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Correlation analysis between Filling Rate and Box Type in Container Loading Problem

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Abstract: This paper aims to study the correlation between filling rate and box type for guiding loading workers to grasp the best loading time. By collecting and analyzing the data in literature, we could find that the mean filling rates of weakly heterogeneous cases are much bigger than strongly heterogeneous instances, and weak heterogeneous loading problems could get far higher volume utilization than strong heterogeneous loading problems do. It is also found that 5-15 types is the best filling rate field in the best loading time.

1. Introduction

As a fundamental issue in the modern logistics, the“size coordination”problem has been widely researched in the past decades. Its main objective is to make a fixed space to be used effectively. One of the derived problems in the logistic is Container Loading Problem (CLP). This problem has been widely existing in many fields like railway, car, ship and container et al. Due to the capacity limitation of the transportation equipment, it is of great importance to maximize its loading volume to improve its utilization rate and economic efficiency in the logistic activities.

Nowadays, the researches mainly focus on the algorithm development to obtain high utilization of the container capacity. However, the proposed algorithm may not be effective to achieve the objective due to the complexity of container packing in practice. In the practical operation, container packing could be divided into two stages. The first stage is for goods accumulation, like compiling a list of goods to be installed (including size, weight, volume, special instructions) when the volume reaches a certain quantity. The second stage is to load the goods into the container. If there is a gap in the container, it will be filled with some isolated materials or fixed with wire. In order to pursue a higher utilization rate of container, freight departments do not begin to load until the total volume of cargoes for loading are several times larger than the volume of the container. When the loading starts, some of them are first selected to load, and the rest must wait for next round.

In the process of cargo loading, one question should be considered: what exactly is characteristics of cargoes to be loaded that affect container’s utilization rate? Apart from the total volume, it is worth investigating whether the type number of goods for loading impacts the filling rate. The research might provide a guide for the time of loading. Therefore, this paper proposes to study the correlation between filling rate and cargo type in container loading problem based on the published data in literature. The paper is organized as follows. In Section 2, we make the problem statement of this study. Section 3 explains the cases and algorithms employed for analysis in this paper, based on which in Section 4 we analyzes the computational results in literature. Finally we come to a conclusion in Section 5 and illustrate the future works.

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2. Problem statement

The CLP is a three-dimensional packing problem in which a large parallelepiped or container has to be filled with smaller parallelepipeds or boxes. In other words, a given container is loaded with a subset of a given set of boxes in such a way that all boxes are positioned in a feasible way. The goal is to maximize the total volume of loaded boxes with the constraints. The two of the most common constraints are:

(1) Constraint 1 (C1)

Orientation constraint: For each box, the number of allowed orientation is restricted. For example, some boxes require that one side be always on top, such as the top side of a refrigerator must be always on top.

(2) Constraint 2 (C2)

Support constraint: To guarantee load stability, in a given packing plan the area of each box not placed on the floor of the container must be supported completely by other boxes.

Following the review paper by Bortfeld and Wascher(2013)[1], besides considering C1 and C2, Liu et al.(2017) [2]also takes the following three constraints into account:

(1) Constraint 3 (C3)

Guillotine cutting constraint: The length of a seam ("guillotine cut") running through the stack must not exceed a certain maximum percentage of the stack's maximum length or width.

(2) Constraint 4 (C4)

Complete-shipment constraint: If one item of a subset is loaded, all other items of that subset must also be loaded. Meanwhile, if one item cannot be loaded, no item of the subset will be loaded at all. For instance, many items that belong to a customer are required to be transported to a single place at the same time.

(3) Constraint 5 (C5)

Loading priority constraint: Since the available container space is not sufficient to accommodate all small items, it has to be decided which items have to be loaded first or be left behind.

It is observed in literature that the most of algorithms consider the C1 constraint in the study. Some of them further consider the C2 constraint. As far as we are concerned, only Liu et al.(2017)[2] takes all the C1-C5 as constraints.

The purpose of this paper is to reveal the correlation between filling rate and cargo type by analyzing the results coming from different algorithms, which consider different constraints.

3. Cases and algorithms used for analysis

Table 1 The list of the existing methods in literature

Approach	Source of Approach	Type of Method
B_HA	Bischoff et al. (1995)[5]	Heuristic Approach(HA)
BR_HA	Bischoff and Ratcliff(1995)[3]	HA
GB_GA	Gehring and Bortfeldt(1997)[6]	Genetic Algorithm(GA)
BG_TS	Bortfeldt and Gehring(1998)[7]	Tabu Search
BG_GA	Bortfeldt and Gehring(2001)[8]	GA
BG_PGA	Bortfeldt and Gehring(2002)[9]	Parallel GA
MO_GR	Moura and Oliveira(2005)[10]	GRASP
P_MSA(5000)	Parreño et al.(2007)[11]	Maximal-Space Algorithm(MSA)
P_MSA(200000)	Parreño et al.(2007)[11]	MSA
Z_HSA	Zhang et al.(2009)[12]	Hybrid Simulated Annealing
FB_TRS	Fanslau and Bortfeldt(2010)[13]	Tree Search(TRS)

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HH_BS	He and Huang(2010)[14]	Beam Search(BS)
P_VNS	Parreño et al.(2010)[15]	Variable Neighborhood Search
GR_PMGA	Gonçalves and Resende (2011)[16]	Parallel Multi-population GA
HH_FDA	He and Huang(2011)[17]	Fit Degree Approach
JM_PMRGA	Jose´and Mauricio(2012)[18]	Parallel Multi-population biased Random-key GA
ZL_GLTRS	Zhu and Lim(2012)[19]	Iterative-doubling Greedy-Lookahead TRS
ZLW_SEBA	Zhu, Lim and Weng(2012)[20]	Six Elements to Block-building Approaches
Z_HBMLS(S)	Zhang et al. (2012)[21]	Heuristic Block-loading Algorithm based on Multi-layer Search(HBMLS)
Z_HBMLS(C)	Zhang et al. (2012)[21]	HBMLS
Z_HBMLS(SC)	Zhang et al. (2012)[21]	HBMLS
Z_HBMLS(S_C2)	Zhang et al. (2012)[21]	HBMLS
Z_HBMLS(C_C2)	Zhang et al. (2012)[21]	HBMLS
Z_HBMLS(SC_C2)	Zhang et al. (2012)[21]	HBMLS
AR_BS	Araya and Riff(2014)[22]	BS
L-TRS	Liu et al.(2017)[2]	TRS
L-HA	Liu et al.(2017)[2]	HA

In this paper, we choose 16 classical experiment cases BR0-BR15 that are commonly employed in literature. BR1-BR7 are generated by Bischoff and Ratcliff [3], while BR0 and BR8-BR15 are generated by Davies and Bischoff [4]. Each set includes 100 instances. There are 1600 instances in total. The number of types in 16 sets ranges from 1 to 100. BR0 only contains one kind of box, which means purely homogeneous loading instances. BR1-BR7 consist of a few types of boxes per instance and belong to weak heterogeneous loading problems. While BR8-BR15 are strongly heterogeneous loading problems that consist of up to 100 types of boxes per instance. All sets impose a variety of restrictions on the possible orientations for individual boxes. These instances can be downloaded from OR-Library or http://59.77.16.8/Download.aspx#p4.

There are many algorithms being proposed to solve container loading problem. We extracted all the results in these 16 sets by different approaches from the papers collected. These approaches are listed in Table 1.Each of them is named after authors and method's acronym.

P_MSA(5000) and P_MSA(200000) come from the same paper and use the same algorithm. The only difference is the iteration number shown in the bracket. The HBMLS approach also comes from the same article, (S) denotes the algorithm using simple block and (C) denotes the algorithm using composite block. (SC) denotes the algorithm that combines simple block with composite block. (S_C2), S(C_C2) and (SC_C2) mean to think about constraint C2 too. Method L-TRS and Method L-HA consider different constraints though they are from one paper.

4. Data analysis

Tables 2-4 are filling rates (%) of the approaches in Table 1. All the data denote the average values for the 100 instances of each test case. Figure1-3 show the linear relationships between box type and filling rate of each approach.

Table 2 Filling Rate of B_HA to PSA(5000)

Class	Box type	Filling rate(%)							
		B_HA	BR_HA	GB_GA	BG_TS	BG_GA	BG_PGA	MO_GR	P_MSA(5000)

BR1	3	81.76	83.37	86.77	92.63	87.81	88.1	89.07	93.27
BR2	5	81.7	83.57	88.12	92.7	89.4	89.56	90.43	93.38
BR3	8	82.98	83.59	88.87	92.31	90.48	90.77	90.9	93.39
BR4	10	82.6	84.16	88.68	91.62	90.63	91.03	90.42	93.16
BR5	12	82.76	83.89	88.78	90.86	90.73	91.23	89.57	92.89
BR6	15	81.5	82.92	88.53	90.04	90.72	91.28	89.71	92.62
BR7	20	80.51	82.14	88.36	88.63	90.65	91.04	88.05	91.86
BR8	30	79.65	80.1	87.52	87.11	89.73	90.26	86.13	91.02
BR9	40	80.19	78.03	86.46	85.76	89.06	89.5	85.08	90.46
BR10	50	79.74	76.53	85.53	84.73	88.4	88.73	84.21	89.87
BR11	60	79.23	75.08	84.82	83.55	87.53	87.87	83.98	89.36
BR12	70	79.16	74.37	84.25	82.79	86.94	87.18	83.64	89.03
BR13	80	78.23	73.56	83.67	82.29	86.25	86.7	83.54	88.56
BR14	90	77.4	73.37	82.99	81.33	85.55	85.81	83.25	88.46
BR15	100	75.15	73.38	82.47	80.85	85.23	85.48	83.21	88.36
Mean 1-7(W)		81.97	83.38	88.30	91.26	90.06	90.43	89.73	92.94
Mean 8-15(S)		78.59	75.55	84.71	83.55	87.34	87.69	84.13	89.39
W-S		3.38	7.82	3.59	7.70	2.72	2.74	5.60	3.55
Box type of best value		8	10	8	5	12	15	8	8

Note: The best values appear in bold

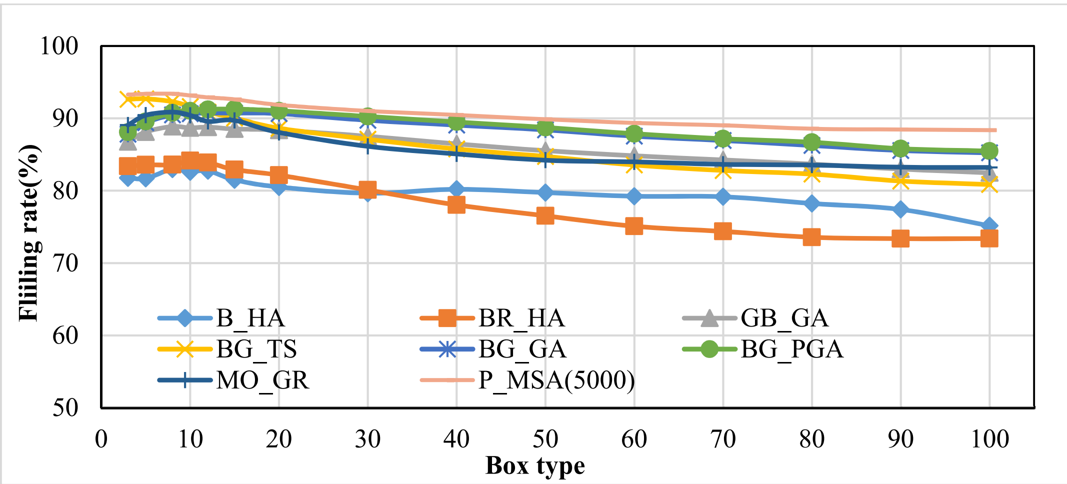

Figure1 Curve Graphs from Method B_HA to Method PSA(5000)

Table 3 Filling Rate of PSA(20000) to JM_PMRGA

Class	Box type	Filling rate(%)							
		P_MSA(20000)	Z_HSA	FB_TRS	HH_BS	P_VNS	GR_PMGA	HH_FDA	JM_PMRGA
BR1	3	93.85	93.81	94.51	87.54	94.9	95.28	92.92	94.34
BR2	5	94.22	93.94	94.73	89.12	95	95.9	93.93	94.88

BR3	8	94.25	93.86	94.74	90.32	95	96.1	93.71	95.05
BR4	10	94.09	93.57	94.41	90.57	94.7	96.01	93.68	94.75
BR5	12	93.87	93.22	94.13	90.78	94.3	95.84	93.73	94.58
BR6	15	93.52	92.72	93.85	90.91	94	95.72	93.63	94.39
BR7	20	92.94	91.99	93.2	90.88	93.5	95.29	93.14	93.74
BR8	30	91.02	90.56	92.26	90.85	92.8	94.76	92.92	92.65
BR9	40	90.46	89.7	91.48	90.64	92.2	94.34	92.49	91.9
BR10	50	89.87	89.06	90.86	90.43	91.9	93.86	92.24	91.28
BR11	60	89.36	88.18	90.11	90.23	91.5	93.6	91.91	90.39
BR12	70	89.03	87.73	89.51	89.97	91.2	93.22	91.83	89.81
BR13	80	88.56	86.97	88.98	89.88	91.1	92.99	91.56	89.27
BR14	90	88.46	86.16	88.26	89.67	90.6	92.68	91.3	88.57
BR15	100	88.36	85.44	87.57	89.54	90.4	92.46	91.02	87.96
Mean 1-7(W)		93.82	93.30	94.22	90.02	94.53	95.74	93.53	94.53
Mean 8-15(S)		89.39	87.98	89.88	90.15	91.46	93.49	91.91	90.23
W-S		4.43	5.33	4.35	-0.13	3.07	2.25	1.63	4.30
Box type of best value		8	5	8	15	5	8	5	8

Note: The best values appear in bold

From Table 2 and Table 3, one can see that the best value is distributed in a certain range of the box types between 5 and 15.This phenomenon can also be found in Figure1 and Figure2. Each curve reaches peak point when box type is less than 20 and then goes down gradually. Meanwhile, all approaches' mean filling rates of BR1-BR7 are far higher than BR8-BR15's, the biggest difference of W-S is 7.82, except for the approach HH_BS whose average filling rate of BR8-BR15 is slightly greater than BR1-BR7's. However, it gets its best value when box type is 15, indicating that in most of cases the volume utilization of weak heterogeneous CLP will be higher than strong heterogeneous CLP's.

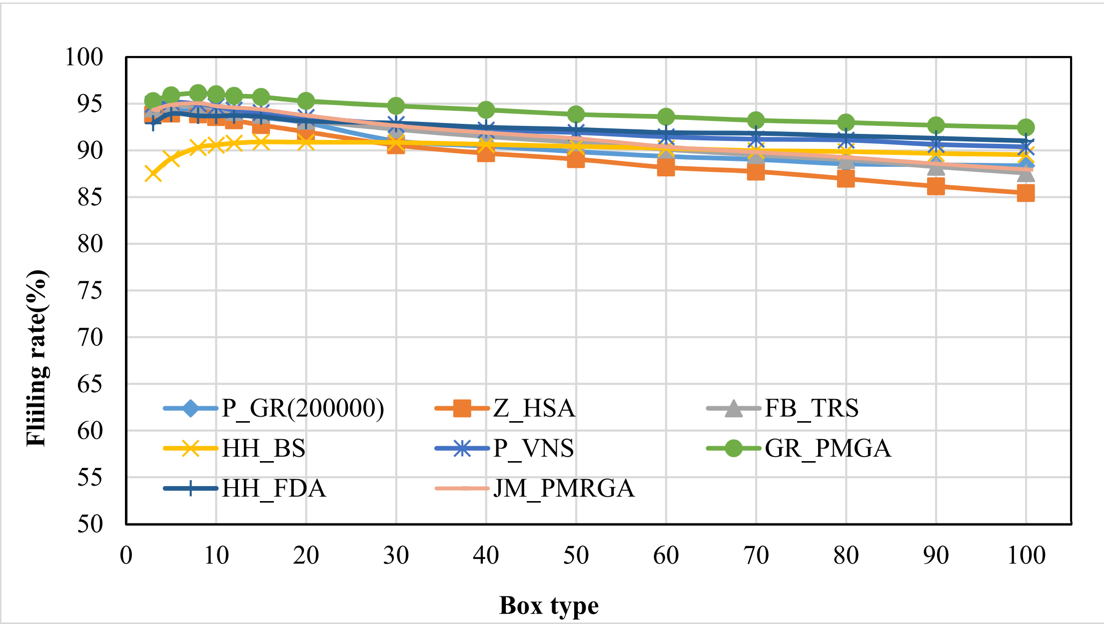

Figure2 Curve Graphs from Method PSA(20000) to Method JM_PMRGA

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Table 4 Filling Rate of ZL_GLTS to AR_BSA

Class	Box type	Filling rate(%)								
		ZL_GLTS	ZLW_SEB	Z_HBMLS(S)	Z_HBMLS(C)	Z_HBMLS(SC)	Z_HBMLS(S_C2)	Z_HBMLS(C_C2)	Z_HBMLS(SC_C2)	AR_BSA
BR0	1	90.79	90.8	89.9	89.77	89.95	89.76	89.69	89.81	90.97
BR1	3	95.59	95.54	94.87	93.54	94.92	94.3	93.95	94.43	95.69
BR2	5	96.13	95.98	95.41	94.47	95.48	94.74	94.39	94.87	96.24
BR3	8	96.3	96.08	95.6	95.12	95.69	94.89	94.67	95.06	96.49
BR4	10	96.15	95.94	95.38	95.1	95.53	94.69	94.54	94.89	96.31
BR5	12	95.98	95.74	95.22	95.08	95.44	94.53	94.41	94.68	96.18
BR6	15	95.81	95.61	95.1	95.21	95.38	94.32	94.25	94.53	96.05
BR7	20	95.36	95.14	94.6	94.87	95	93.78	93.69	93.96	95.77
BR8	30	94.8	94.63	94.16	94.6	94.66	92.88	93.13	93.27	95.33
BR9	40	94.53	94.29	93.76	94.24	94.3	92.07	92.54	92.6	95.07
BR10	50	94.35	94.05	93.38	94.08	94.11	91.28	92.02	92.05	94.97
BR11	60	94.14	93.78	92.87	93.86	93.87	90.48	91.45	91.46	94.8
BR12	70	94.1	93.67	92.59	93.67	93.67	89.65	90.91	90.91	94.64
BR13	80	93.86	93.54	92.25	93.45	93.45	88.75	90.43	90.43	94.59
BR14	90	93.83	93.36	91.84	93.34	93.34	87.81	89.8	89.8	94.49
BR15	100	93.78	93.32	91.53	93.14	93.14	86.94	89.24	89.24	94.37
Mean 1-7(W)		95.90	95.72	95.16	94.77	95.35	94.46	94.27	94.63	96.10
Mean 8-15(S)		94.17	93.83	92.80	93.80	93.82	89.98	91.19	91.22	94.78
W-S		1.73	1.89	2.37	0.97	1.53	4.48	3.08	3.41	1.32
Box type of best value		8	8	8	15	8	8	8	8	8

Note: The best values appear in bold

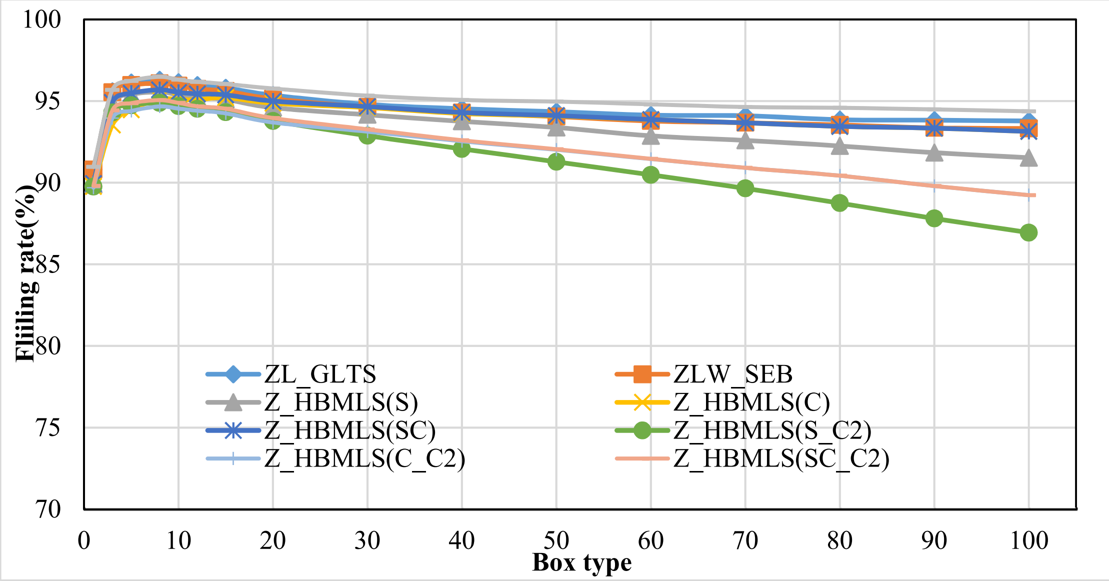

Figure 3 Curve Graphs from Method ZL_GLTS to Method AR_BSA

In Table 4, all the approaches have the value of set BR0 whose box type equals to 1. We can see from Table 4, the BR0's filling rate is much lower than BR1's, method Z_HBMLS(S_C2)'s is even smaller than its BR15's. Each algorithm gets its best value when box type equals to 8 except method Z_HBMLS(C), which reaches its peak point when the box type is 15. Similarly, the BR1-BR7's average filling rates largely outweigh the BR8-BR15's. Figure3 also demonstrates these characteristics. For instance, a dramatic growth could be noticed from BR0 to BR1, next to mild and short increase, then smooth decline. Thus, assuming that the quantity is sufficient, if there is only one type or too many types boxes (more than 30) to be loaded, the container volume utilization is not good, only in the case of a intermediate number of box types (greater than 3 and less than 20) can the container be better utilized or even reach the best filling rate irrespective of algorithms adopted. In a word, it is easy to get the higher volume utilization in weakly heterogeneous situations instead of strongly heterogeneous instances.

Some authors report computational results where the support constraint(C2) is not enforced, but approaches that enforces the support constraint(C2) still show the same characteristics, such as, Z_HBMLS(S_C2), Z_HBMLS(C_C2), Z_HBMLS(SC_C2) in table 4. In order to observe the characteristics incorporating other three constraints C3-C5 mentioned in section 2, let's take a look at the data (Table 5) cited from Liu et al.(2017)[2]. Approach L-TRS considers constraints C1, C2&C3.Algorithm L-HA takes constraints C1-C5 into account, and the items are grouped into orders which have different loading priorities. Specifically, we divide the sequence of orders in each case of BR1-BR15 into two subsets (named sub1 and sub2) according to 9 different ratios: 9:1, 8:2, . . . , 1:9. For each proportion, the orders in sub1 are expiring, while the orders in sub2 are non-expiring. All the data in Table 5 denotes the mean filling rate(%) for each case. As shown in Table 5, BR1-BR7 obtain better results than BR8-BR15, their mean differences are more than 3 except by method L-TRS which is 1. The number of box type obtaining best value ranges between 8, 10, and 12. As can be seen from Figure4, the curve of L-TRS goes up sharply and then goes down slowly, with only one place fluctuating slightly. All the curves of approach L-HA also show the same trend, but they are near and overlapped. In addition, the descent speed are gently greater and more places are fluctuated. However, all features are similar to those mentioned in the previous two paragraphs. As a result, no matter what constraints are consideration, weakly heterogeneous cases have better volume utilization than strongly heterogeneous instances, and the best filling rate always occurs not in the strongly heterogeneous situations, but in the weakly heterogeneous situations.

Now let us have a look at the mean of all the approaches and the number of cases which get the best value. Since some algorithms do not solve BR0, here we calculate the mean filling rates of BR1-BR15(Table 6) for the purpose of comparison. The difference between W and S is 3.24, telling that weak heterogeneous loading problems can acquire greater filling rates than strong heterogeneous loading problems. In weakly heterogeneous cases, BR3 has the highest chance to get the best value, which is 65.71% according to Figure6. Next are BR2, BR5 and BR6 respectively and BR4 is the last. In the approaches collected in this paper ,the number of BR7 gets the best value as zero and strongly heterogeneous cases are not mentioned.

Table 5 Filling Rate of L-TRS and L-HA

Class	Box type	Filling rate(%)									
		L-TRS	L-HA								
			9:1	8:2	7:3	6:4	5:5	4:6	3:7	2:8	1:9
BR1	3	90.62	87.96	87.44	87.48	87.19	87.3	87.72	87.8	87.75	87.64
BR2	5	91.51	88.18	87.97	87.46	87.53	87.57	87.62	87.76	87.47	87.99
BR3	8	92.43	88.75	88.16	88.33	88.22	88.34	88.19	88.25	88.44	88.52
BR4	10	92.35	88.61	88.02	88.0	87.97	87.98	88.13	88.45	88.21	88.4
BR5	12	92.45	88.57	88.18	88.11	87.92	88.17	87.89	88.35	88.27	88.03
BR6	15	92.37	88.18	87.85	87.91	87.59	87.56	87.77	88.02	87.47	87.63
BR7	20	92.13	88.04	87.5	87.15	87.48	87.61	87.22	87.44	87.37	87.11
BR8	30	91.95	87.1	86.56	86.6	86.19	86.55	86.46	86.61	86.35	86.54
BR9	40	91.64	86.44	86.08	85.68	85.8	86.0	85.93	85.54	86.02	85.9
BR10	50	91.42	85.84	85.28	84.92	84.79	85.4	84.8	85.34	84.83	84.72
BR11	60	91.14	85.37	84.83	84.95	84.76	84.85	84.47	84.21	84.75	84.43
BR12	70	90.98	84.91	84.06	84.1	84.0	84.03	84.57	83.97	84.12	83.89
BR13	80	90.60	84.28	83.88	83.61	83.88	83.63	83.98	83.77	84.14	83.75
BR14	90	90.27	83.95	83.34	83.23	83.75	83.37	83.49	83.53	83.45	83.14
BR15	100	89.84	83.9	83.21	83.09	82.97	83.25	82.94	83.43	83.41	83.29
Mean 1-7(W)		91.98	89.87	88.33	87.87	87.78	87.70	87.79	87.79	88.01	87.85
Mean 8-15(S)		90.98	87.63	85.22	84.66	84.52	84.52	84.64	84.58	84.55	84.63
W-S		1.00	3.10	3.22	3.25	3.18	3.16	3.21	3.46	3.22	3.45
Box type of best value		12	8	8	12	8	8	8	8	10	8

Note: The best values appear in bold

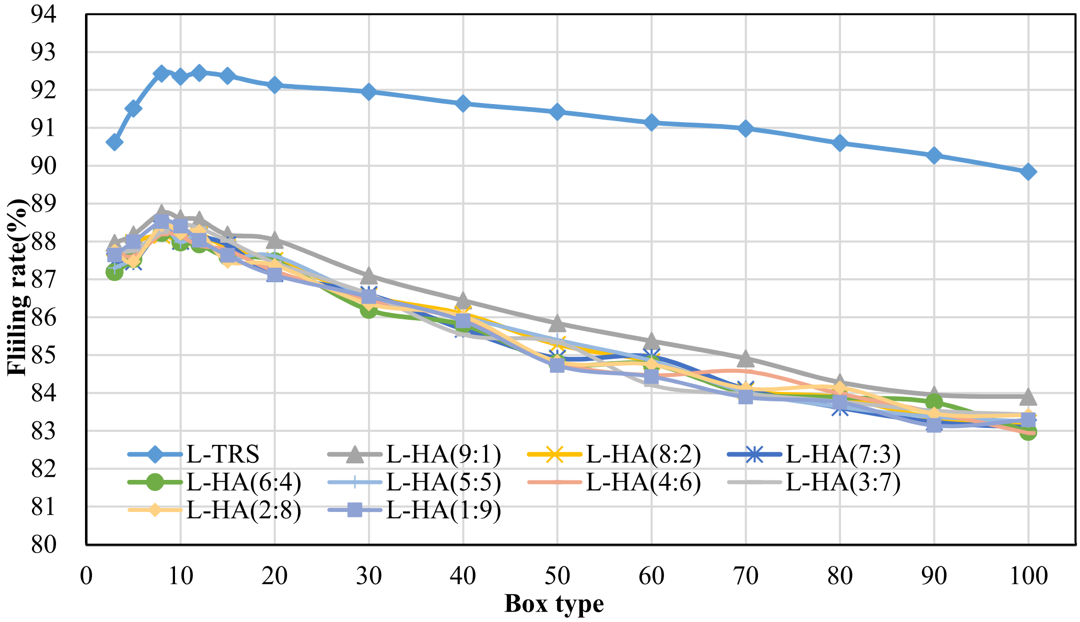

Figure 4 L-TRS's and L-HA's Curve Graph

Table 6 Mean Filling Rate of All Approaches

Class	Box type	Mean	No. of Best Value
BR1	3	90.91	0
BR2	5	91.42	4
BR3	8	91.82	23
BR4	10	91.68	2
BR5	12	91.55	3
BR6	15	91.28	3
BR7	20	90.78	0
BR8	30	89.93	0
BR9	40	89.32	0
BR10	50	88.71	0
BR11	60	88.2	0
BR12	70	87.77	0
BR13	80	87.38	0
BR14	90	86.94	0
BR15	100	86.6	0
Mean 1-7(W)		91.35	0
Mean 8-15(S)		88.11	0
W-S		3.24	0

Note: The best values appear in bold

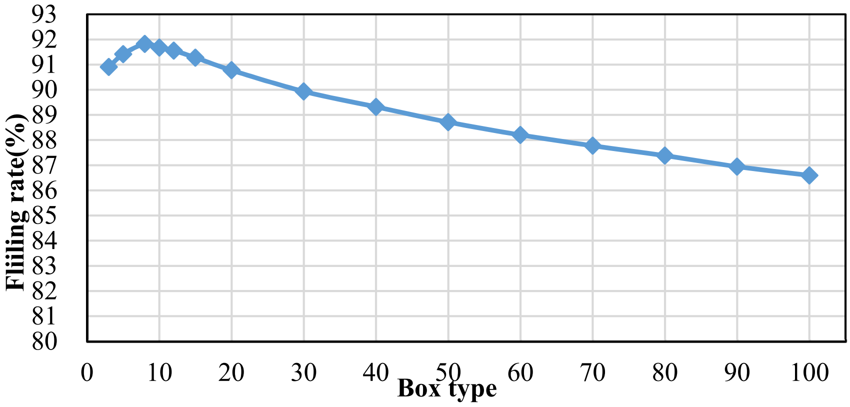

Figure 5 Curve graph of Mean Filling Rate of All Approaches

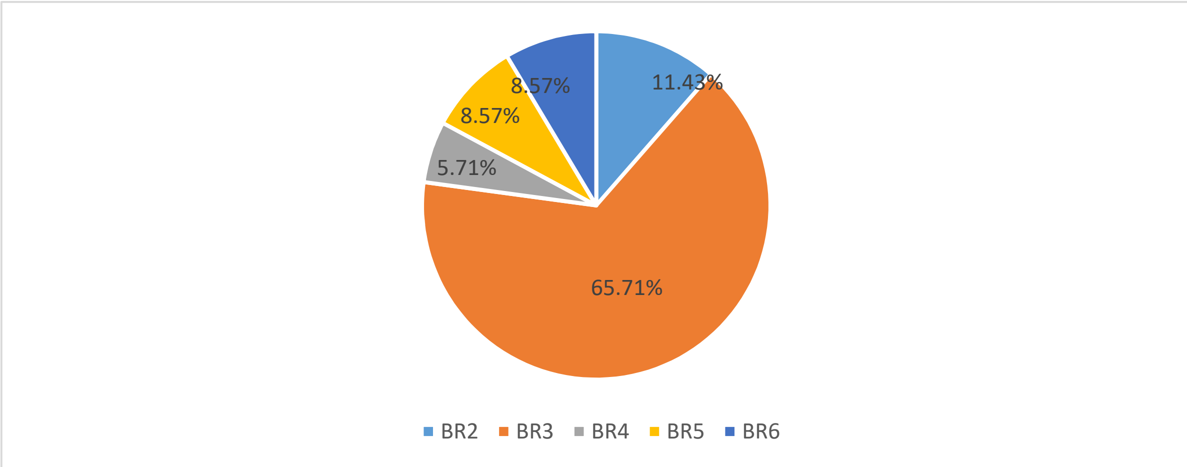

Figure 6 the Percentage of Cases Getting Best Value

5. Conclusions and future works

All in all, from the analysis of section 4, whichever algorithms and constraints taken according to existing literature, the mean filling rates of weakly heterogeneous cases are far bigger than strongly heterogeneous instances. Box type ranging from 5 to 15 has the opportunity to obtain the best filling rate, and has the maximum possibility when it equals to 8. Besides, the filling rate under purely homogeneous loading instances is also not better than weakly heterogeneous cases. So in practical loading operation, loading workers need wait for cargoes with different size, but not too many types. 5-15 types are the best loading time, which is also the best value fields. While, the results were just gotten by statistically and not been mathematically deduced, which might have defects and deficiencies, and the future work may lie in further mathematical deduction of the foundation drawn in this work. In addition to volume utilization, this paper just discusses volume utilization, it is necessary to consider weight capacity utilization in the future research.

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