International Journal of
Intelligent Systems and Applications in Engineering

ISSN:2147-6799 www.ijisae.org Original Research Paper

Optimization of Location Assignment for Unit-Load AS/RS with a Dual-Shuttle

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Submitted: 04.04.2019 Accepted : 07/05/2019

Abstract: Automated Storage and Retrieval Systems (AS/RS) offer several advantages such as gaining space, reducing human errors, and completing more storing and retrieving tasks in less time to large size warehouses. Machines included multi-shuttle systems are designed to carry multiple loads in one cycle on the purpose of develop the performance. This paper deals with a quadruple command cycle location assignment method in unit-load dual-shuttle AS/RS. Also, it is shown how to solve location assignment problem using Particle Swarm Optimization (PSO) with the objective of shortest travel distance therewithal shortest travel time. Binary Coded Genetic Algorithm (BGA) and Real Coded Genetic Algorithm (RGA) are developed to validate result obtained. At the end, ten numerical examples for two scenarios designed small size and large size are presented to prove the implementation of the proposed method. Results showed that PSO accomplished to find optimal solution for shortest travel distance of AS/RS machine.

Keywords: *AS/RS, genetic algorithms, particle swarm optimization, quadruple command cycle, warehouse*

1. Introduction

Logistics has begun to be pronounced by many people in recent years with the dissolve of the borders of trade. Increasing product range and delivery of orders to customers in a short time have forced companies to make improvements to carry out effective and result oriented logistics operations [1]. The ability of the logistics network to operate efficiently is directly related to the process in the storage systems. It is an inevitable to keep the systems and methods up-to-date as the developments in technology happen very fast and the sectors follow these developments closely. Information technology (IT) has turned into an integral component of storage process. Warehouses need to be modified by the rising request for added-value services and automation integrated processing. This technology involves a Warehouse Management Systems (WMS) that have reformed the techniques in time, plan and carry through orders, provide the handing over the right product on-time and check inventories [2]. WMS are designed to develop inventory correctness, shorten the order reply time, ensure momentary order situation report, boost the workforce efficiency and administrate warehouse area.

The main targets of the WMS are given as follows:

- Clear order accomplishment faults by product recognition and uninterrupted cycle enumerating;
- Owing to electronic communication, send and receive crucial data on least delivery time;
- Enhance workforce productivity through operating tasks and giving priority to them;
- Increase area usage by determining a suitable storage location;
- Thanks to uninterrupted transmit of information, decrease inventory and handling needs [2-3].

There are several warehouse types are equipped with automation technologies in real industry. These technologies can be called as Automated Storage and Retrieval Systems (AS/RS). AS/RS can be classified into: unit-load autonomous vehicle based AS/RS, fixed aisle unit-load crane based AS/RS, movable aisle unit-load crane-based AS/RS, mini-load crane based AS/RS and mini-load shuttle-based AS/RS [4].

AS/RS have various advantages over conventional process of warehouses. The main advantage is AS/RS need less time in storing or retrieving the products. Minimizing the time of requests means warehouse has much time to handle more products in unit-time [5]. There is a consensus that developing the performance of AS/RS is essential since they are utilized more often. Because performance of the algorithm affects the efficiency of AS/RS directly [6].

Roodbergen and Vis presented a paper that provides a comprehensive survey of literature on AS/RS. The research investigates the systems in terms of system configuration, travel time evaluation, storage location assignment, dwell-point location, and request sequencing according the studies which presented in the past 30 years. Considering the recommendations given in this study, it is obvious that control policies can be developed for dynamic systems instead of static systems. Furthermore, most of the existing papers approach the decision problems in one or two terms. According to the authors, it is beneficial that finding solutions to multiple problems in one model [3].

A travel time model that is based on Federation Européenne de la Manutention (F.E.M.) standards was proposed. F.E.M. 9851 standard rules are valid for real logistics sector and travel time estimation is given for single-shuttle AS/RS. In this proposal travel time estimation for dual-shuttle systems is determined by Bozer and White formulations. Monte Carlo simulation is prepared and executed with previous suggested methods to compare the results that achieved by proposed method. It is proven that proposed method yields applicable results on various applications of industry [7].

Another study has underlined the request sequencing problem was very popular subject of AS/RS. However, most of the researches

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provide methods to find minimum length of the path that includes exact storage and retrieval locations are known. They have focused the sequencing problem too but requested item can be found multiple place. A step-by-step dual cycle sequencing method for unit-load AS/RS was developed and minimum dual command cycle times are determined successfully [8].

In another research an application of Genetic Algorithm (GA) was studied to solve sequencing problem of triple-shuttle AS/RS in class-based storage. The research emphasizes that, they focused on triple-shuttle AS/RS (sextuple-command cycle) while most of the studies handle the sequencing problem for mono-shuttle systems (dual-command cycle). Storage locations are separated 2 zones which are L-shaped according to priority of goods [9].

Because of AS/RS need to solution for complex sorting and location assignment tasks, another research shows how to organize AS/RS tasks using multiple objective Ant Colony Optimization (ACO). To scale down space usage and investment costs, an AS/RS that has not corridor and work with only one elevator for several products was chosen. Factor of inquiry, product dimensions, storage space usage and path to dispatch are criteria for multi-objective optimization. In conclusion, planning the distribution of products accomplished successfully with ACO [10].

Most of the researchers focus on optimizing the travel time of AS/RS that has single-crane in one corridor. On the contrary, a paper was presented on a new approach that to optimize the efficiency of multiple stacker cranes on common rails in an automated storage/retrieval system. A new method which must be plan the transports with the principle of avoiding the collisions of the cranes is proposed. Dynamic programming is used to optimize the combination of order clustering [6].

In order to optimize the storage location assignment and schedule tasks, researchers presented a paper that joint optimization is investigated in multi-shuttle AS/RS. The research handles the optimization problem in a different rule is called shared storage, in which AS/RS machine is enabled for storing unit-load to empty location that discharged by retrieval operation. An algorithm was developed based on Variable Neighbourhood Search (VNS) heuristic to obtain optimum solution for location assignment and scheduling problems. The research shows that VNS algorithm is effective and efficient for large-sized numerical examples [11].

A survey of single crane scheduling in AS/RS was presented by Boysen and Stephan. A classification of crane scheduling problem was presented elaborately to identify specific optimization of crane scheduling. They treated the systems in terms of I/O station locations as front end depot, two depots at both ends, and multiple I/O points at the bottom row of the rack. The research separates the studies into groups and shows the algorithms are used for optimizing the travel time of single crane AS/RS. Most of the researches dedicated to single I/O station systems according to the authors. It is emphasized that multiple I/O points deserving more attention [12].

In another study a double-command cycle dynamic sequencing method which is composed a storage request and then a retrieval request was proposed in unit-load multiple-rack AS/RS system. ACO is suggested to find out optimum solution with the objective of minimizing the total cost of the greenhouse gas that oscillating from AS/RS. GA is used to validate the result obtained from suggested method. Results verify that GA was able to find out closer optimum solutions than ACO [4].

In this paper we address Particle Swarm Optimization (PSO) algorithm to find an optimum solution for a location assignment problem in dual-shuttle AS/RS as a new approach. This study is original in terms of adapting the PSO algorithm to AS/RS optimization if related researches considered. When the rack system is considered as the coordinate plane, it is aimed that the machine must travel in shortest path and must complete the cycle in shortest time, by optimizing the route in both X and Y axes. With the realization of these objectives, the capability of companies which own AS/RS would increase in unit time, and they would be more efficient in energy using as the shortest route will be preferred. In order to compare the algorithm performance, it is planned to perform simulations using Binary Coded Genetic Algorithm (BGA) and Real Coded Genetic Algorithm (RGA) with the same data sets.

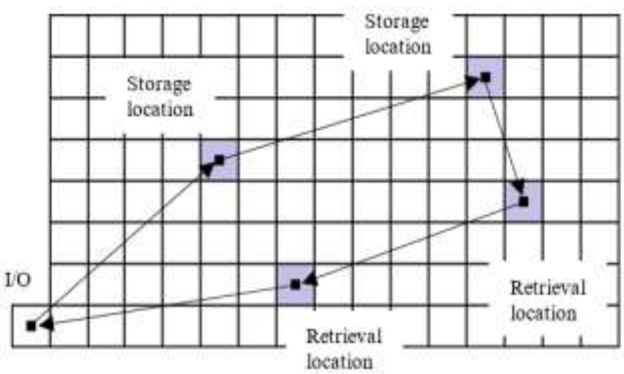
The next section where the problem definition is made. In Section 3, algorithms are given. In Section 4, results are given, and comparison is made between the algorithms. Finally, in Section 5 conclusions describe some future research advices.

2. Problem Definition

It is defined a warehouse with an AS/RS which built on one aisle, and single crane. In order to keep the performance of AS/RS high, dual-shuttle system was preferred for loading and unloading tasks. In today’s world multi-shuttle systems are chosen instead of single-shuttle to handle more operations in same period [10]. AS/RS machine can carry the unit loads like pallets or packages in constant dimensions. Cell dimensions are defined as 1 m × 1 m × 1 m. Since all cells have the same dimensions the goods can be stored regardless of location. Input/output station is located lower left-hand corner of the rack system. AS/RS machine can execute quadruple command (QC) cycle which consists of two storage tasks and two retrieval tasks, by means of dual-shuttle. Items that must be retrieved are known exactly and every item is different from each other. AS/RS machine moves around two dimensions. Motion on the X axis and Y axis are provided by the separate drive systems. Velocity of drives are accepted as a constant 1 meter per second. Acceleration and deceleration characteristics are neglected. Empty locations and filled locations are known by the system already.

All types of AS/RS have two typical problems. The first of these is sequencing of demanded items and the other is location assignment of goods to be stored [13]. Both problems can cause time wasting during the operational commands executing. For a better understanding quadruple command cycle is shown in Fig. 1.

Fig. 1. Quadruple command cycle path



Path of the AS/RS machine consist of six locations defined as (X_m, Y_m) where (X_0, Y_0) is starting point, from (X_1, Y_1) to (X_4, Y_4) are storage/retrieval points and (X_5, Y_5) is finishing point. The travel distance which begins from I/O station, including the storage/retrieval points and finishes I/O station is calculated by (1). Starting location and finishing location are the same location.

$$f\text{obj} = \sum_{m=1}^{5}\left(\sqrt{(X_m - X_{m-1})^2 + (Y_m - Y_{m-1})^2}\right) \quad (1)$$

The objective function of optimization problem, f_{obj}, must be minimum to obtain efficient results thereby more operations are handled. Distances between the locations were obtained from pre-calculated lookup table instead of calculating in each iteration to use time more effectively. In order to see the effects of the problem size, two different scenarios were defined. When the small size problem is considered, rack system has 1000 cells consisting of 10 rows and 100 columns ($0 \leq X_m \leq 99$ and $0 \leq Y_m \leq 9$). On the other hand, when the large size problem is taken into consideration, rack system has 3000 cells consisting of 30 rows and 100 columns ($0 \leq X_m \leq 99$ and $0 \leq Y_m \leq 29$). Rack systems are considered as matrix. The perspective of the AS/RS examined in this study is given in Fig. 2.

3. Algorithms

Many researchers believed that the solution algorithm of AS/RS is similar to the traveling salesman problem. Although this idea is partly true, it will not be right to participate completely. Even though order scheduling is similar to the traveling salesman problem, location assignment of products to be stored is far from this issue. While traveling salesman problem is to find the shortest travel distance between different combinations of certain points, the route optimization problem of AS/RS is to find the shortest travel distance of machine by uncertain points [14]. In this paper three heuristic optimization algorithm which PSO, RGA, and BGA are adapted to AS/RS route optimization problem. The research discusses the solution of route optimization problem in terms of location assignment. Heuristic algorithms must be tuned fine through parameters. Required parameters of BGA and RGA which the population size, the crossover probability (P_c), the mutation probability (P_m) and the number of generations are given in Section 3.1. Parameters of PSO are also given in the Section 3.2. Those parameters are the population size, learning rates (c_1 and c_2) and the number of generations.

3.1. Particle Swarm Optimization

PSO is a population-based algorithm introduced by Kennedy and Eberhart. PSO, inspired by the behaviour of bird flocks and fish schools in natural life, was used frequently in solution of combinational optimization problems [15]. The algorithm constitutively based on swarm intelligence. PSO is a population-based algorithm, that already resembles to GA in many aspects [16-17]. The iteration begins with a randomly determined particles which tries to reach the optimum result by providing particles to follow the best available solutions [18]. If PSO and GA are compared, PSO is easier to apply due to not containing crossing over and mutation operators. Moreover, PSO has less parameters to set. Implementation of the PSO algorithm to the location assignment problem of AS/RS composes of following steps.

Step 1: Assigning parameters of algorithm
Step 2: Generating particles randomly by using empty locations
Step 3: Converting the location numbers to coordinate plane
Step 4: Calculating p_{best} vector and g_{best}
Step 5: Generating velocity vector
Step 6: Adding velocities to particles
Step 7: If new particle doesn't coincidence the empty locations, kill the particle and generate randomly new one
Step 8: If stopping criteria hasn't met yet, go to Step 4
Step 9: End

Particles consist of storing locations coordinates because of retrieval locations are same for every particle. Two storing locations have four coordinates. A particle consists of a consecutive combination of these four coordinates as X_{S1} Y_{S1} X_{S2} Y_{S2}. For example, a vector of [73 5 41 9] represents a particle.

3.2. Genetic Algorithm

GA is an optimization method that searches for the best solution in random solution clusters inspired by evolutionary laws. GA is a population -based algorithm [19]. The iteration begins with randomly specified individuals called chromosomes. The individuals converge the optimum solution through crossing over and mutation operators [20]. There are several parameters to be determined in GA like population size, crossing over rate and mutation rate [21]. Implementation of the BGA to the location assignment problem of AS/RS composes of following steps.

Fig. 2. A view of unit-load, crane-based, dual-shuttle, fixed aisle AS/R

Step 1: Assigning parameters of algorithm
Step 2: Generating chromosomes randomly by using empty locations
Step 3: Converting the location numbers to coordinate plane
Step 4: Converting the coordinates to binary codes
Step 5: Calculating fitness values of chromosomes
Step 6: Selection of individuals for crossing-over and applying crossing-over operator

Step 7: If formed chromosome after the crossing-over doesn't coincidence the empty locations, kill the individual and generate randomly new one
Step 8: Applying mutation operator
Step 9: Converting the binary codes to coordinates
Step 10: If formed chromosome after the mutation doesn't coincidence the empty locations, kill the individual and generate randomly new one
Step 11: If stopping criteria hasn't met yet, go to Step 5
Step 12: End

Chromosomes consist of storing locations coordinates because of retrieval locations are same for every particle. Two storing locations have four coordinates. A chromosome consists of a consecutive combination of these four coordinates as X_{S1} Y_{S1} X_{S2} Y_{S2}. Implementation of the RGA to the location assignment problem of AS/RS is a replica of BGA. There is only one difference that converting to binary between RGA and BGA. Implementation of RGA does not have Step 3 and Step 9.

4. Results and Discussion

PSO, BGA, and RGA were implemented the small size problem and large size problem separately. Both systems have 10 different data sets with varying occupancy rate. Every data sets simulated 40 times with three algorithms. The results are average of 40 simulations' results. When the errors were calculating, minimum solution was accepted the travel distance of I/O station and 2 retrieval locations. Simulation results are given in Table 1.
Parameters of PSO algorithm are given as follows; Population size=100, c_1=c_2=1, and Number of generations=1000. Parameters of BGA are given as follows; Population size=100, P_c=0.25, P_m=0.01, and number of generations=1000. Parameters of RGA are given as follows; Population size=100, P_c=0.25, P_m=0.05, and Number of generations=1000.
The performance analysis of the algorithms is based on the MAE given in (2), MAPE given in (3) and RMSE given in (4).

$$Mean\ Absolute\ Error = \frac{1}{n}\sum_{1}^{n}|C - M| \quad (2)$$

$$Mean\ Absolute\ Percentage\ Error = \frac{1}{n}\sum_{1}^{n}\frac{|C - M|}{M} \quad (3)$$

$$Root\ Mean\ Square\ Error = \sqrt{\frac{1}{n}\sum_{1}^{n}(C - M)^2} \quad (4)$$

where C is calculated path value, M is minimum path value and n is number of simulations run. The results obtained from the error rates are given in Table 2 for small size system and Table 3 for large size system.
As seen in Table 2, PSO is suitable for small size problem according to all error rates in every data set. BGA and RGA are have same error rates. In terms of CPU time, Fig. 4 shows that RGA gives the best results in small size problem. BGA need more time to accomplish the iterations due to the converting to binary code process if it is compared to other methods. We can conclude that occupancy rate is not important from the point of CPU time for small size system. All the algorithms have same CPU times in 10 different data sets. In the sense of convergence, PSO is quicker than RGA and BGA (Fig.5). PSO converges the optimum solution nearly 30 iterations. RGA and BGA behave similar convergence graph in small size problem.
As seen in Table 3, PSO is suitable again for large size problem according to all error rates in every data set. BGA and RGA are have same error rates. In terms of CPU time Fig. 7 shows that RGA gives the best results in large size problem. BGA is 3-4 times slower than other algorithms. On the contrary of small size problem, it is obvious that all the algorithms need more time to accomplish the iterations as occupancy rates increase. PSO is quicker than BGA and RGA again regarding convergence in Fig. 8. PSO converges the optimum solution about 70 iterations. RGA converges the optimum solution about 230 iterations.

Table 1. Simulation results

Problem size	*Data set*	*Occup. rate*	*PSO*		*RGA*		*BGA*	
			f_{obj} [m]	*CPU Time [s]*	*f_{obj} [m]*	*CPU Time [s]*	*f_{obj} [m]*	*CPU Time [s]*
1000	1	30%	123.67047573	1.5402	123.67097496	0.7355	123.67133961	15.1767
1000	2	30%	174.59813351	1.4595	174.59825638	0.7295	174.59841583	14.0430
1000	3	35%	125.59709792	1.6894	125.59733912	0.8013	125.59748449	15.5309
1000	4	35%	110.06547296	1.7193	110.06617853	0.8219	110.06611686	14.5611
1000	5	40%	152.85897330	1.8524	152.85904679	0.8710	152.85911438	14.7020
1000	6	40%	160.48095074	1.8131	160.48117375	0.8733	160.48128747	15.0126
1000	7	45%	189.99914800	2.0284	189.99924094	0.9847	189.99928910	15.1935
1000	8	45%	160.39562477	1.8654	160.39596510	0.9883	160.39601252	15.2829
1000	9	50%	184.39868394	2.0144	184.39870882	1.1492	184.39876083	15.5359
1000	10	50%	166.31316366	2.1004	166.31332311	1.0571	166.31337655	16.1354
3000	1	25%	133.29643800	2.6193	133.29775149	1.3590	133.29914855	15.9670
3000	2	30%	164.31568057	3.0716	164.31662907	1.5946	164.31764746	15.6179
3000	3	35%	124.12975568	3.4261	124.13223994	1.8162	124.13293718	16.9013
3000	4	40%	191.64548994	3.9022	191.64609305	2.0567	191.64662850	16.1570
3000	5	45%	126.16053235	4.3514	126.16247470	2.3459	126.16308186	17.8314
3000	6	50%	189.50176189	4.6748	189.50240368	2.5158	189.50358602	18.0527
3000	7	55%	172.21113020	5.1338	172.21180130	2.7209	172.21211959	18.4953
3000	8	60%	160.92131236	5.3490	160.92264726	2.9781	160.92233766	17.9891
3000	9	65%	156.21655984	5.7329	156.21887922	3.2245	156.21879776	18.5815
3000	10	70%	176.82985857	6.1098	176.83033207	3.4415	176.83062119	18.6148

Table 2. Performance comparation of algorithms for small size system

Occup. rate	Minimum value	Method	MAE	MAPE	RMSE
30%	123.670273	**PSO**	**0.000201**	**0.000163**	**0.000440**
		RGA	0.000701	0.000566	0.000941
		BGA	0.001051	0.000850	0.001385
30%	174.598092	**PSO**	**0.000040**	**0.000023**	**0.000054**
		RGA	0.000163	0.000093	0.000219
		BGA	0.000259	0.000148	0.000354
35%	125.596879	**PSO**	**0.000218**	**0.000174**	**0.000244**
		RGA	0.000459	0.000366	0.000530
		BGA	0.000605	0.000481	0.000771
35%	110.064475	**PSO**	**0.000997**	**0.000906**	**0.001065**
		RGA	0.001703	0.001547	0.001795
		BGA	0.001642	0.001491	0.001764
40%	152.858943	**PSO**	**0.000030**	**0.000019**	**0.000031**
		RGA	0.000103	0.000067	0.000188
		BGA	0.000171	0.000112	0.000286
40%	160.480914	**PSO**	**0.000036**	**0.000023**	**0.000068**
		RGA	0.000260	0.000162	0.000392
		BGA	0.000373	0.000233	0.000527
45%	189.999108	**PSO**	**0.000040**	**0.000021**	**0.000066**
		RGA	0.000133	0.000070	0.000177
		BGA	0.000181	0.000095	0.000220
45%	160.395484	**PSO**	**0.000140**	**0.000087**	**0.000226**
		RGA	0.000480	0.000299	0.000584
		BGA	0.000528	0.000329	0.000635
50%	184.398624	**PSO**	**0.000060**	**0.000032**	**0.000077**
		RGA	0.000084	0.000046	0.000110
		BGA	0.000136	0.000074	0.000164
50%	166.313125	**PSO**	**0.000038**	**0.000023**	**0.000042**
		RGA	0.000197	0.000119	0.000304
		BGA	0.000251	0.000151	0.000364

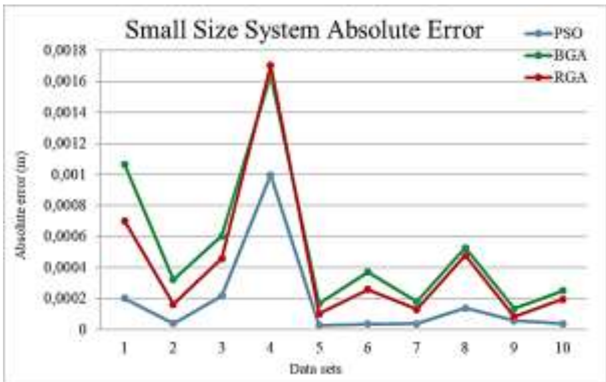


Fig. 3. Absolute error for small size system

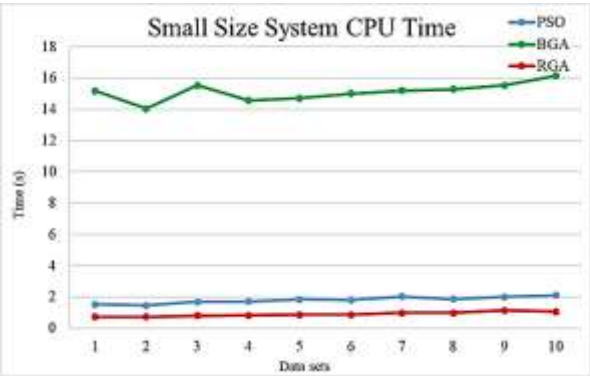


Fig. 4. CPU times for small size system

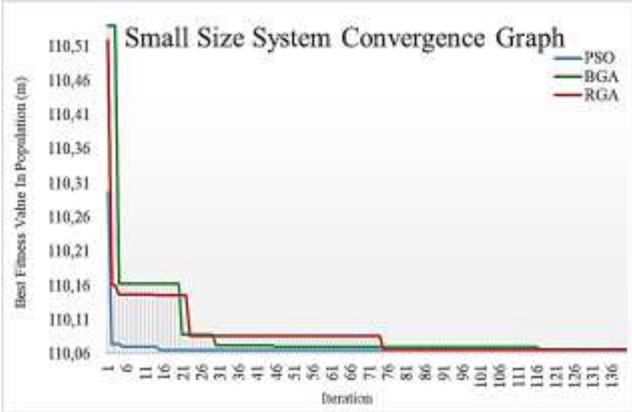


Fig. 5. Convergence of algorithms for small size system

Table 3. Performance comparation of algorithms for large size system

Occup. rate	Minimum value	Method	MAE	MAPE	RMSE
25%	133.295971	**PSO**	**0.000467**	**0.000350**	**0.000521**
		RGA	0.001780	0.001335	0.002259
		BGA	0.003177	0.002383	0.004135
30%	164.315379	**PSO**	**0.000301**	**0.000183**	**0.000341**
		RGA	0.001250	0.000761	0.001466
		BGA	0.002268	0.001380	0.003353
35%	124.129152	**PSO**	**0.000603**	**0.000486**	**0.000680**
		RGA	0.003087	0.002487	0.004461
		BGA	0.003785	0.003049	0.005079
40%	191.645420	**PSO**	**0.000069**	**0.000036**	**0.000107**
		RGA	0.000672	0.000351	0.001026
		BGA	0.001208	0.000630	0.001834
45%	126.159671	**PSO**	**0.000861**	**0.000682**	**0.001576**
		RGA	0.002803	0.002222	0.004057
		BGA	0.003410	0.002703	0.004431
50%	189.501398	**PSO**	**0.000364**	**0.000192**	**0.000507**
		RGA	0.001005	0.000531	0.001631
		BGA	0.002188	0.001154	0.002535
55%	172.210972	**PSO**	**0.000158**	**0.000092**	**0.000262**
		RGA	0.000829	0.000481	0.001222
		BGA	0.001147	0.000666	0.001722
60%	160.921049	**PSO**	**0.000263**	**0.000163**	**0.000339**
		RGA	0.001598	0.000993	0.002384
		BGA	0.001288	0.000801	0.001997
65%	156.215920	**PSO**	**0.000639**	**0.000409**	**0.001029**
		RGA	0.002959	0.001894	0.004483
		BGA	0.002877	0.001842	0.005024
70%	176.829758	**PSO**	**0.000100**	**0.000056**	**0.000118**
		RGA	0.000573	0.000324	0.000974
		BGA	0.000862	0.000488	0.001383

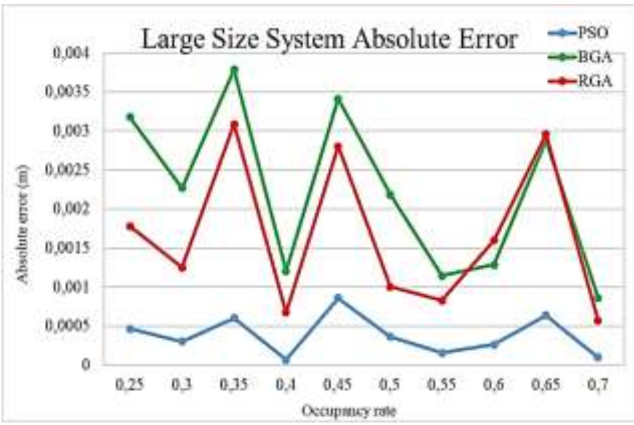


Fig. 6. Absolute error for large size system

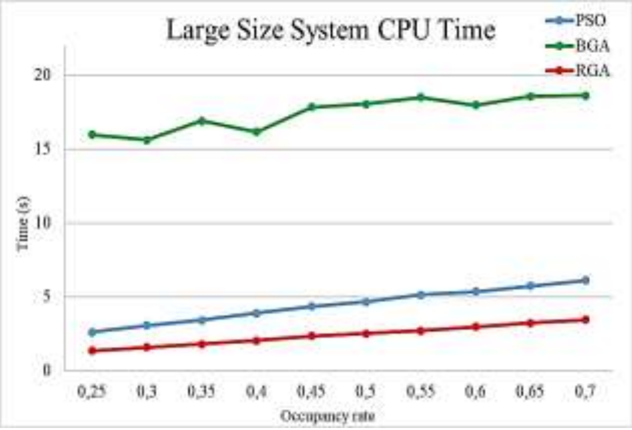


Fig. 7. CPU times for small size system

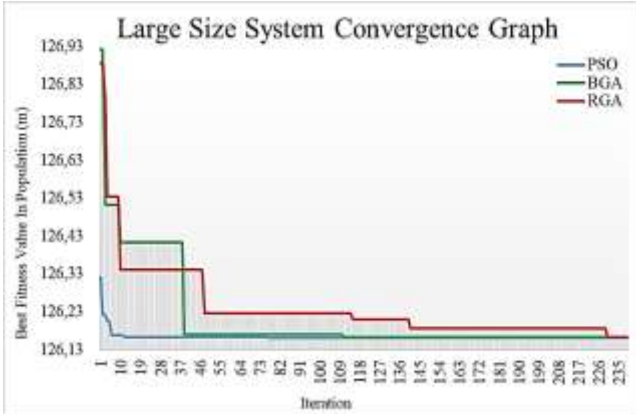


Fig. 8. Convergence of algorithms for large size system

5. Conclusion

In this study three optimization methods are implemented for location assignment problem of AS/RS. As the working time is important for an AS/RS, the requested tasks should be completed in the shortest time and the shortest way. Location assignment problem of multi-shuttle AS/RS has millions of solutions according to the warehouse size. Heuristic algorithms are suitable for searching the optimum solutions. Although there is a lot of research in the literature on this issue, as far as we know, we did not encounter any similar work because of the defined system is specific. In this paper, simulation results show us the PSO should be selected if it is required to operate the AS/RS machine with minimum error. Considering the MAE, MAPE, and RMSE the PSO is more effective. On the other hand, results show that RGA gives the best results in all circumstances if calculation time is important. It will be useful if these criteria are considered in the design and operation of the AS/RS machine. In the future, it is aimed to find solution to combination of location assignment and order sequencing problems in class-based storage for multi-shuttle AS/RS.

References

[1] Y. H. Hu, Z. D. Zhu, and W. J. Hsu, "Load shuffling algorithms for split-platform AS/RS," *Robotics and Computer-Integrated Manufacturing*, vol. 26, pp. 677-685, May 2010.

[2] H. Min, "The applications of warehouse management systems: an exploratory study," *International Journal of Logistics: Research and Applications*, vol. 9, no. 2, pp. 111-126, June 2006.

[3] K. J. Roodbergen and I. F. A. Vis, "A survey of literature on automated storage and retrieval systems," *European Journal of Operational Research*, vol. 194, pp. 343-362, 2009.

[4] A. R. Nia, H. Haleh, and A. Saghaei, "Dual command cycle dynamic sequencing method to consider GHG efficiency in unit-load multiple-rack automated storage and retrieval systems," *Computers & Industrial Engineering*, vol. 111, pp. 89-108, July 2017.

[5] M. Rajković, N. Zrnić, N. Kosanić, M. Borovinšek, and T. Lerher, "A multi-objective optimization model for minimizing cost, travel time and CO_2 emission in an AS/RS," *FME Transactions*, vol. 45, no. 4, pp. 620-629, 2017.

[6] Y. Kung, Y. Kobayashi, T. Higashi, M. Sugi, and J. Ota, "Order scheduling of multiple stacker cranes on common rails in an automated storage/retrieval system," *International Journal of Production Research*, vol. 52, no. 4, pp. 1171-1187, 2014.

[7] A. Azzi, D. Battini, M. Faccio, A. Persona, and F. Sgarbossa, "Innovative travel time model for dual-shuttle automated storage/retrieval systems," *Computers & Industrial Engineering*, vol. 61, pp. 600-607, 2011.

[8] K. Hachemi, Z. Sari, and N. Ghouali, "A step-by-step dual cycle sequencing method for unit-load automated storage and retrieval systems," *Computers & Industrial Engineering*, vol. 63, pp. 980-984, 2012.

[9] D. Popović, M. Vidović, and N. Bjelić, "Application of genetic algorithms for sequencing of AS/RS with a triple-shuttle module in class-based storage," *Flexible Services and Manufacturing Journal*, vol 26, pp. 432-453, 2014.

[10] S. Brezovnik, J. Gotlih, J. Balič, K. Gotlih, and M. Brezočnik, "Optimization of an automated storage and retrieval systems by swarm intelligence," *Procedia Engineering*, vol. 100, pp. 1309-1318, 2015.

[11] P. Yang, L. Miao, Z. Xue, and B. Ye, "Variable neighborhood search heuristic for storage location assignment and storage/retrieval scheduling under shared storage in multi-shuttle automated storage/retrieval systems," *Transportation Research Part E*, vol. 79, pp. 164-177, 2015.

[12] N. Boysen and K. Stephan, "A survey on single crane scheduling in automated storage/retrieval systems," *European Journal of Operational Research*, vol. 254, pp. 691-704, 2016.

[13] T. Wauters, F. Villa, J. Christiaens, R. A. Valdes, and G. V. Berghe, "A decomposition approach to dual shuttle automated storage and retrieval systems," *Computers & Industrial Engineering*, vol. 111, pp. 325-337, 2016.

[14] X. H. Shi, X. L. Xing, Q. X. Wang, L. H. Zhang, X. W. Yang, C. G. Zhou, and Y. C. Liang, "A discrete PSO method for generalized TSP problem," in *Proc. ICMLC*, Shangai, China, 2004, pp. 2378-2383.

[15] J. Kennedy and R. Eberhart, "Particle Swarm Optimization," in *Proc. ICNN*, Perth, WA, Australia, 1995, pp. 1942-1948.

[16] P. Özkan-Bakbak and M. Peker, "Particle swarm optimization design of optical directional coupler based on power loss analysis," *International Journal of Intelligent Systems and Applications in Engineering*, vol. 1, no. 2, pp. 29-33, 2013.

[17] H. Kahramanlı and N. Allahverdi, "Particle swarm optimization with flexible swarm for unconstrained optimization," *International Journal of Intelligent Systems and Applications in Engineering*, vol. 1, no. 1, pp. 8-13, 2013.

[18] H. H. Çevik, H. Harmancı, and M. Çunkaş, "Forecasting hourly electricity demand using a hybrid method," in *Proc. ICCED*, London, UK, 2017, pp. 8-12.

[19] J. C. H. Pan, P. H. Shih, M. H. Wu, and J. H. Lin, "A storage assignment heuristic method based on genetic algorithm for a pick-and-pass warehousing system," *Computers & Industrial Engineering*, vol. 81, pp. 1-13, 2015.

[20] D. Whitley, "A genetic algorithm tutorial," *Statistics and Computing*, vol. 4, no. 2, pp. 65-85, June 1994.

[21] M. Kurdi, "An effective genetic algorithm with a critical-path-guided Giffler and Thompson crossover operator for job shop scheduling problem," *International Journal of Intelligent Systems and Applications in Engineering*, vol. 7, no. 1, pp. 13-18, 2019.