable modes. This section mainly tests the performance of the algorithms in balancing adjustment efficiency, network cable switching cost, and bandwidth leakage limitation efficiency. The results of the three methods for performance comparison are shown in Table 3. It can be seen that the MLLPR algorithm has the highest balance adjustment efficiency. At the same time, it generates switching cost of the lowest network cable in different network cable modes. In addition, this algorithm has the highest bandwidth leakage limitation efficiency for different network cable modes. In summary, the MLLPR algorithm outperforms the other two algorithms in various aspects. The MCLPR algorithm has the worst performance.



(a) "2+1" (b) "3+1"



(c) "4+1" (d) "5+1"

Figure 13. Comparison of different network cable modes

Table 3. Performance comparison of three methods

	Dynamic adjustment ability	Seamless operation	Reduction of wasted network resources
MCLPR algorithm	√	√	√
PLPR algorithm			
MLLPR algorithm	√√√	√√√	√√√

Note: √√√ indicates the best performance. √ indicates the worst performance.

6 Conclusions and Future Work

This section introduces the conclusions of the article and future work ideas.

A. Conclusions

In the industrial Internet environment, combined with cloud services, it is very important to solve the problem of AGV system lacking network resource management mechanism. The problem includes three aspects: 1) the delay of AGV system caused by insufficient bandwidth; 2) Waste of flow resources; 3) Unable to dynamically regulate network resources. Therefore, this paper proposes three methods to solve this problem. The experimental results show that the bandwidth leakage limiting ability of PLPR algorithm and MLLPR algorithm is higher than that of MCLPR algorithm. The MLLPR algorithm is improved by 2.15% on the basis of PLPR algorithm. At the same time, the balance regulation rates of the four network cables of PLPR algorithm are 100%, 93.33%, 100%, and 100% respectively, which has the highest network cable balance regulation efficiency. In addition, cost generated by MLLPR is the lowest. Further, the experimental results under different network cable modes show that MLLPR has the highest balance regulation efficiency without considering “4 + 1” mode. To sum up, the method proposed in this paper can help effectively arrange network resources and improve the reliability, economy, and real-time performance of AGV system.

B. Future Works

This paper can go further to design suitable linear programming objective function according to different situations to realize the on-demand regulation of network resources in the future. At the same time, in order to train a more accurate model by optimizing the training set, improving the reliability of the network resource management mechanism of AGV system is an interesting research topic. Moreover, the network resource management method designed in this paper is based on the 5G environment. In the future, safety factors can also be considered on the basis of this paper. Those methods in this paper extended for 6G environment are an another interesting research topic.

Acknowledgment

This work was supported by the Natural Science Foundation of Shandong Province (ZR2020MF048).

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