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Effects of relocation to AS/RS storage location policy with production quantity variation

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Abstract

Most research on AS/RS (Automated Storage & Retrieval Systems) operation policy concludes that class-based storage policy has better performance than random storage policy. This result would be obtained if the system performance is evaluated with a fixed production plan. However, the production quantity of each item can not be kept at the same level at all times. The effect of production quantity variation per product between 10 and 80% is studied with random storage policy, 2 class-based, and 3 class-based storage policies with/without relocations to find acceptable ranges of variations. A typical AS/RS model is developed using GPSS/PC to be used for the evaluations. An applicable operation policy could be selected based on the degrees of production plan variation or a necessary variation point for re-location could be determined with the current policy.

Keywords: Automated Storage & Retrieval Systems; Simulation; Storage policies

1. Introduction

This research is to find the tolerance limits and appropriate strategies for random and class-based storage policies of AS/RS's (Automated Storage & Retrieval Systems) as applied to production plan changes. Class-based storage has been evaluated as a better policy than random storage in most research (Graves, Hausman, & Schwarz, 1977; Hausman, Schwarz, & Graves, 1976; Schwarz, Graves, & Hausman, 1978). However, in practice, random storage or closest open location storage policy is frequently used instead of the recommended class-based policy (Chow, 1986; Hausman et al., 1976). There could be various reasons why the recommended policy is not used in practice. Possible reasons could be the difficulties involved with applications of class-based storage policy in practice, or the complexities involved in following up possible frequent production plan changes. Class-based storage policy must be the better performer if the AS/RS performance is evaluated with a fixed production plan. However,

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the production quantity of each item cannot be kept at the same level at all times. If current storage policy is kept in place, regardless of production quantity variation, the performance of the AS/RS will not be good.

It would be valuable to know how much production variation can be allowed with one of the above storage policies, or which policy would be good with certain production variations. To find tolerances and appropriate strategies for every AS/RS operation policy, production plans are created by changing production quantity of each item between 0% and 80%, and simulation models are developed using GPSS/PC, a PC version of GPSS (General Purpose Simulation System). Using the production plans and simulation models, the performances of random, 2 class-based and 3 class-based storage policies of AS/RS are examined.

2. Literature review

Graves et al. (1977), Hausman et al. (1976) and Schwarz et al. (1978) calculated the average operation time of a stacker crane based on the assumption that the time required to get to the farthest column is the same as the time required to get to the farthest row. They introduced the calculation method for the average time of a stacker crane per random storage, storage by turning ratio and class-based storage with single and dual commands. Also, they found that the storage policy based on turning ratio reduced the average operation time of a stacker crane through computer simulation. Bozer and White (1984) calculated the average operation time of a stacker crane with random storage when the rack is rectangular, not square as assumed by Hausman et al. (1976). Bozer and White pointed out that this type of square rack is not realistic. Therefore, they introduced a shape factor to calculate the average operation time of a stacker crane with rectangular racks. Chow (1986) studied AS/RS with a direct access handler which has on-board storage, not the stacker crane. Elsayed and Lee (1996) developed an algorithm to minimize total tardiness in AS/RS's with due dates. Rosenblatt and Eynan (1989) studied boundaries between the classes for optimum operation. They reported that there is a tendency towards less travel time with many classes, however, 10 classes or fewer are recommended to keep the AS/RS utilization most efficient. Taboun and Bhole (1993) developed a discrete simulation model of AS/RS using SIMAN. They studied AS/RS with two aisles in order to study the difference in throughput and efficiency of the S/R machine with different types of pallets or area assignments. Muralidhran, Linn, and Pandit (1995) suggested a shuffling heuristic-based approach by combining random storage and class-based storage methods.

3. Development of an evaluation model

Production plans and simulation models are developed to study the effect of production quantity variation to three different AS/RS operation policies. Production quantities vary between 10 and 80% by increasing 10%. Nine different production plans are created to represent production quantity variation and six different AS/RS models are developed to represent the three different operation policies with and without relocations.

Table 1
Production quantity variation data (superscript numerals are the original item number with 0% quantity variation)

2CLS	3CLS	Item no.	0%	10%	20%	30%	40%	50%	60%	70%	80%
CL1	CL1	1	230	240	241	254	110^{6}	212^{5}	210	140	190^{7}
		2	173	182	120^{5}	120^{5}	165	160	120^{5}	140^{5}	240^{10}
		3	151	145	175	82^{7}	180	177	187^{6}	130^{5}	180^{15}
		4	90	95^{9}	112	167	190^{10}	195^{7}	144^{9}	175^{10}	110
CL2	CL2	5	65	68	84^{2}	67	38	51^{1}	17^{2}	65^{2}	10
		6	60	30	81	79	56^{1}	37	82^{3}	14	20
		7	40	45	35	17^{3}	28	70^{4}	37	25	45^{1}
		8	37	30	24	31	45	35	28	21	1
		9	25	26^{4}	20	21	14	20	81^{4}	9	4
		10	20	24	20	20	69^{4}	17	21	50^{3}	50^{2}
	CL3	11	17	18	15	18	8	13	15	10	10
		12	15	14	14	17	9	10	21	15	6
		13	15	15	14	15	5	12	14	40	5
		14	12	10	14	14	7	8	12	14	5
		15	10	14	13	10	12	7	10	23	95^{3}
		16	10	8	11	9	8	5	10	85^{4}	7
		17	9	9	10	6	40	5	8	8	8
		18	8	5	9	11	5	14	8	5	5
		19	5	7	9	5	5	1	7	5	5
		20	5	9	4	4	10	1	5	5	10
		Total	997	994	1025	967	1004	1050	1037	979	1006

3.1. Experiment design

The assumed total number of items to be produced is 20 in the production plan. The top four items out of 20 based on quantities are assigned to the racks for the first class if the 2 class-based storage is applied then rest of the items will be assigned to the racks in the second class. For the 3 class-based storage, the top four items are assigned to the first class, the next six items to the second class, and the remaining 10 items to the third class. These assignments are given in the columns titled '2CLS' and '3CLS' in Table 1. The quantity of each item to store per hour is calculated based on proportions of the production quantities.

It is assumed that production variation in each item does not change the total production quantity. If a production quantity of a particular item is increased or decreased, another item quantity is decreased or increased to keep the total production quantity remaining the same or similar in every case. A detailed production quantity variation used in this experiment is provided in Table 1. The numbers under the column '0% variation' are the original production quantity per item. The superscripts are the item numbers with the original production quantities. For example, the superscript '9' at 10% of item number '4' in the table means that this item's original item number is '9'. The item number 9 with 0% variation becomes item number 4 since it ranks 4th in production quantity after a 10% production quantity variation and item number 4 becomes class 2 since it ranks 9th after the variation. If relocation is not applied with class-based storage, item number 9 is stored in the second class racks even though it is now qualified for the first class racks and item 4 is stored in the first class racks even though it is not qualified for the first class racks any more.

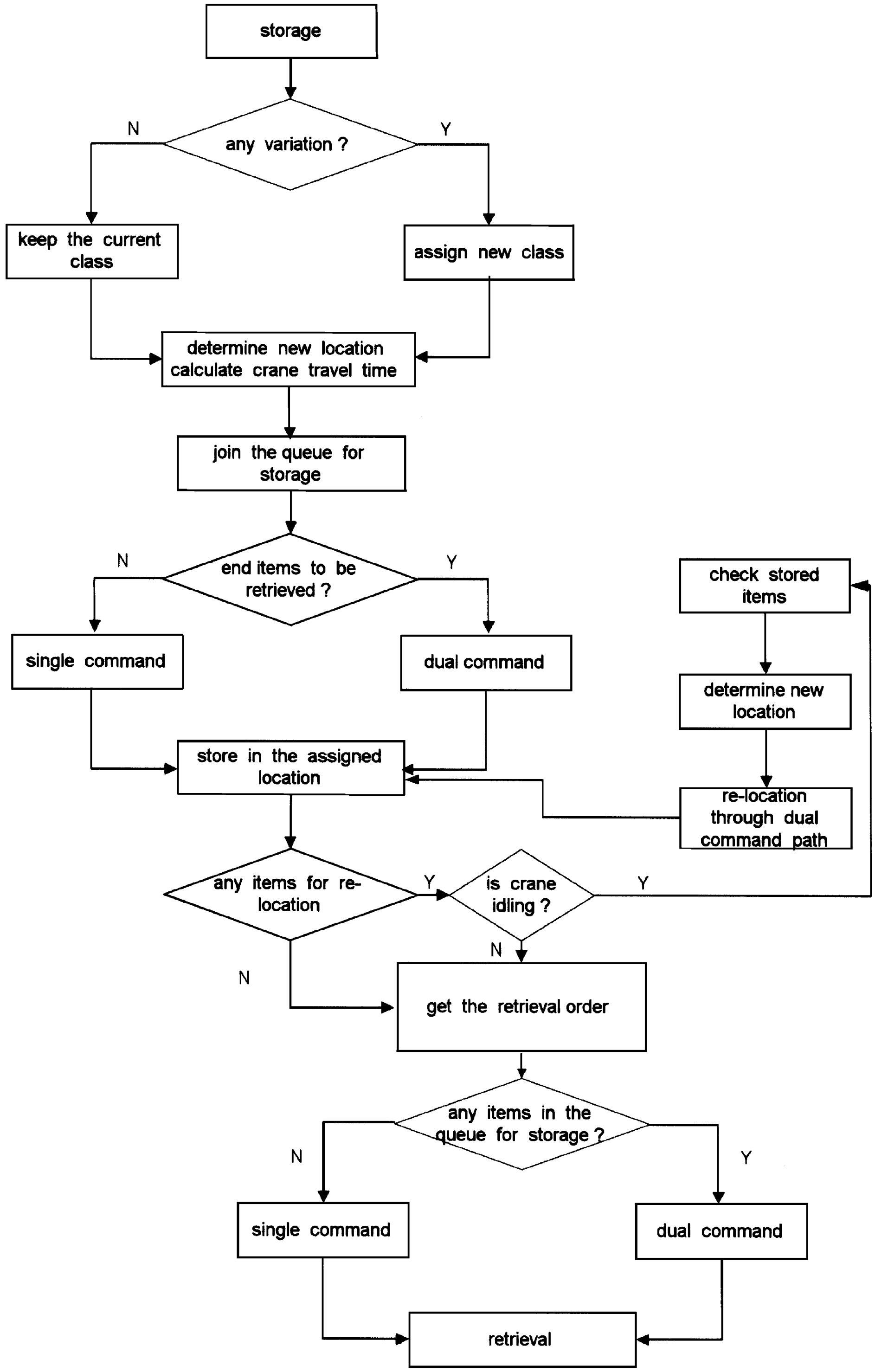

Fig. 1. Logical flow of the AS/RS model.

The effects of production quantity variations between 10 and 80% with random storage, 2 class-based storage and 3 class-based storage policies are examined using the production plan. Also the three policies with relocation to meet production variation are examined. Relocation is made possible during the simulation process in order to reflect possible production plan changes. In this research, relocation is the process of changing the current physical location of an item. The relocation process is necessary for the items stored in AS/RS before production variation. A different class is assigned with a production variation. For example, the number four items stored in the first class racks must be moved to the second class racks if a 10% production variation occurs. It is assumed that relocation includes re-assignment. Re-assignment changes the assigned class of items to different ones based on the new production quantity after variations. This also changes assigned storage times and input frequencies to reflect the production quantity variation.

3.2. AS/RS model development

Simulation experiments are performed with an AS/RS model which is assumed to have one stacker crane at an aisle consisting of the storage space of 27×10, that is 540 storage racks. The size of one rack is 2 m in width and 1.5 m in length. The total length of one side is 54 m in width and 15 m in length. Theoretically, the average speed of the stacker crane is 1.05 meters per second and the vertical speed is 1.48 m/s. An average of 42 items will be stored per hour in the AS/RS. Items to be handled with the system are assumed as end products; so it has an independent demand. The AS/RS operates 24 h/day.

GPSS/PC is used to create the AS/RS model for simulation studies. Several programs are developed to represent random storage policy, 2 class-based storage, and 3 class-based storage policies with and without relocation. The basic logical flow of the model for storage and retrieval operations is given in Fig. 1. A GENERATE block of GPSS/PC is used to simulate the entering items to be stored. If an item for storage is generated, production quantity variations are checked. If any changes are found in the plan, new classes are assigned; otherwise, the current classes are kept. A rack is assigned for each new item and a necessary crane moving time is calculated. Items for retrieval are checked and the new item is stored by either a single or a dual command. Relocation processes are followed if necessary. These are done whenever the crane idles. A single command operation or a dual command operation is determined based on retrieval and storage orders. This process repeats for a given period of simulation time.

4. Simulation and result analysis

All of the AS/RS models are simulated for 900,000 unit times. The data obtained between 0 and 300,000 unit times are ignored to avoid unstable initial operations. The simulation results obtained between 300,000 and 600,000 unit times are collected to calculate the system's performances with the original production plan. The results from the time interval of 600,000 and 900,000 are for the system performances with changed production plans between 10 and 80% of eight different cases. The 900,000 unit time simulation experiments are repeated 10 times each for all cases.

4.1. Random storage

With random storage policy, three different storage times are assigned to every item based on the

Table 2
Simulation result of random storage

V%	Throughput			Test			Rack (%)		Test			Queue		Crane (%)	
	W/O	REL	Δ (%)	*t*-val	2 Tail	5% Significance	W/O	REL	*t*-val	2 Tail	Significance	W/O	REL	W/O	REL
0	9648	–	–	–	–	–	70.01	–	–	–	–	0	–	77.09	77.09
10	9632	9668	0.374	1.31	0.223	N	73.40	68.11	7.59	0	Y	0	0	76.90	77.10
20	9645	9632	−0.135	−0.82	0.433	N	72.30	69.30	4.84	0.01	Y	0	0	77.20	76.90
30	9590	9628	0.396	1.39	0.198	N	78.60	69.22	19.98	0	Y	0	0	76.50	76.74
40	9553	9672	1.246	6.28	0	Y	84.32	67.10	25.53	0	Y	0	0	76.27	77.16
50	9617	9695	0.811	3.02	0.014	Y	82.63	62.48	33.04	0	Y	0	0	76.96	77.46
60	9550	9663	1.183	8.20	0	Y	87.97	69.82	27.90	0	Y	0	0	75.93	77.22
70	9321	9644	3.465	21.97	0	Y	95.40	68.25	83.90	0	Y	164	0	70.40	76.87
80	9397	9645	2.639	21.97	0	Y	95.45	71.03	83.90	0	Y	80	0	71.53	77.07

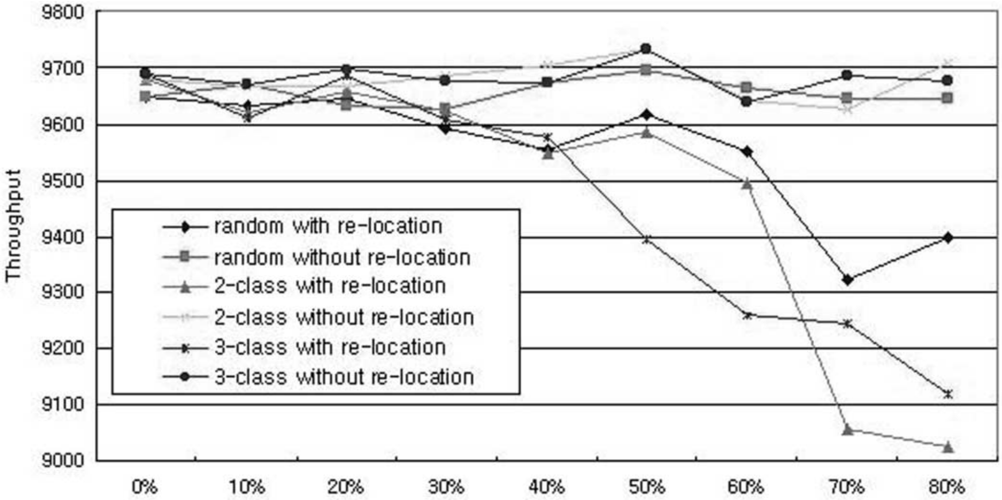

Fig. 2. Throughputs with and without relocations on production variations.

production quantities in the plan. The upper four items with larger production quantities are stored for 15,000 unit times, the next six items are stored for 50,000 unit times, and the remaining 10 items are stored for 95,000 unit times in the AS/RS. During the simulation study, throughputs, rack utilization, waiting line and crane utilization are calculated with the original production plan. Then, 10–80% of production variation cases are simulated again by increasing 10% every case. Simulation results on throughput, crane and rack utilization, and input queue are summarized in Table 2 with statistical test results at the 5% level. Under the column named 'W/O' is the simulation result without relocation while 'REL' is with relocation. 'Δ%' is the percentage of increased amount in throughputs. This is calculated by {100 × (REL-W/O)/(W/O)}. The values in '*t*-val' and '2 tail' are the values obtained using SPSSWIN

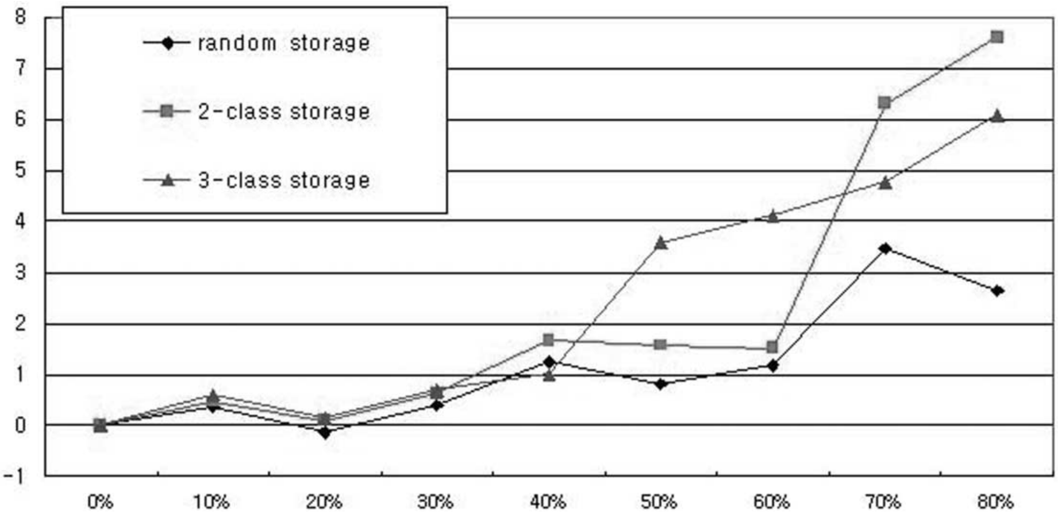

Fig. 3. Increased percentages of throughputs with and without relocations.

to determine if there are statistically significant differences between the mean level of throughputs on the basis of with relocation and without relocation at production quantity variation ($\alpha = 0.05$ and $n_1 = 10$, $n_2 = 10$). If any value in '2 tail' is less than 0.05, it can be concluded that relocations can improve throughputs with production quantity variation at a 95% confidence level. The values in 't-val' can be used for a different confidence level. The value of $t(n_1 + n_2 - 2, \alpha)$ from the table is necessary for testing. For instance, the table value for $t(10 + 10 - 2, 0.05)$ is 2.101. 'Rack%' is for rack utilization, 'Queue' for the length of waiting line to be stored in the system, and 'Crane%' for the utilization of the crane in the AS/RS.

Throughputs with and without relocation are found to be different if the variations in the production plan are greater than or equal to 40% variation. This means the relocation would be beneficial with 40% or higher variations. However, the percentages of increased amounts in throughputs are only more or less 1% between 40 and 60% variations with relocations. However, relocation could increase 3.465 and 2.639% of throughputs with 70 and 80% variations, respectively. Graphs for the throughputs with and without relocations to the production variations and the increased percentages of throughputs are provided in Figs. 2 and 3, respectively.

A long waiting line is formed from 70% variations. The utilization of the crane agrees with this long waiting line. This indicates that relocations must be done to resolve the problem. Big differences are found in crane utilizations at both 70 and 80% variations with and without relocations. Rack utilization also goes up from 40% variation if no relocation is made. The rate reaches up to 95% at 70 and 80% of production variations.

4.2. Class-based storage

Simulation studies for 2 class-based storage for the AS/RS are done in two different cases. One is without relocation action to the changed production plans and the other is with relocation to follow up the changes in production quantities. Simulation experiments are performed for every production quantity variation case by keeping the upper four items in the original production plan as the first class, even though their production quantities are changed. These are the 'without relocation' cases. Then, other simulation experiments are followed after making necessary relocations for the items with changed production quantities. The simulation results are summarized in Table 3. The 'CL1' and 'CL2' under 'Queue' stand for the first class and the second class, respectively. Therefore, the numbers under the column 'CL1' indicate queue length to enter the racks in the class 1 area.

With 2 class-based storage policy, the throughputs with and without relocation are found to be different from 30% production plan variations. However, the increased percentages of throughputs remain 1%'s with 60% variation or more. However, 6.305 and 7.592% of increases in throughputs are obtained with relocations at 70 and 80% variations. A long waiting line is formed from 60% variation, if no relocation is made for the production quantity variations. Please refer to the graphs in Figs. 2 and 3 for throughput changes and increased percentages of throughputs with and without relocations for production variations. Crane utilizations are lower than random storage policies because the storage spaces are divided into two classes to reduce the crane travel distances. The long waiting line, lower crane and rack utilizations are the operation results of two separated storage spaces.

Table 3
Simulation results of 2 class-based storage

V%	Throughput W/O	Throughput REL	Δ (%)	Test *t*-val	2 Tail	5% Significance	Rack (%) W/O	Rack (%) REL	Test *t*-val	2 Tail	5% Significance	Queue W/O CL1	Queue W/O CL2	Queue RELO CL1	Queue RELO CL2	Crane (%) W/O	Crane (%) RELO
0	9678	–	–	–	–	–	70.18	–	–	–	–	0	0	–	–	56.12	–
10	9620	9665	0.468	−1.97	0.09	N	72.63	68.23	−11.3	0	Y	0	0	0	0	57.35	54.84
20	9656	9665	0.093	−1.7	0.868	N	72.53	70.39	−3.95	0.003	Y	0	0	0	0	57.87	56.54
30	9623	9683	0.624	−2.64	0.027	Y	78.48	70.32	−12.3	0	Y	0	0	0	0	60.53	56.20
40	9549	9707	1.655	−5.12	0.001	Y	82.77	68.10	−20.9	0	Y	0	0	0	0	61.49	56.49
50	9584	9734	1.565	−5.15	0.001	Y	81.38	63.75	−31.8	0	Y	0	2	0	0	63.54	53.78
60	9497	9641	1.512	−8.07	0	Y	85.78	69.82	−30.3	0	Y	0	97	0	0	62.67	56.24
70	9057	9628	6.305	−24.65	0	Y	84.85	72.48	−20.2	0	Y	0	492	0	0	55.81	57.43
80	9023	9708	7.592	-45.89	0	Y	83.62	61.34	−53.5	0	Y	0	549	0	0	57.14	53.32

4.3. Class-based storage

The concept of 3 class-based storage is the same as 2 class-based storage except for the number of classes in storage spaces. 3 class-based storage has three separated storage spaces while 2 class-based storage has two separated storage spaces. Items are classified into three different classes with 3 class-based storage. Similarly, they are classified into two with 2 class-based storage as shown in Table 1. Therefore, simulation studies are similar to the 2 class-based case except there is one more class in the storage area and item classification. Simulation results of AS/RS operation with 3 class-based storage with and without relocation are summarized in Table 4. The 'C1,' 'C2,' 'C3' under 'Queue' indicate the first class, the second class and the third class, respectively.

With 3 class-based storage policy, there are differences in throughputs between the cases with and without relocations from 10% of production quantity variation. However, throughput increases remain more or less 1% with up to 40% of production plan variations. Please refer to the graphs in Figs. 2 and 3 for throughput changes and increased percentages of throughput with and without relocations for production variations. The increased percentages of throughputs are minor with up to 40% variation. However, queues are formed to class 2 and class 3 storage areas. These waiting lines can be avoided with relocations. The results are similar to the 2 class-based case except lower numbers in crane and rack utilizations. More classes in the storage area makes this possible since it reduces crane travel distance. This efficiency also creates a problem. Fewer racks in a class makes this policy perform worse with production quantity variations. This policy is found to be too sensitive to be used under production quantity variations.

4.4. Result analysis and comments

Relocations could be valuable with production plan variations. It helps to maintain stable throughputs with any AS/RS operation policy as shown in Fig. 2. However, random storage policy is not affected much with production variations up to 60%. A sharp drop of throughputs with 2 class-based policy is found at 70% variation and with 3 class-based at 50%. It is possible to see how a policy can be beneficial with relocation at a certain production quantity variation in Fig. 3. With up to 60% of variations, the performances of random and 2 class-based policies are not much improved while the performance of 3 class-based is improved considerably, even from 50% variation. However, relocations would be necessary even with lower variations if a waiting line is formed. Relocations are strongly recommended with waiting line formations. A summary of significant test results for throughputs and interesting features is provided in Table 5.

Random storage policy would be appropriate for an AS/RS if 1.2% of losses of throughputs are not a problem and frequent production quantity variations are expected. This policy tolerates up to 60% of production quantity variations. It does not improve throughputs with relocation at up to 30% variations. However, 3 class-based would be better if the system capacity is near full. Class-based performs better than random, but it does not tolerate quantity variations well, like random. Relocations can improve throughputs at 10% variation with 3 class-based storage policy.

Higher throughputs, lower rack and crane utilizations can be obtained with class-based storage policies. More classes make better throughputs. The obtained throughputs are 9648, 9678, and 9686 by random, 2 class-based and 3 class-based storage policies, respectively. More classes in storage area mean less crane travel distance, but also require frequent relocations due to the limited number of racks

Table 4
Simulation results of 3 class-based storage

V%	Throughput			Test			Rack (%)		Test			Queue						Crane (%)	
	W/O	REL	Δ%	*t*-val	2 Tail	5% Significance	W/O	REL	*t*-val	2 Tail	5% Significance	W/O			REL			W/O	REL
												C1	C2	C3	C1	C2	C3		
0	9686	–	–	–	–	–	69.41	–	–	–	–	0	0	0	–	–	–	54.76	–
10	9612	9670	0.603	−3.57	0.006	Y	72.27	68.29	7.78	0	Y	0	0	0	0	0	0	55.48	54.16
20	9684	9698	0.145	−0.58	0.574	N	72.73	71.01	2.69	0.025	Y	0	0	0	0	0	0	55.87	55.36
30	9608	9674	0.687	−2.27	0.049	Y	78.12	70.05	11.01	0	Y	0	0	0	0	0	0	57.43	54.91
40	9575	9671	1.003	−7.31	0	Y	84.29	66.96	30.45	0	Y	0	25	1	0	0	0	58.71	53.56
50	9396	9732	3.576	−17.2	0	Y	74.99	63.11	19.5	0	Y	0	239	0	0	0	0	53.12	52.14
60	9258	9638	4.105	−18.3	0	Y	78.4	69.33	16.5	0	Y	1	359	0	0	0	0	53.9	54.54
70	9242	9683	4.772	−36.9	0	Y	84.38	69.37	35.9	0	Y	0	78	275	0	0	0	56.91	54.75
80	9119	9674	6.086	−14.1	0	Y	83.61	70.86	32.4	0	Y	0	403	74	0	0	0	55.32	55.14

Table 5
Quantity variation ranges changing the system status

Descriptions		Random	2 Class	3 Class
Relocation begins to improve throughputs		40%–	30%–	10%–
Queue formation from		70%–	60%–	40%–
Rack utilization (%)	1970s	0–30%	0–30%	0–60%
	1980s	40–60%	40–80%	70–80%
	1990s	70–80%	–	–
Remarks			Throughput +1.5% at 60% queue 2 units at 50%	Queue 25 units at 40%

in a class. Therefore, a more detailed class-based operation policy is recommended if AS/RS performance is the most critical issue due to limited system capacity. However, random storage policy would be better with expected frequent production plan changes and when the system performance is not the most critical issue. As shown in Fig. 4 random storage policy has a larger tolerance. Also, an applicable operation policy can be selected based on the production plan variation of a company, or a necessary relocation point with a current policy of an AS/RS can be decided using the boundaries in Fig. 4.

To summarize, class-based storage policies perform better than random storage with stable production plans. However, random storage policy would be a better option with production quantity variations since it tolerates variations up to 60%. Second, class-based storage policies need to have relocations if production quantities are changed. A sharp drop of throughputs is found at 70% variation with 2 class-based policy and at 50% with 3 class-based policy. Third, an appropriate policy can be selected based on a system capacity. Class-based operation policies would be better if an AS/RS performance is the most critical issue, while random storage would be better if a system performance is not critical and frequent production plan changes are expected.

5. Conclusions

In this research, performance evaluations of three typical AS/RS operation policies are done under possible production quantity changes. The simulation results are used to analyze the sensitivities and tolerances of the operation policies against the variations. Random storage policy performs well with

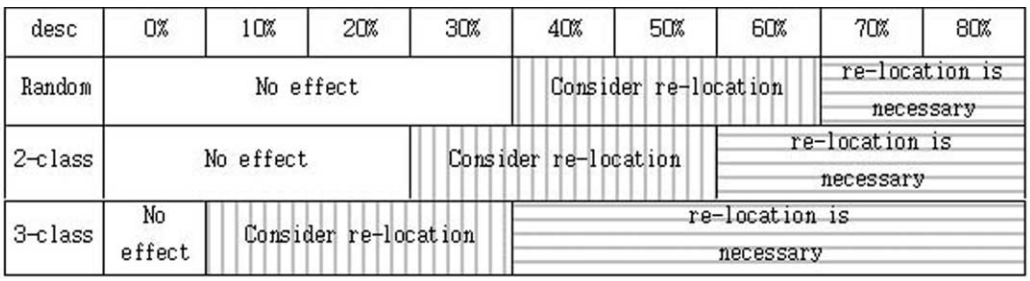

Fig. 4. Recommended actions to production plan variations.

production quantity variations. The policy tolerates up to 60% of the variations. In addition, relocations are not helpful to increase throughputs with variations up to 30%.

Relocations are helpful to maintain stable throughputs with all the three types of AS/RS operation policies. They are also helpful to avoid losses caused by crane travel distance increase and lack of storage with a system under unstable production plans. Relocation does not cause any crane operation problems since the time to re-locate items in an AS/RS is too minor to affect the crane utilization. With class-based storage policies, better throughputs and lower rack and crane utilizations are achieved. However, the policies are too sensitive to continue to apply the current classification against production quantity variations. An applicable operation policy can be selected based on the production plan variation, or a necessary variation point for relocation to the current policy can be determined using the simulation results.

References

Bozer, Y. A., & White, J. A. (1984). Travel-time models for automated storage/retrieval system. *IIE Transactions*, *16* (4), 329–338.

Chow, W. M. (1986). An analysis of AS/RS in manufacturing assembly lines. *IIE Transaction*, *20*, 204–214.

Elsayed, E. A., & Lee, M. K. (1996). Order processing in automated storage/retrieval systems with due dates. *IIE Transaction*, *28*, 567–577.

Graves, S. C., Hausman, W. H., & Schwarz, L. B. (1977). Storage/retrieval interleaving in automatic warehouse systems. *Management Science*, *23*, 935–945.

Hausman, W. H., Schwarz, L. B., & Graves, S. C. (1976). Optimal storage assignment in automatic warehouse systems. *Management Science*, *22* (6), 935–945.

Muralidharan, B., Linn, R., & Pandit, R. (1995). Shuffling Heuristics for the Storage Location Assignment in an AS/RS. *International Journal of Production Research*, *33* (6), 1661–1672.

Rosenblatt, M. J., & Eynan, A. (1989). Deriving the optimal boundaries for class-based automatic storage/retrieval systems. *Management Science*, *35* (12), 1519–1524.

Schwarz, L. B., Graves, S. C., & Hausman, W. H. (1978). Scheduling policies for automatic warehousing systems: simulation results. *AIIE Transactions*, *10*, 260–270.

Taboun, S. M., & Bhole, S. D. (1993). A simulator for an automated warehousing system. *Comparative and Industrial Engineering*, *24* (2), 281–290.