International Journal of Control and Automation
Vol.7, No.10 (2014), pp.53-64
http://dx.doi.org/10.14257/ijca.2014.7.10.06

# The AVS/RS Scheduling Optimization Based on Improved AFSA

Yanjun Fang and Meng Tang

*Department of Automation, Wuhan University, China*
*2012102080026@whu.edu.cn*

***Abstract***

*This paper addresses the problem of the autonomous vehicle storage and retrieval system (AVS/RS) scheduling optimization. AVS/RS relies on rail guide vehicle (RGV) to provide horizontal movement within a tier and uses lifts to provide vertical movement between tiers. Firstly, the process of RGVs' compound operation is analyzed, and the corresponding mathematical model is established. Then, an improved artificial fish swarm algorithm (IAFSA) is proposed to solve the model. According to the characteristics of the storage and retrieval operation in the system, an encoding and decoding method is designed, which contains RGV task allocation and elevator selection information. The tabu list and the optimal strategy are introduced into this algorithm, coupled with memory action and communication action to avoid the algorithm to trap in local optimal solution. Meanwhile, the adaptive step and visual are used to increase the late convergence of this algorithm. Finally, simulations based on the concrete living example of AVS/RS in a provincial verification center are given.The results obtained by the proposed algorithm are compared with another two optimization algorithm. Analysis shows that the proposed algorithm has the characteristics of fast convergence and the best solution, so as to improve the practicality and robustness of the algorithm.*

***Keywords:*** *AVS/RS, scheduling, AFSA, RGVs, Lifts*

## 1. Introduction

In 2003, Professor Malmborg's team at Rensselaer Poly real technic Institute in US proposed the autonomous vehicle storage and retrieval system(AVS/RS), which is more flexible and efficient with respect to throughput capacity in the transfer of unit loads in high density storage areas than the traditional automated stereoscopic warehouse (AV/RS)[1]-[3]. The characteristics of the AVS/RS are relying on the rail guide vehicle (RGV) in the warehouse for three dimensional motions to achieve access operation of unit load, and its vertical movement should be with the aid of elevator. The AVS/RS mainly includes RGV system, elevator system, aisle and shelf, which are shown in Figure 1. Each RGV can service any bay, every car as spare each other.

For the RGV scheduling problem in the AVS/RS, LUO and WU [1] proposed an improved QPSO to improve the performance of RGVS in AVS/RS, but not involving the aspect in elevator selection. Fukunari [2] mainly discussed the interleaved operation, established RGVs in interleaving mode of circulation time model, based on the use of queuing theory method to carry on the theoretical analysis and experimental research. WU [3] proposed a deadlock control modeling method based on Petri nets and directed graph to avoid the cycle-deadlock of RGVs system in AVS/RS, but there only exists one elevator in his system. Y. Ekren [4]

ISSN: 2005-4297 IJCA

considered the AVS/RS analytical model as a semi-open queuing network (SOQN), which consists of customers, a secondary resource and servers. However, the scheduling of AVS/RS with multiple RGVs and multiple elevators has received limited attention at present.

**a. RGV**

**b. Elevator and Shelf**

**c. Aisle**

**Figure 1. The Main Parts of the AVS/RS**

To improve the throughout and efficiency of the AGV/RS with multiple RGVs and multiple elevators, it is significantly important to find an optimal scheduling policy. In this paper, we present a new AVS/RS compound operation scheduling mathematical model, which contains multiple RGVs and multiple elevators that has greatly increased the complexity of AVS/RS scheduling. An improved AFSA is proposed to solve the optimal solution of the mathematical model, and get the optimal scheduling strategy of the system.

## 2. AVS/RS Scheduling Description and Modeling

### 2.1. Problem Description

The scheduling in AVS/RS with multiple RGVs and multiple elevators is when new tasks are arriving in the system, it will finish task allocation of RGVs and choose the right elevator to complete each RGV's vertical movement, so as to improve the efficiency of the AVS/RS and fulfill the shortest overall task completion time.

There are three kinds of assignments: outbound operation, inbound operation and compound operation. This paper mainly discussed the third condition, which is the most complex condition. When outbound operation and inbound operation are appearing in the system at the same time, RGV adopts compound operation can greatly improve the efficiency of the system, that means the outbound operation and inbound operation going interleaving, we show a diagram for compound operation of RGV in Figure 2. All tasks are firstly divided into several groups according to the number of available RGVs and RGVs carry out the cycle compound operation. Owing to the most of the tasks need the RGV moving between tiers, so the RGVs must take use of the elevator to complete vertical movement.

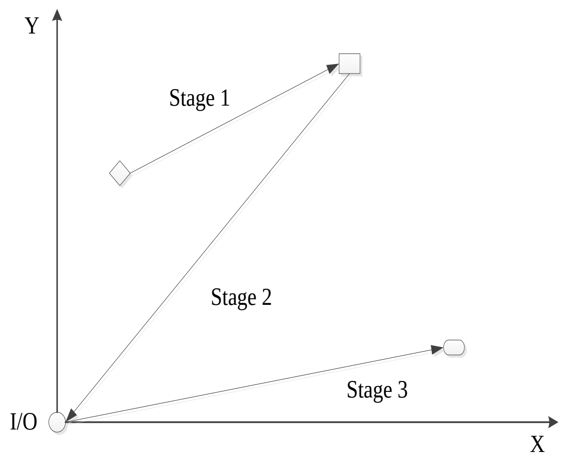


**Figure 2. The RGV Compound Assignment Plane Sketch**

There are three stages in a RGV compound operation: (i) RGV runs from the current position to the starting point of the outbound task. (ii) RGV runs from the starting point of the outbound task to the I/O point.(iii) RGV runs from the I/O point to the ending point of the inbound task.

After completing the task allocation, the system needs to give path planning in every stage for each RGV. For the across layer task, due to the horizontal path is determined by the selected elevator, RGV path planning should consider the elevator scheduling. Therefore, the tasks allocation of RGVs, sorting, and the choice of elevator in every stage are the key points of the system scheduling.

### 2.2. The Conversion of Problem

Owing to most of the tasks in the system are cross layer task, so in a RGV compound operation, every stage includes two parts of moving time:

(i) the horizontal moving time $T_{hk}$ is consisted of the consumed time of RGV runs from the current position to the elevator point $t_{hk1}$ and the consumed time of RGV runs from the elevator point to the destination point $t_{hk2}$.

(ii) the vertical moving time $T_{vk}$ is RGV waiting time $W_T$ plus the actual delivery time of the elevator $R_T$. $W_T$ is related to the current position of elevator, the condition of the elevator and $t_{hk1}$.This paper proposed a RGVs compound operation scheduling model, which involved multiple elevators. Figure 3 shows the AVS/RS scheduling model.

Stage 1 is the task assignment phase, Stage 2~Stage 4 are the RGVs' actual operating phase. In a RGV compound operation, there are at least two actual operating phase involving the selection of the elevator. In other words, there would appear the condition there is no need for RGV to use the elevator in some stages (no-cross layer task). So, We add a virtual elevator in the system, if one RGV selecting this elevator that means the RGV can reach it's destination without using elevator in this stage, the consumed time of the RGV $T_{vk}$ is zero. Each RGV can choose any idle elevator in one stage.

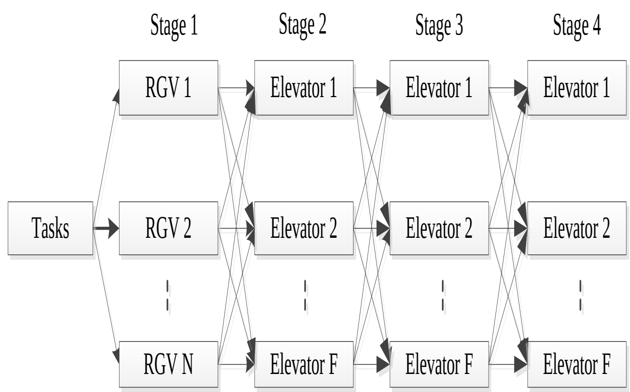


**Figure 3. The AVS/RS Scheduling Model Schematic Diagram**

## 2.3. The AVS/RS Scheduling Modeling

We model the AVS/RS by the directed graph G=(V , E), there are some assumptions:

a. All of the path are bidirectional.
b. The speed of RGV along the x,y,z axis are Vx,Vy,Vz.
c. Each RGV only take one task at a time.
d. Each elevator only transports one RGV at a time.

The AVS/RS scheduling mathematical model is given as follow. There are M inbound tasks and M outbound tasks arriving in the system, the number of RGVs is N, the number of elevators is F-1, N≥M. The all tasks are divided into M group, which consists of M/N=P batches.Every group includes a inbound task and an outbound task. Each cycle operation (batch) has N task group. The first stage consumed time is zero, F elevators exists in the later stages. One RGV choose different elevators in the same stage has different consumed time. Our job is finding the shortest time consuming scheduling scheme to complete all tasks.

$$MinT(I) = \min \sum_{s=1}^{4} t_{s,i} + R_{t_{s,i}} + t_{k2}, i = 1,2 \dots M \quad (1)$$

$$t_{s,i} = \left| t_{s,i,k1} - t_{s,i,f} \right|, f = 1,2,\dots F+1 \quad (2)$$

$$t_{s,f,i} = t_{s,i} + R_{t_{s,i}} \quad (3)$$

 

$$y_{s,i,f} = \begin{cases} 1, \text{the RGV taked group ith uses} \\ \quad \text{the elevator } f \text{ in stage } s \\ 0, \text{otherwise} \end{cases} \tag{4}$$

$$\sum_{f=1}^{F} y_{s,i,f} = 1, i = 1, 2 \ldots M, s = 1, 2, 3, 4 \tag{5}$$

Formula (1) is the objective function. Formula (2) is the consumed time of RGV took group i from the current moment to the moment of beginning to use the elevator f, which contains the RGV actual traveling time $t_{s,i,k1}$ and the consumed time of elevator f from the current moment to reaching the RGV layer $t_{s,i,f}$ . $R_{ts,i}$ is the actual consumed time of group i taking elevator, $t_{k2}$ is the consumed time of RGV traveling from the elevator point to the destination point of the task. Formula (3) is the elevator f occupied time by the group i in stage s. Formula (5) means each RGV only occupying one elevator in one stage.

# 3. Improved Artificial Fish Swarm Algorithm

## 3.1. The Basic Artificial Fish Swarm Algorithm (AFSA)

In basic artificial fish swarm algorithm (AFSF), artificial fish model is structured firstly, then they search the food by simulating three kinds of fish behavior pattern as follows: swarming, following and preying [5]-[8]. The state of the artificial fish is defined as $X=(x_1,x_2,\ldots x_n)$,$x_i$ is the optimization variable, the dimension of the vector X is n. The food concentration of the artificial fish in current location is defined as Y=f(x), Y is the fitness function. $d_{ij}=\|x_i-x_j\|$ is the distance between individuals, Visual is the vision field of the artificial fish, Step is largest moving step length, $\delta$ is the congestion degree factor.

Although the AFSA has strong global search ability, the effect of congestion degree makes the individuals not be able to rally near the optimal value, that resulting in slowing the late convergence speed and easily falling into the local extreme value point.

## 3.2 The Improved Artificial Fish Swarm Algorithm (IAFSA)

There are various improved the artificial fish algorithm [9]-[12].DUAN[9]proposed the PSO-FSA to improve convergence speed and searching precision of the AFSA.SUN[10] proposed an AFSA adding the fish jumping behavior, XU [11]proposed an adaptive meta-cognitive artificial fish swarm algorithm to speed up the convergence in the later period of the basic AFSA. Tsai [12] introduced the survival competition mechanism into the AFSA.

Different from those studies, in this study, we proposed an improved AFSA with tabu list, and adding two new behaviors: the memory behavior, the communication behavior. Meanwhile, we used the adaptive step length and visual field to avoid into the local optimum.

1) The tabu list: to avoid the AF moving to a location particular repeatedly, we set a tabu list for each AF k (k=1,2,... N) to record the visited location in the previous iteration. Before the next moving, the artificial fish will check if the new location is included in the tabu list. Only the new location is not included in the tabu list or included in the table list but meeting the defy rules [8], will the AF move to new location, otherwise, choose another location within it's vision field.

2) The adaptive Step and Visual: the adaptive step and visual are used to make AF reach the near of the optimal value rapidly in the early of the process, and complete the search precision near the optimal value in the late, which reducing the overall optimization time and improving the efficiency of optimization. Before each iteration, the center of all the AF is calculated as their gravity position, and getting the n dimension Euclidean distance between the position of every AF and the gravity position as their initial Step, so the initial Visual of each individual is Visual=(|1-Yj/Yi|*Step)/ λ. The current state of the AF is $X_i$, the next state of the AF is $X_j$ , it's next move can be defined as follow:

$$X_{i\,|\,next} = X_i + \left|1 - \frac{Y_j}{Y_i}\right| \cdot (Step) \frac{X_j - X_i}{\left\| X_j - X_i \right\|} \quad (6)$$

Xi|next represents the next state of the AF, $Y_i$ and $Y_j$ are the fitness function value of $X_i$ and $X_j$, |1-Yj/Yi| is the step regulator.

3) The memory behavior and communication behavior:

a. The memory behavior: AF $X_i$ moves one step to its own history best position that made next step consider its experie- nced optimal position ,which strengthening the directionality of AF behavior.

b. The communication behavior: AF $X_i$ moves one step to the history optimal position $H_{best}$ in the bulletin that made next step consider the optimal position of whole fish swarm ,which enhancing the information exchange and sharing between individuals.

## 4. The IAFSA for AVS/RS scheduling

According to the characteristics of the AVS/RS scheduling, encoding and decoding, fitness function, the process of the proposed algorithm are given in this section.

### 4.1. Encoding and Decoding

According to the characteristics of the AVS/RS scheduli- ng model described in section I-C, this paper mainly focuses on the RGV's task allocation and the elevator selection in each actual operation phases. We adopt floating point encoding method: integer part represents RGV's task allocation or elevator number selected by RGV in each stage, decimal fraction part represents service sequence of tasks choosing the same RGV or elevator. The state vector $X_i$ represents a AF, the dimension of AF is 4M that includes the scheduling information of RGVs and elevators, different AF represents a feasible scheduling solution. For example, let a AF state is $X_i=(x_1,x_2,\ldots x_M|x_{M+1}, x_{M+2}\ldots x_{2M}|x_{2M+1},x_{2M+2}\ldots x_{3M}|x_{3M+1},x_{3M+2}\ldots\ldots x_{4M})$ =(1.1,2.1,2.2| 2.1,1.2,1.1|1.2,2.1,1.1), each character elements are a random value in[1,1+N].The first three character element represents the information of RGV's task allocation, such as the third element 2.2 means the task 3rd serviced by No.2 RGV. The other character element represents the information of elevator selection in actual operation stages, such as the last element 1.1 means the task 3 transported by No.1 elevator in stage 4. According to the constraint conditions described in section I-C determining the task allocation and elevator selection in operation stage are called decoding.

### 4.2. Fitness Function

In this paper, the optimization of objective function is the maximum completing time of all the tasks, the fitness function is:

$$Y = 1/T_{\max} = 1/\max\left\{T_1, T_2, \ldots\ldots T_m\right\} \quad (7)$$

 

$T_{max}$ is the maximum completing time of a scheduling scheme represented by a AF.

### 4.3. Procedure of IAFSA for AVS/RS Scheduling

1) Setting the AF swarm scale N, the maximum iteration numbers $G_{max}$, initialing information of the AF, included the position, Step and Visual.

2) Calculating the fitness function of each AF and recording the optimal value of AF state to the bulletin board, adjusting Step and Visual.

3) Assessing the behaviors of N AF, and selecting the optimal behavior, including swarming behavior, following behavior, memory behavior and communication behavior. If the optimal behavior meet the taboo condition, perform the optimal behavior, update the state and tabu list of AF. Otherwise, then choose a new behavior.

4) Determining whether it is reach the maximum iteration $G_{max}$ . If do, output the optimal solution , if not, come back to step (2).

## 5. The Application of IAFSA in AVS/RS

Taking a AVS/RS in warehouse of a provincial power company as an example, the system contains 5 RGVs, 4 elevators,6 shelves .The length of shelf is 12 m, the height of shelf is 11.5 m, the number of bays per aisle is 13.So the total storage capacity of the AVS/RS is 10764 unit-load positions. Each aisle has S/R locations on both sides. The horizontal velocity of RGV $V_x$ is 2 m/s ,the speed of the elevator $V_y$ is 2 m/s.

### 5.1 Parameter Setting

In order to verify the effectiveness of the proposed IAFAF to solve this problem, we randomly generate a compound operations containing 5 outbound tasks and 5 inbound tasks. Comparing the proposed IAFSA with basic AFSA, QPSO [1]by the simulation of the above instance. The AF swarm scale N= 50,the maximum iteration numbers $G_{max}$=160,the dimension n=20,the three algorithms runs independently 50 times, other parameters are as follow: [13]-[15]

Basic AFSA: Visual=5, Trynumber=8, $\delta$=0.75,Step=1.

QPSO: $\omega$=0.8, $C_1$=$C_2$=2, $r_1$, $r_2$, $\mu \in$ (0 , 1).

IAFSA: $\lambda$=0.8, Trynumber=8, $\delta$=0.75.

The 10 unit loads is given as follow:

D=[(2,8,20),(6,10,5),(8,10,22),(7,9,13),(12,6,16),(13,3,9),(9,1,5),(6,2,8),(5,6,2),(3,6,1)].The task 1,3,5,7,9 are the outbound tasks, The task 2,4,6,8,10 are the inbound tasks. The task $10^{th}$ means the load located in $20^{th}$ floor,8 rank,No.2.

### 5.2. Comparison Analysis

1) Comparison of convergence rate: the convergence process curve of three algorithms are shown in Figure 4, and we can find that QPSO has poor performance on the speed of convergence. Although the convergence of AFSA is higher than the QPSO, falling into local optimum easily. The IAFSA can achieve convergence rapidly than the others. It denoted that, IAFSA has better global astringency ability.

2) Comparison of the optimal results: the average of the optimal results by the three algorithms with 10 unit loads are shown in Table I. Under the same condition, the QPSO has the shortcomings at speed of convergence and optimal solution. Therefore, the AFSA is better than the QPSO in solving such problem. Owing to add two new behaviors: memory behavior and communicating behavior, that avoids falling into the location optimum. The adaptive Step and Visual can increase the rate of convergence in the later period of the optimization.

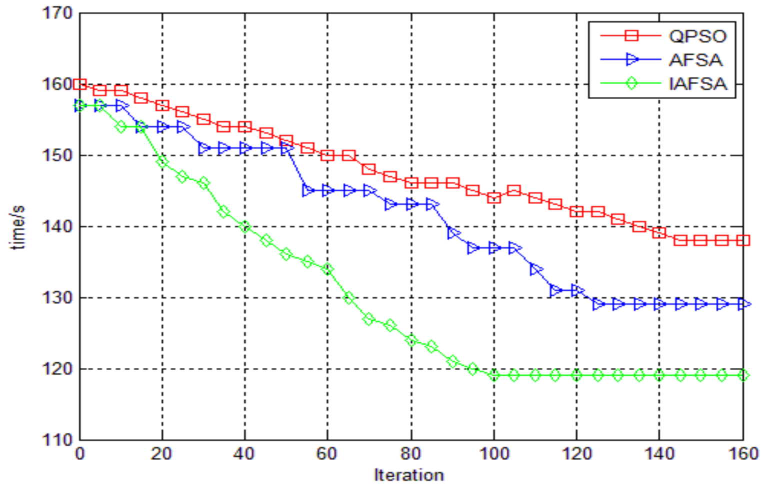


**Figure 4. The Convergence of Three Algorithms**

**Table 3. The Comparison Results of the Three Algorithms with 10 Unit Loads**

| Algorithm | Average convergence iteration | The optimal solution(/s) | The average solution(/s) |
|---|---|---|---|
| AFSA | 116 | 121 | 129.2 |
| QPSO | 130 | 132 | 138.5 |
| IAFSA | 80 | 112 | 119.3 |

We use the improved gant chat to show the optimal solution in the instance by IAFSA in Figure 5.The stage 1 is the stage of RGV's task allocation, the elevator No.5 in stage2~stage4 is the virtual elevator, if some RGV choose the elevator in some stage that means there is no need to take elevator for the RGV in this stage.

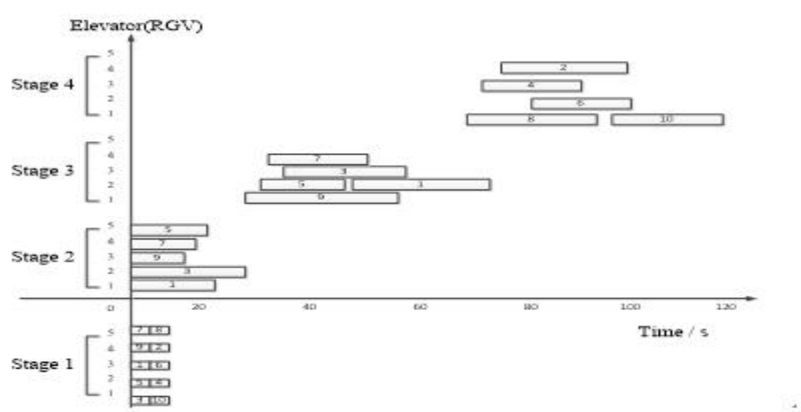


**Figure 5. Improved Gant Chat of Optimal Solution with 10 Unit Loads**

 

In order to verify the superiority of the proposed algorithm, we give the situation of 20 unit loads and 30 unit loads existing in the system, the comparison of simulation results are shown in Table II and III. The improved gant chat of optimal solution in the instance with 20 and 30 unit loads by IAFSA  is shown in Figure 6 and Figure 7.

**Table 2. The Comparison Results of the Three Algorithms with 20 Unit Loads**

| Algorithm | Average convergence iteration | The optimal solution(/s) | The average solution(/s) |
|---|---|---|---|
| AFSA | 126 | 260 | 269.2 |
| QPSO | 145 | 268 | 273.5 |
| IAFSA | 109 | 253 | 258.3 |

**Table 3. The Comparison Results of the Three Algorithms with 30 Unit Loads**

| Algorithm | Average convergence iteration | The optimal solution(/s) | The average solution(/s) |
|---|---|---|---|
| AFSA | 131 | 402 | 408.2 |
| QPSO | 160 | 396 | 412.5 |
| IAFSA | 116 | 386 | 388.3 |

Above all, we can get the conclusion the the proposed IAFSA converges faster than the other algorithms, and be able to find the optimal solution that they can't be. The comprehensive performance of IAFSA is better than others, which can provide more theoretical basis for the AVS/RS scheduling.

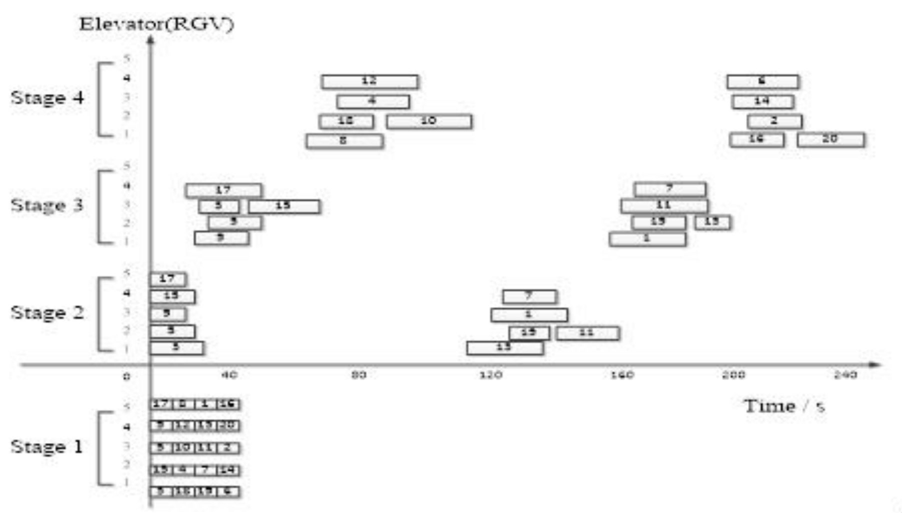


**Figure 6. Improved Gant Chat of Optimal Solution with 20 Unit Loads**

 

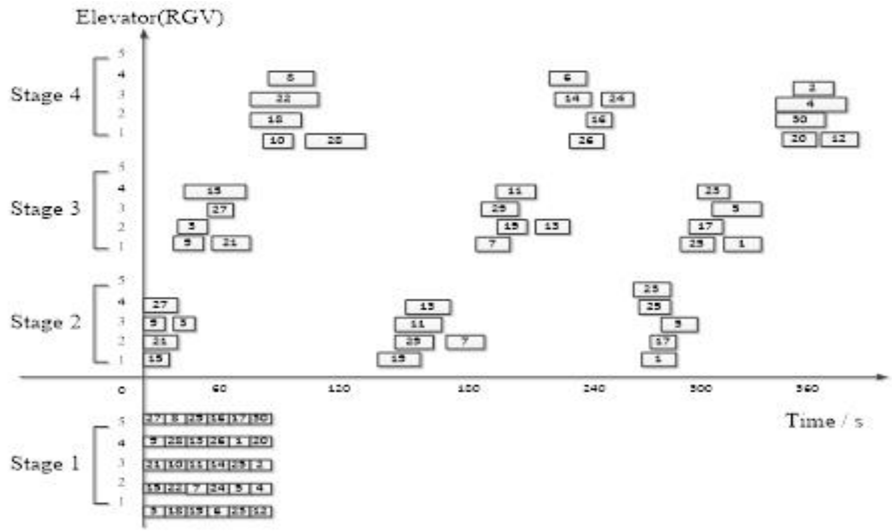


**Figure 7. Improved Gant Chat of Optimal Solution with 30 Unit Loads**

## 6. Conclusion

In this paper, a new model of AVS/RS scheduling is proposed, and an improved AFSA was introduced to solve the mathematical model. The tabu list and two new behaviors: the memory behavior, the communication behavior were added in IAFSA. Meanwhile, we used the adaptive step length and field of vision to avoid the algorithm into the local optimal solution. However, in the actual operation, the delaying, the collision and other factors should be considered. In our future work we will focus on the cycle-deadlock control of RGVs.

## Acknowledgements

The authors would like to thank the editor and reviewers for providing detailed comments, which have significantly improved the quality of this paper.

## References

[1] L. Jian, W. Chang-qing and L. Bo, "Modeling and optimization of RGV system based on improved QPSO", Computer Integrated Manufactur- ing Systems, vol. 17, no. 2, **(2011)**, pp. 321-328.
[2] M. N. Fuku, M. Al and C. J. MBORG, "An network queuing approach for evaluation of performance measures in autonomous vehicle storage and retrieval systems", European Journal of Operational Research, vol. 193, no. 2, **(2009)**, pp. 152-167.
[3] W. Chang-qing, H. Shan-jun and L. Jian, **"**Cycle-deadlock control of RGVs in autonomous vehicle storage and retrieval systems", Computer Integrated Manufacturing Systems, vol. 14, no. 9, **(2008)**, pp. 1767-1773.
[4] B. Y. Ekren and S. H. Sunderesh, "An Approximate Solution for Semi-Open Queuing Network Model of an Autonomous Vehicle Storage and Retrieval System", Transaction on Automation Science and Engineering, **(2013)**, pp. 205-215.
[5] T. Hsing-Chih and L. Yong-Huan, "Modification of the fish swarm algorithm with particle swarm optimization formulation and communication behavior", Applied Soft Computing, vol. 11, no. 8, **(2011)**, pp. 5367-5374.
[6] Q. K. J. Pan, M. F. Tastigeren and P. N. Suganthan, "A discrete artificial bee colony algorithm for the lot-streaming low shop scheduling problem", Information Sciences, vol. 181, no. 12, **(2010)**, pp. 2455-2468.
[7] W. Sheng-yao, W. Ling and X. Ye, "Estimation of distribution algorithm for solving hybrid flow-shop scheduling problem with Identical parallel machine", Computer Integrated Manufacturing System, vol. 12, no. 6, **(2013)**, pp. 15-51.
[8] X. Wang and L. Tang, "A tabu search heuristic for the hybrid flow-shop scheduling with finite intermediate buffers", Computers & Operations Research, vol. 36, no. 3, **(2008)**, pp. 907-918.

 

[9] D. Qi-chang and T. Ruo-li, "Simulation analysis of the fish swarm algorithm optimized by PSO.Control and Decision", vol. 28, no. 9, **(2013)**, pp. 1436-1440.
[10] S. Di-hua and S. Xiao-xiao, "Scheduling model of motorcycle parallel conveyor belt flow shop and its solution", Computer Integrated Manufacturing Systems, **(2011)**, vol. 17, no. 2, pp. 294-300.
[11] A. ALFIERI, "Workload simulation and optimization in multicriteria Hybrid Flow-shop Scheduling", A Case Study.International of Product ion Research, vol. 47, no. 18, **(2009)**, pp. 29-45.
[12] T. Hsing-Chih and L. Yong-Huan, "Modification of the fish swarm algorithm with particle swarm optimization formulation and communication behavior", Applied Soft Computing, **(2011),** vol. 11, no. 8, pp. 5367-5374.
[13] C. L. Chiang, "Genetic algorithms for power economic", IET on generation transmission and distribution, vol. 11, no. 2, **(2007)**, pp. 261-269.
[14] W. Ling, Z. Gang and X. Ye, "Advances in the study on hybrid flow-shop scheduling", Control and Instrument in Chemical Industry, vol. 38, no. 1, **(2011)**, pp. 1-8.
[15] X. Hong-rui and L. Ran, "An Adaptive Meta-cognitive Artificial Fish School Algorithm", International Forum on Information Technology and Applications, **(2009)**.

## Authors

**Yanjun Fang** received the B.S the B.S degree in thermal measurement and automation from Wuhan University, Wuhan, China, in 1982, and M.S. and Ph.D degrees in automation of electronic power system from Wuhan University, Wuhan, China, in 1985 and 1988, respectively. In 1992, he became a Research Fellow in Delft Hydraulic, Holladd. Currently, he is a Professor with the Department of Automation of Wuhan University, China, the PhD supervisor from 2000. His research interests include industrial automation, control theory, intelligent algorithms, multi-agent scheduling. He has won several awards including cross-century talents by the Ministry of Electric Power of China, 1997. He set up the "Wuhan automation engineering technology research center", and server as the director of the center.

**Meng Tang** received the B.S the B.S degree in electric- al engineering and its automation from Three gorges University, Yichang, China, in 2005, and M.S degrees in automation of electronic power system from Wuhan University, Wuhan, China, in 2012. He is currently pursuing the Ph.D degree from the school of Electric power construction and operation, Wuhan University, China. His research interests include industrial automation, intelligent algorithms, multi-agent scheduling.

 