Slotting optimization of automated storage and retrieval system (AS/RS) for efficient delivery of parts in an assembly shop using genetic algorithm: A case Study

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Abstract. In recent years, the competitive pressure on manufacturing companies shifted them from mass production to mass customization to produce large variety of products. It is a great challenge for companies nowadays to produce customized mixed flow mode of production to meet customized demand on time. Due to large variety of products, the storage system to deliver variety of products to production lines influences on the timely production of variety of products, as investigated from by simulation study of an inefficient storage system of a real Company, in the current research. Therefore, current research proposed a slotting optimization model with mixed model sequence to assemble in consideration of the final flow lines to optimize whole automated storage and retrieval system (AS/RS) and distribution system in the case company. Current research is aimed to minimize vertical height of centre of gravity of AS/RS and total time spent for taking the materials out from the AS/RS simultaneously. Genetic algorithm is adopted to solve the proposed problem and computational result shows significant improvement in stability and efficiency of AS/RS as compared to the existing method used in the case company.

Keywords: workshop distribution, slotting optimization, simulation method, automated storage and retrieval system, genetic algorithm

1. Introduction

For multi variety and small batch mixed flow assembly system, it is not only involved in the variety and quantity of parts, but also it is necessary for the parts to be delivered to the specified location at the time required. Due to this, the requirement of larger storage capacity and fast and accurate operations is reasonable. Therefore, AS/RS is widely used in the automotive, construction machinery and other industries. It becomes one of the signs in enterprise production automation and management information. But the application of AS/RS often need a huge investment in manpower, material resources and financial resources. It also requires lean management and some auxiliary control systems accordingly. So it is difficult to implement AS/RS in so many companies which are small or old. The initial warehouse operation management mode is to store goods by virtue of personal experience in general. The goods are often stored nearby, without considering the dynamic changes of material such as weight changes and customer demand changes which may often lead to uneven stress, slow operation of outcoming and incoming and low utilization. Therefore, slotting optimization came into being. Slotting optimization management refers to the reconfiguration of the storage assignment in the warehouse based on the current storage location assignment, so as to ensure the rational allocation of warehouse location. Reasonable slotting optimization plays an important role to reduce useless consumption, shorten the order fulfilment time, improve the efficiency.

In recent years, both domestic and foreign, the slotting optimization of AS/RS is one of the research hotspots. Thonemann and Brandeau [1] discussed the storage assignment method based on the turnover rate of goods location assignment and the principle of classification under stochastic environment. Hsieh and Tsai [2] studied storage assignment method for bill of material based on the classification, so as to realize the classification storage according to the region. Poulos et al. [3] proposed a new multi-objective genetic algorithm to solve the location allocation problem for the replenishment task demand of AS/RS. Muppani and Adil [4] presented a nonlinear integer programming model with an aim to reduce storage cost and the picking time simultaneously for the classification based reallocation of storage problem. Branch and bound method is used to solve this problem. Onut et al. [5] set up a multi-level warehouse shelf pattern in order to minimize the transportation costs, and the location is determined by the corresponding product turnover rate, moreover, particle swarm algorithm (PSO) is adopted to solve the problem. Zu et al. [6] design a kind of hybrid genetic algorithm to solve the problem which made turnover rate of goods and stability of goods shelves as the optimization objective. Li et al. [7] put forward the goods assignment optimization algorithm based on correlation for the slotting optimization problem with the effect of correlation on the goods picking efficiency in consideration; furthermore it is solved with an objective of minimizing the total picking time of goods. The above research results have laid the foundation for our further research, but these optimization models are not comprehensive including the influence of material demand fluctuation of mixed models. For this issue, research on the slotting optimization problem requires the integrated consideration of turnover rate of goods and stability of goods shelves and the different corresponding frequency of material demand of mixed models simultaneously. So this way, better scheme for the actual operation of AS/RS can be obtained and also the effective implementation of the assembly plan can be carried out.

2. Company problem description

A very famous pump truck manufacturer (hereafter Company X) in Changsha China has a final assembly workshop with the layout shown in Fig. 1. Three different kinds of pump trucks are produced in this shop floor which includes, pump truck, trailer pump and on-board pump truck. Beside the material distribution channel A and channel B, there are final goods assembly lines. The upper and left production line from west to east are final trailer pump assembly line and the on-board pump truck assembly line is adjacent. Under these two lines from top (north) to bottom (south), there are landscape belt and two parallel final pump truck assembly lines respectively. Beside the assembly line area, there are two visit channels. The two automated storage and retrieval systems (AS/RS) are both in the east (right) of the plant and are located in north (NAS/RS) and south (SAS/RS) respectively.

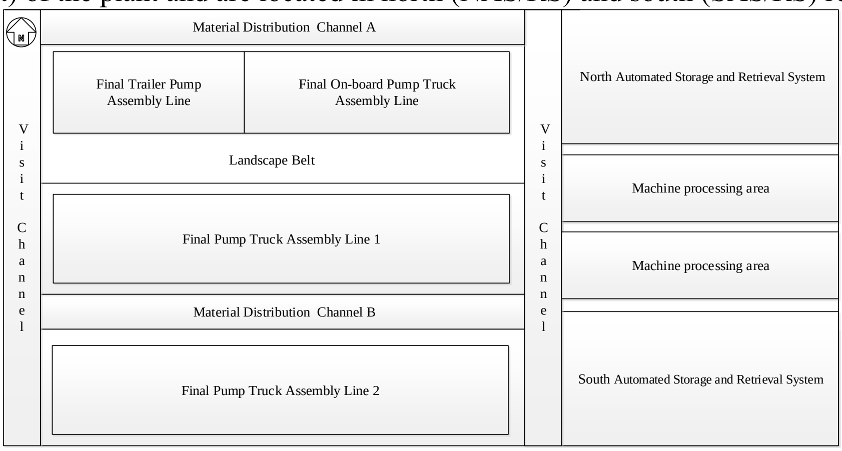
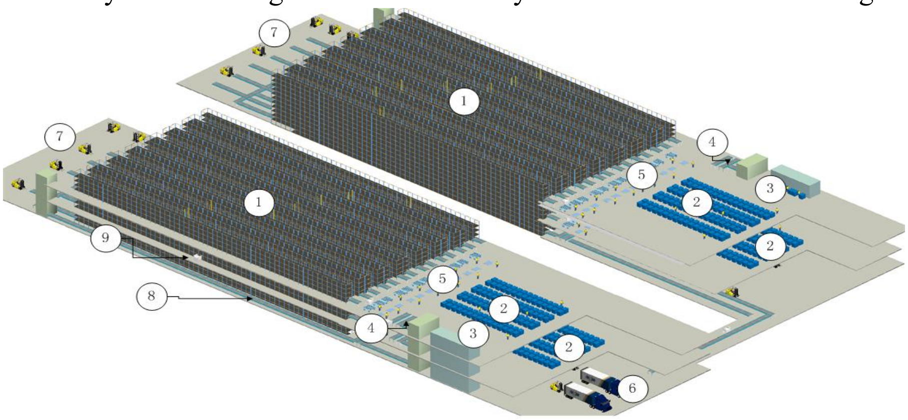


Figure 1. Final assembly workshop layout

The AS/RS mainly affords the material distribution service to the final assembly lines. The NAS/RS is used to store materials of pump trucks, while the materials of final trailer pumps and on-board pump trucks are deposited in SAS/RS. The materials of NAS/RS are transported from material entry of SAS/RS by the conveyor belt underground. The detail layout of AS/RS is shown in Fig.2.



1. ASRS
2. Material dispatching area
3. Elevator depot sorting Area
4. Full container Exit
5. ASRS sorting Area
6. Entry of ASRS material in first floor
7. The place of container receipt of AGV
8. The conveyor belt of empty container recycling
9. Conveyor line of full container

Figure 2. The detail layout of AS/RS in X assembly workshop

（1）It can be seen from Fig.2 that the area ① is used to represent storage rack area. Both SAS/RS and NAS/RS have 14 storage racks and 7 roadways as clearance space for moving and transporting the parts from storage. Furthermore, there are totally 9016 goods allocations in SAS/RS while 6910 goods allocations in NAS/RS.

（2）Symbol ② indicates material sorting and collecting area of AS/RS which is used for materials packaging and waiting to be delivered to assembly lines.

（3）Symbol ③ denotes a cubic elevator depot sorting area. It is used to store materials which have weight equal or less than 1 kilogram. Unilateral has three independent elevator depots and each elevator depot has 130 layers of area to store materials.

（4）Symbol ④ indicates the full container exit area and the empty container recycling area. The full container goes to the transport region and waits to be transported to final lines. The empty container is lifted from first floor to third floor and then transported to empty container recycling area by conveyer.

（5）Symbol ⑤ is used to represent material sorting area and exit, the second and third floor of SAS/RS and SAS/RS both have material exits. Each floor has 12 exits for SAS/RS and for NAS/RS there are 6 exits.

（6）Symbol ⑥ denotes the material entry of AS/RS which is located in first floor of AS/RS. The material from suppliers and self-made components are unloaded, tested on quality and then placed in storage in this area.

（7） Symbol ⑦ indicates the automated guided vehicle (AGV) waiting area. The AGVs wait in this area and receive full container here. The full container is transported by conveyor and delivers it to the assembly line. On the other hand, the AGVs help to deliver the empty containers back to the conveyor.

（8）Symbol ⑧ and ⑨ indicate the conveyor of full container and empty container respectively. The conveyor of full container starts from the second floor to the third floor and used to deliver full container to AGV waiting area. The conveyor of empty containers located in the first floor is used to transport empty container from AGV waiting area to material sorting and collecting area of AS/RS.

3. Analysis of AS/RS operations based on simulation

3.1. Operation process of AS/RS for material delivering

AS/RS is the storage system used to store the material from supplier and self-made components in less space. The material required by the assembly lines is distributed in kitting methods in it. The stored material needs a sorting method to store material in different shelf. Fig. 3 indicates the second and third floor of the AS/RS which are in charge of four kinds of processes including AS/RS material sorting and sowing, elevator depot material sorting and sowing, empty container sowing and full container distribution etc. The second and third floor has an area for material sowing and packaging in order to put material into containers. All the material from AS/RS and other warehouse and elevator depot needs kitting distribution are packaged to deliver the material on time to final assembly lines. The storage and retrieval machine (SRM) in AS/RS gets the pallet of the material which is needed to supply from the shelf and place it on the sorting platform. The material is sorted and sowed by worker and the pallet on the sorting platform is transported back to the original location by SRM simultaneously. This process is shown by the red arrow in Fig.3. The sorting workers sort the material from elevator depot and use sorting trolley to deliver the material to sowing area for packaging as shown by blue arrow in Fig.3. The empty container from first floor is placed in empty container buffer. When the empty container is needed in material sowing area, the empty container is transported to the corresponding workstation area by forklift and the process is indicated in purple arrow in Fig.3. The full containers are distributed from sowing area to assembly lines on time. Part of the full containers is transported to the south conveyor of AS/RS and then transported to AGVs waiting area by conveyor, another part of the full containers is transported directly to AGVs waiting area by SRM and the process is indicated by green arrow in Fig.3.

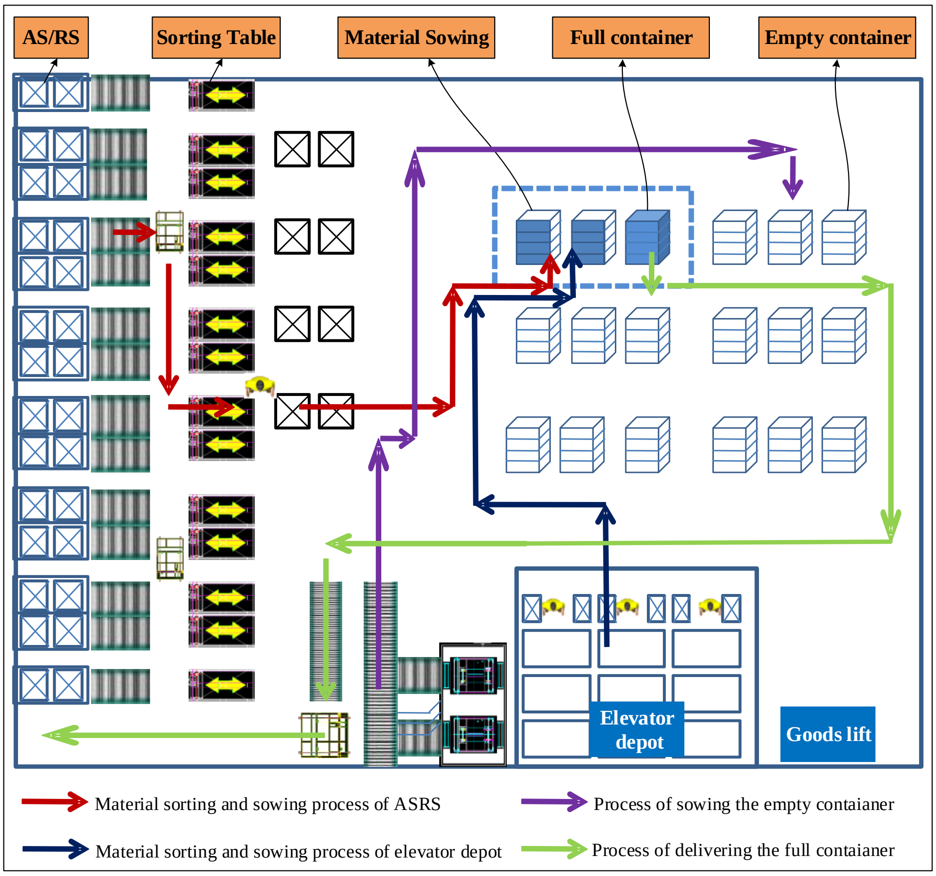


Figure 3. The operation process of AS/RS for material delivering

3.2. Simulation modeling and analysis of operation of AS/RS

In the case company, there is requirement of in time distribution of material and the number of containers needed to deliver the parts to assembly line in a distribution cycle (4 hours = 4 * production cycle time) is shown in table 1. The distribution cycle and required number of containers for assembly lines determine the pressure of material coming out of AS/RS.

Table 1. The number of containers needed to deliver in 4 hours

Assembly line	Types of container	Number of container	Number of container needed to be delivered
Pump truck line 1	25	27.1	78
Pump truck line 2	25	27.1	78
Trailer pump line	24	30	60
On-board pump truck line	17	31	31

The total number of distribution cycles when the material is coming out of AS/RS and moving into AS/RS including incoming of raw materials, outcoming of large-size materials, outcoming and incoming of full containers and outcoming and incoming of empty containers are indicated in table 2.

Table 2. Number of times of outcoming and incoming operations of AS/RS

AS/RS	Outcoming and incoming of materials	Incoming of raw materials	Outcoming of large-size materials	Outcoming and incoming of full containers	Outcoming and incoming of empty containers	Total number of times
SAS/RS	726	240	4	114	114	1276
NAS/RS	348	80	0	0	0	460

In the Case Company, the elevator can transport 25 containers per hour, i.e., the elevator can transport 100 containers in one distribution cycle at most. It can be seen from table 1 that it is needed to distribute 247 containers in every 4 hours, therefore elevator does not satisfy the demand of full container transportation. Therefore, it is required that part of full containers to be delivered by other ways.

It is needed about 4.65 hours to finish the sorting and collecting of AS/RS materials for 4 sets of material off-loading. Therefore, it cannot be finished that all the sorting and collecting of AS/RS materials are picked out from AS/RS in a distribution cycle (4 hours). The utilization ratio of RSMs for the case company is illustrated in Fig. 4. It can be seen from Fig.4, when using 4 sets of material off-loading from AS/RS, the utilization ratio of some RSMs are more than 90%, as a result, the RSM has higher probability to break down.

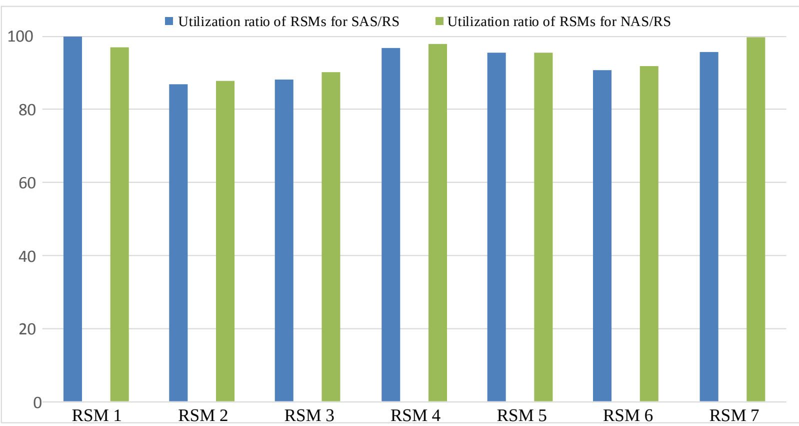


Figure 4. The utilization ratios of RSMs

According to the result of simulation model of AS/RS, it is hard to satisfy the material requirement of production line for the AS/RS due to inefficient and not optimized goods location of AS/RS. Moreover, the capacity of elevator cannot meet the demand of material coming put from AS/RS in current location method of AS/RS. As a result, a much better goods location method is needed to propose to improve the efficiency of AS/RS. Furthermore, in a distribution cycle, the off-loading time of material from AS/RS can be greatly reduced by optimizing the goods locations; therefore it is necessary to optimize the goods locations for AS/RS.

4. Genetic algorithm based slotting optimization

The current problem of AS/RS is a multi-objective programming problem and it is hard to solve the multi-objective problem using simulation. Genetic algorithm (GA) is a famous method to solve the multi-objective problems and is therefore used in current research.

4.1. Slotting optimization model for AS/RS

4.1.1. Encoding strategy

The material is only associated with the corresponding workstation in bill of material (BOM), but in real operation it is difficult to know the outcoming exit of material. However, in current study, the real data of company is connected with algorithm, and the material information is changed to genetic code information. The proposed encoding strategy for the current research is shown as below in Fig.5. The detail of different elements of the encoding strategy is explained in this section.

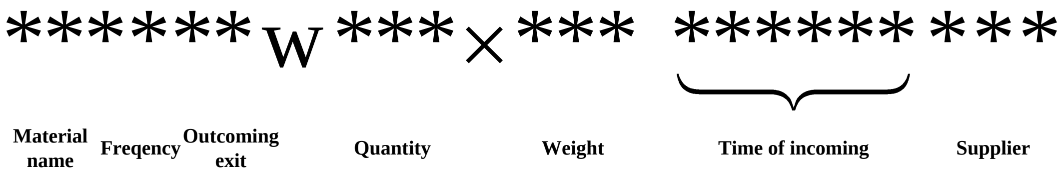


Figure 5. Encoding strategy of the current problem

It can be seen from Fig. 5 that there are different names given to the elements in the encoding strategy. The material name, frequency of the material, outcoming exit, quantity, weight, time of incoming of material and supplier information is included in the encoding strategy.

Material name: The current material name of company is indicated by English letters and numbers simultaneously is used here.

Frequency: The frequency of outcoming and incoming of material is used to judge the priority of outcoming and incoming of material in AS/RS. In order to show directly the code used here is the real frequency multiply by 100.

Outcoming exit: It is generally indicated by workstation information, but there is not only one outcoming exit and some material does not need sorting to deliver to production lines, therefore, it is not encoded here by workstation information. In current study, 00 is used to indicate the material which can both off-loaded from second and third floor, 01 is used to indicate the material which is moved to the assembly line, 02 is used to denote the material off-loading from second floor and 03 is used to represent material which is only off-loaded from the third floor of AS/RS.

W: it is used to distinguish digitals.

Quantity × weight: It is used to know the quantity and weight of the materials in container. The weight is for single material.

Time of incoming: Time of information is used to know the sequence of the arrival of materials to make sure which material arrives first to make sure the first in first out (FIFO) rule. Due to this, the material stays for less time.

Supplier: It is used to represent the set of material to make replenishment in time.

For example, the material spring steel wire is indicated by SY5250GJB8.5-47 in company. The weight is 0.15kg for each one spring steel wire. The material belongs to workstation 1, the frequency is 0.32, the incoming (uploading to AS/RS) time is May 7, 2016, and the No. of supplier is 125. According to the BOM, this material is small-size which need to package and the outcoming exit is located at second floor. Then the material is encoded as “THG3202W150×0.15 160507 125”.

There are some special materials which are large-size and directly distributed to production lines. Due to different sequence of models to assemble, the frequency of these material changes in different periods. When encoding for these materials, it is required to be indicated by sequence of mixed models to assemble. The relation is shown in Eq.1.

$$P(\mathrm{i}) = \mathrm{p}(i) * m(i) \div M \tag{1}$$

Where $P(\mathrm{i})$ is the final frequency of material, $\mathrm{p}(i)$ is the frequency of material outcoming and incoming, $m(i)$ is the priority value of material i in a sequence. For common usage parts, in a sequence of mixed model to assemble, $m(i)$ is as same as M and the ratio of $P(\mathrm{i})$ and $\mathrm{p}(i)$ is 1.

For example, the material motor A with the weight 23.5kg, with the quantity 3, frequency of 0.06, required on workstation 2, the time of incoming is April 15, 2016 and supplier is 98. Suppose that the current production sequence is CACBA, the priority of the first C is 1, the second B is 0.8, the third C is 0.6, the fourth B is 0.4 and the last A is 0.2. According to this, the priority value of C can be obtained as 1 + 0.6 = 1.6, and for A the final priority value is 0.8 + 0.2 = 1. Therefore, the final frequency of motor A is 0.02 which is calculated by P(A)= （0.06×1） / （1.6+1+0.4） = 0.02. Then the material is encoded as “MDA0601W3×23.5 160415 98”.

The encoding strategy described above is a general strategy. However, for the demand of real algorithm, the code is required to be simplified by only showing the outcoming exit, quantity × weight, final frequency of material and name. The time of incoming and supplier do not affect the result of algorithm.

4.1.2. The establishment of objective function for slotting optimization

According to the common principles of slotting optimization, the stress stability and efficiency of AS/RS are selected to make mathematical models. In current research, a row of shelves of AS/RS is studied. The AS/RS has *m* layer and *n* column, the layer at the bottom is the first layer, and the column nearest to outcoming exit is the first column. The vertical speed and horizontal speed are V_y and V_x respectively. The length of shelf is L and the height of it is H.

1) According to the stress stability principles, the position of the center of gravity in the vertical direction is required to be located in the lower part of the shelf to make it stable in its position when the material or part is removed from it. In order to facilitate the solution of the center of gravity of the entire shelf, it is assumed that the center of gravity of the each good is located in geometry center of slot. The objective function of stress stability is indicated in Eq.2.

$$\min f_1 = \frac{\sum_{i=1}^{m}\sum_{j=1}^{n} W_{ij} \times (i-0.5)H}{\sum_{i=1}^{m}\sum_{j=1}^{n} W_{ij}} \tag{2}$$

$$1 \le i \le m ; 1 \le j \le n$$

Where f_1 indicates the position of the center of gravity of shelf in the vertical direction. Using W_{ij} denotes the weight of materials in layer *i* and column *j*.

2) According to the principle of outcoming from and incoming to the nearest slot, the sum of all the material product of the frequency and time spent for taking the material out from the AS/RS should be minimized. Therefore, the sum is obtained from Eq.3 and Eq.4.

$$\min f_2 = \sum_{i=1}^{m}\sum_{j=1}^{n} t_{ij} \times p_{ij} \tag{3}$$

$$t_{ij} = \left[L \times (j-0.5)/V_x , H \times (i-1)/V_y \right] \tag{4}$$

Where f_2 indicates the sum of all the material product of the frequency and time spent for taking the material out from the AS/RS, and t_{ij} indicates the time spent for taking the material out from the AS/RS once.

In current study, the AS/RS has 10 layers and 13 columns. The first column and fourth column in layer 8 are the outcoming exit of full container, and the 13th column in layer 1 is the direct outcoming exit for certain materials. The time spent for taking the material out from the AS/RS once time is different when the outcoming exit changes. And the other three equations of t_{ij} are shown from Eq.5-Eq.7.

a. Equation for the outcoming exit 01

$$t_{ij} = \left[L\times(12.5-j)/V_x \;, H\times(i-1)/V_y \right] \tag{5}$$

b. Equation for the outcoming exit 02

$$t_{ij} = \left[L\times(j-0.5)/V_x \;, H\times(i-4)/V_y \right] \tag{6}$$

c. Equation for the outcoming exit 03

$$t_{ij} = \left[L\times(j-0.5)/V_x \;, H\times(i-8)/V_y \right] \tag{7}$$

4.2. The steps of algorithm for slotting optimization

The slot allocation optimization is required to consider both the shelf stability and storage efficiency. This is a multi-objective optimization problem. The concept of Pareto optimal solution is combined with the improved genetic algorithm in the current research. The detailed steps are as follows:

Step 1: Encoding. According to the characteristics of goods allocation, the $p\times q$ matrix is used to encode the problem. If the *j*th column in row *i* is material *m*, it indicates that the material m is stored on *i*th colum and (*q+1* —*i*) th layer.

Step 2: Calculating fitness function value. The fitness functions are the maximum value of objective functions minus the objective functions respectively.

Step 3: Selection operator. Before selecting the operator, there is need to consider coordination of the process of population group selection and classification operation. In the process of coordinate selection, the whole population is divided into two sub populations equally, and two sub populations of the same population are generated corresponding to the two objective functions.

Population classification: in order to get the optimal solution, it is needed to make the classification of the population according to the level of non -inferiority of the individual before the selection operation is carried out. The specific implementation method is as follows: all the non-dominated solutions in the population are divided into the same level, and assign 1 to the level value. Repeat the above process until all individuals in the population have been given the appropriate levels. In the selection process, the selection probability of the point of *i* level can be determined by the formula 9.

$$F_i = M(N_r - i + 1) \Bigg/ \sum_{i=1}^{N_r} (N_r - i + 1) P_{si} \tag{8}$$

Where, *M* is the population size, N_r is the number of levels of population group and P_{si} is the population size for level *I*.

Step 4: Crossover operation. In the genetic algorithm, two individuals are randomly selected for crossover operation. In the current multi-objective optimization problem, the mating restriction is introduced. Only when two individuals are not in the same group, the cross operation can be carried out. In this way, the better genes can be combined under different objective functions. Moreover, there is a larger probability to find an optimal compromise solution. According to the objective function value of the optimal allocation of goods directly depends on the location of goods on the shelves, the cross operation using a partially matched crossover method.

Step 5: Mutation operation. Mutation operator selects a part of the individual to implement mutation according to the probability. Select two locations randomly, and then change the goods in the two locations of AS/RS.

Step 6: Niche technology. In order to ensure that the optimization process does not converge to a certain part of the feasible region and make the populations evolve toward the direction of evenly distributed from the Pareto front, the niche technology is used here. Penalties are imposed to the individuals in the population which are aggregated into small pieces, so that their fitness value is reduced.

Step 7: Elite preservation strategy. In order to keep the best individual in the population evolution, parent generation and the sub generation population are combined to make one population. Later, sorting of the individual in the population is performed and penalty function is shared. According to the level of non-inferiority and level of individual fitness, the first 50% individuals in the population are made as a new population for the next cycle of the algorithm. The niche technology and optimization strategy can not only give solutions converging to Pareo front, but also make sure the solutions are distributed uniformly.

Step 8: Pareto solution set filter. The effect is to keep the non-dominated points in each generation and to remove the bad points of the solution set. The level 1 Pareto points in each generation are put into the Pareto filter. The size of the Pareto solutions set can be arbitrarily set. When the number of new points is more than the size of Pareto solution set, then make gain sorting is performed to remove the bad points. If the number of the remaining non -dominated points is still more than the size of the Pareto solution set, then the nearest point from the other point are deleted to improve the diversity.

4.3. Computational result

According to the above description, the shelf stability and storage efficiency are the two evaluation index. Genetic algorithm is coded in Visual C# and runs on an Intel Core i7, 3.4 GHz CPU, 4 GB RAM computer. The prepared material encoding table is directly imported into the algorithm for computational experiment, and the detailed parameters are as follows: L=1.3m, H=1.4m, V_x=2m/s, V_y =0.67m/s, m=10, n=13. The current real significant allocation for the AS/RS is shown in table 3.

Table 3. The significnat allocation before optimization

44	120	74	58	56	101	34	5	19	7	94	86	1
0	75	27	72	13	91	6	14	18	23	9	10	125
26	47	52	87	3	36	48	12	41	62	25	57	50
103	54	49	93	2	111	68	55	53	127	92	16	42
35	102	129	46	37	40	81	85	126	67	61	45	71
63	22	77	15	122	116	30	88	69	117	80	8	39
104	119	107	95	33	21	84	108	31	76	59	123	70
38	79	73	60	90	98	28	121	128	105	99	118	29
43	78	124	17	113	96	20	110	97	11	82	24	100
65	114	83	112	32	89	4	66	115	51	106	64	109

It can be seen from table 3 that the total frequency of material outcoming from and incoming into the AS/RS for the current situation is 155.2065, and the center of gravity is 7.0366. Through the proposed GA, after the 20 generation of crossover and mutation, more than one solution is obtained and one of the selected solution from the Pareto set is shown in table 4.

Table 4. The goods allocation after optimization

114	66	25	18	20	74	0	9	16	64	97	83	125
81	116	61	8	121	94	11	90	40	37	127	31	110
85	70	126	129	29	51	68	111	107	86	123	63	32
30	80	119	115	4	1	71	50	6	118	101	79	19
17	95	120	62	47	53	34	43	106	113	91	54	103
104	55	49	73	88	26	57	67	45	21	96	112	109
58	78	10	33	36	2	23	28	5	84	7	3	77

60	38	72	124	14	41	46	69	12	48	15	100	92
39	27	99	122	13	76	102	89	117	75	56	44	108
128	87	82	24	98	65	93	35	22	59	52	105	42

It can be seen from table 4 that the new storage allocation scheme gives AS/RS a frequency of 135.6705, the position of the center of gravity is 6.4057. Furthermore, from table 4 it can be seen that the frequency of new storage allocation scheme is reduced by about 12.9% as compared to previous company solution, significantly accelerates the storage efficiency and saves the precious time for the whole workshop distribution section, which improves distribution capacity to meet the demand of practical production. Although there is not a big change in the center of gravity, it improves the shelf stability and can prolong the service life of the AS/RS.

5. Conclusion

Current research introduces a final assemble workshop and the AS/RS system in it. According to the principles of AS/RS location assignment, the objective and constraint functions for the proposed problem are established. The problem of storage assignment is integrated with actual demand of mixed flow production style and a new mathematic model for slotting optimization is proposed. Moreover, a genetic algorithm with a new encoding strategy is proposed for the real company slotting optimization problem. Computational experiments are performed on real company data and computational result shows a big improvement in stress stability and efficiency of AS/RS as compared to the empirical solutions.

6. References

[1] Thonemann U W, Brandeau M L. Optimal storage assignment in an automated storage and retrieval systems with stochastic demands. Management Science, 1998, 44(1): 142-148.
[2] Hsieh S, Tsai K C. A BOM oriented class-based storage assignment in an automated storage and retrieval systems. International Journal of Advanced Manufacturing Technology, 2001, 17(9): 683-691.
[3] Poulos P N, Rigatos G G, Tzafestas S G, et al. A Pareto-optimal genetic algorithm for warehouse multi-objective Optimization. Engineering Applications of Artificial Intelligence, 2001, 14(6): 737-749.
[4] Muppani V R, Adil G K. A branch and bound algorithm for class based storage location assignment. European Journal of Operational Research, 2008, 189(2): 492-507.
[5] Onut S, Tuzkaya U R, Dogac B. A particle swarm optimization algorithm for the multiple-level warehouse layout design problem. Computers and Industrial Engineering, 2008, 54(4): 783-799.
[6] Zu Q, Cao M, Guo F, et al. Slotting optimization of warehouse based on hybrid genetic algorithm. In: Proceedings of 6th International Conference on Pervasive Computing and Applications, 2011, 19-21.
[7] Yin L, Jian S, Guo P. Slotting optimization based on SKUs correlations with serpentine routing policy. Journal of Zhejiang University (Engineering Science), 2012, 46(8): 1424-1430.

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