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by The Jin Ai

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Combination of nearest neighbor and heuristics algorithms for sequential two dimensional loading capacitated vehicle routing problem

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Abstract. Vehicle Routing Problem (VRP) is a method for determining the optimal route of vehicles in order to serve customers starting from depot. Combination of the two most important problems in distribution logistics, which is called the two dimensional loading vehicle routing problem, is considered in this paper. This problem combines the loading of the freight into the vehicles and the successive routing of the vehicles along the route. Moreover, an additional feature of last-in-first-out loading sequencesis also considered. In the sequential two dimensional loading capacitated vehicle routing problem (sequential 2L-CVRP), the loading must be compatible with the trip sequence: when the vehicle arrives at a customer *i*, there must be no obstacle (items for other customers) between the item of *i* and the loading door (rear part) of the vehicle. In other words, it is not necessary to move *non-i*'s items whenever the unloading process of the items of *i*. According with aforementioned conditions, a program to solve sequential 2L-CVRP is required. A nearest neighbor algorithm for solving the routing problem is presented, in which the loading component of the problem is solved through a collection of 5 packing heuristics.

1. Introduction

Distribution is one of the logistic system components which has the responsibility to handle material movement among facilities. Even though, it is believe that the distribution process has a broader scope than just transportation of goods. Distribution is the factor that determine total profit of company because it affects the supply chain cost and direct customers satisfaction, simultaneously [1]. Survey said that distribution cost of American company is equal to 20% of cost of goods sold of a product [2]. So, distribution planning is one of the most important activities to make supply chain process more efficient. Scope of distribution problem consists of several aspects, such as route determination, facility location, and delivery capacity [3].

The vehicle routing problem (VRP) is one of the most frequently studied problems in distribution. It consists of finding an optimal set of trips for a fleet of vehicles which must serve a given set of customers. Several versions of the vehicle routing problem exist in the literature, in particular the capacitated VRP (CVRP). In this variant, customers with known demands are spread over an undirected network and must be visited using a fleet of identical vehicles with limited capacity [4]. CVRP has been solved with many methods, heuristics or metaheuristics in [5], [6], [7], [8], and [9]. Gendreau *et al*. [10] has developed Tabu search algorithm and Fuellerer *et al*. [11] used Ant Colony System (ACO) to solve CVRP problem. Exact method also used in [12], [13], and [14] which is able to solve this CVRP properly. Beside the problem settings defined in the CVRP, we should know that loading and unloading problem to-from container is a common setting in real distribution cases.

Two-dimensional bin packing problem (2BPP) is the term for defining a loading problem which seen the problem in two dimensions only. Exact algorithms and lower bounds was used by [15], [16], [17], [18], [19], [20], and [21] to solve the 2BPP. A lot of heuristics methods have also been used to solve this problem [22]. Beside that, metaheuristics method such as GRASP algorithm and tabusearch [23, 24], and also iterated local search method [25] have been used to solve the 2BPP.

This paper addresses the two-dimensional loading capacitated vehicle routing problem, which is denoted as 2L-CVRP [26, 27]. The 2L-CVRP is a variant of one of the most frequently studied combinatorial optimization problems, the capacitated vehicle routing problem (CVRP). If it is viewed from the loading type, there are two version of 2L-CVRP, unrestricted and sequential loading.

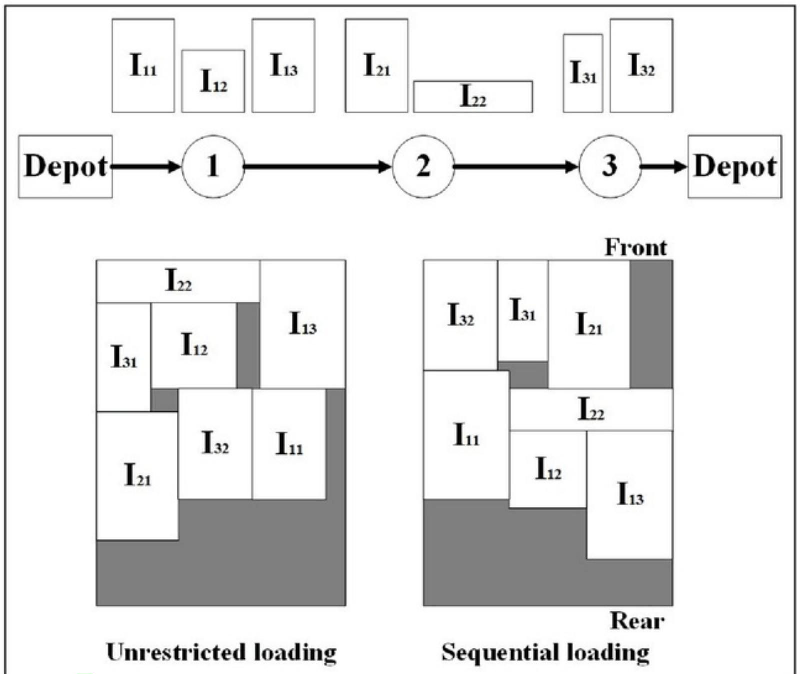

Figure 1. Example of a 2L-CVRP route with unrestricted and sequential loadings

Figure1 depicts that unrestricted version does not pay attention between items location in container and the order of customers that should be visited. This version is used for the vehicle which the container can be unloaded vertically using crane. Beside, sequential version have additional feature named last-in-first-out, in other words there is no need to move *non-i*'s items when unload the items of customer *i*. In this version, we need to pay attention in items arrangement inside the container, because it should be compatible with the order of customers that should be visited. Specifically, thie paper addresses the 2L-CVRP with sequential version of loading, named sequential 2L-CVRP.

The 2L-CVRP was first solved by an exact algorithm which used the branch-and-cut technique [28]. In the test dataset, their approach can deal with the instances with no more than 30 customers and 91 items. As for the larger scale problems, a metaheuristic approach was proposed by Gendreau et al. [29]. Precisely, the Tabu search was employed for routing aspects of the problem. Usually, the means of lower bounds, heuristics, local search and a truncated branch-and-bound were used to check the loading feasibility. 180 problem instances were tested in their work. The number of customers went up to 255 and the items up to 786. Recently, a new method, the guided Tabu search [30], which combines

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the Tabu search with guided local search, was presented. For checking the feasibility of loading, a collection of packing heuristics was used. To accelerate the algorithm, two strategies that reduced the neighborhoods explored, and record of the loading feasibility information, were employed. A nature inspired metaheuristic algorithm, an effective heuristic based on ant colony optimization, has been proposed by Fuellerer *et al*. [11]. The costs of four different loading configurations were compared in this work.

The importance of the 2L-CVRP is mainly reflected in two aspects. Theoretically, composed of two NP-hard optimization problems (CVRP and 2BPP), it is also a high complexity NP-hard problem. For practical applications, this problem may exist at many companies. An efficient method to solve this problem can significantly reduce costs for the companies.

2. Problem description

This paper considers the sequential version of the 2L-CVRP defined as follows:

- Like the VRP, the problem is based on a complete undirected graph with a set of n + 1 nodes. Node 0 is a depot while node 1 to n are customers. The edge $[i, j]$ between any two distinct nodes i and j models a shortest path of length $d_{ij} = d_{ji}$.
- The depot contains a virtually unlimited fleet of homogeneous vehicles with a capacity Q (maximum weight) and a rectangular loading surface of length L and width W. The loading surface is denoted as $A = WL$.
- A set D of m items must be delivered to customers. Item $t(t = 1, 2, \ldots, m)$ has a length $l_t \leq L$ and a width $w_t \leq W$. When loaded in a vehicle, its l-edge and w-edge must be respectively parallel to the vehicle L and W-edges, i.e., rotations are not allowed.
- D is partitioned into n subsets $D_1 \cup D_2 \cup \ldots \cup D_n$, where D is the subset of items requested by customer i, with a known total weight q_i.
- Each set D_i must be loaded into a single vehicle.
- Each customer must be visited by one, and only one vehicle, once.
- Every vehicle starts from, and ends at, the central depot.
- The weight of the items loaded in a vehicle must not exceed the capacity of the vehicle Q.
- All the items in a vehicle must be loaded in area A. Overlapping loading is not permitted.
- When a vehicle is visiting customer i, all of the items in the set of D_i can be unloaded from the vehicle by means of forklift trucks parallel to the length dimension of the vehicle surface, without moving other items required by other customers

The sequential 2L-CVRP objective is to determine a set of routes of minimal total length that satisfy the following constraints: (a) every route starts and ends at the central depot, (b) the demand of every customer is totally covered, (c) each customer is visited once, (d) the total weight of all items demanded by the set of customers covered by a route must not exceed the capacity of the vehicle Q, (e) there must be a non-overlapping loading of all items demanded by the set of customers covered by a route into the $L \times W$ loading surface of the vehicles and (f) the loading of the items must ensure that whenever a customer i is visited, all items in the set D_i can be unloaded by employing a sequence of straight movements (one per item) parallel to the length dimension of the vehicle surface. In other words, no item of customer j, visited after customer i, can be placed between items of customer i and the rear part (loading door) of the vehicle.

3. Proposed algorithm

The proposed algorithm for the solution of the 2L-CVRP employs nearest neighbor (NN) to solve route determination problem. Regarding loading constraints of the problem, the bundle of packing heuristics designed in Zachariadis *et al*. [7] are applied.

3.1. Route determination

Route-first-cluster-second concept is used in this research. The meaning of route-first concept is that the determination of the route made at the beginning, in which nearest neighbor method is applied here. After that, routes are cut to form cluster as the cluster-second concept whenever one of these following two constraints are violated: (1) if the weight of customers items exceed the container weight capacity (weight capacity constraint) and if (2) the item cannot be loaded into the same container (area capacity constraint). If one of these two constraints violation happened, a new container are needed and consequently a new route cluster is created.

We are proposing two technique to form route clusters, which are called regular cutting NN and skip cutting NN. In regular cutting NN, routes are cutting off if the next customer cannot fulfill one of the two constraints that has been explained above, which is the weight of customers items exceed the container weight capacity or the item that should be delivered to the customer is not enough anymore if loaded on the same container. In skip cutting NN, the route should be cutting off if two constraints feasibility from all customers have been checked. If in that checking process the customer can fulfill two constraints, so that customer's item can be loaded into the same container.

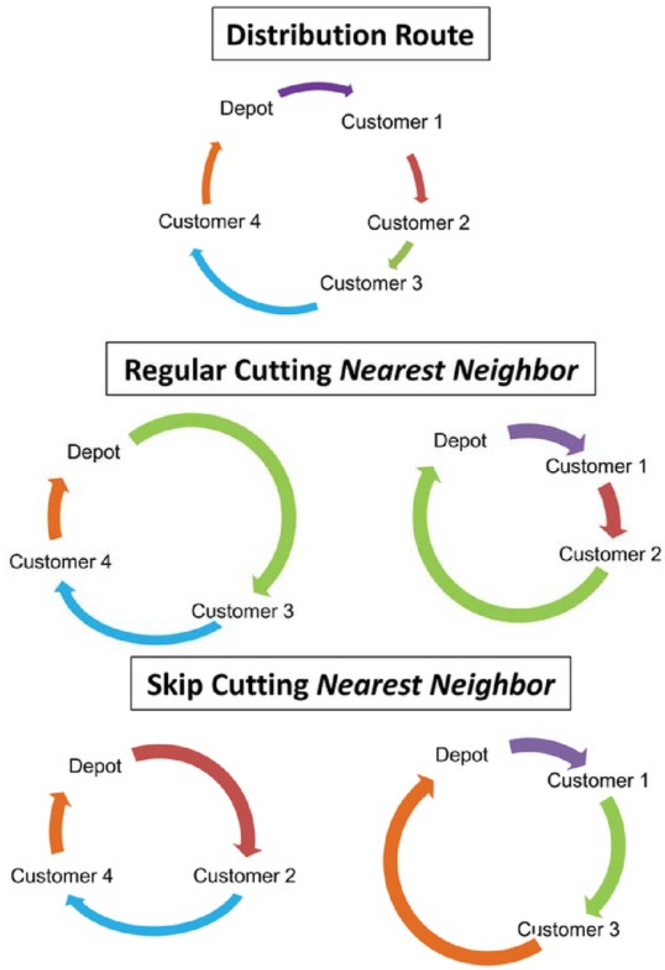

Figure 2. The difference between regular and skip cutting NN

The bottom part of figure 2 (skip cutting NN) illustrates that customer 2 cannot fulfill one of two existing loading constraints, but customer 3 can fulfill those two constraints and then the condition of

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customer 4 are same with customer 2. So, this condition affect the routes cutting process, customer 1 and 3 are loaded on the same container, while customer 2 and 4 are loaded on the different container. From figure 2 we can see that in skip cutting NN, all of customer are checked for its loading feasibility.

3.2. The bundle of packing heuristics

For loading items in the container, there are five heuristic methods used in this research which are combined with the two proposed route determination methods. These five heuristics are bottom-left fill (W axis), bottom-left fill (L axis), maximum touching perimeter, maximum touching perimeter (no walls), and minimum area. Every heuristic method have its own characteristics for determining the location of an item to be loaded into the container. Each customer have at least 1 item and not more than 5 item to be loaded. Order of each customers item that should be loaded are determined from area of the item which sorted from smallest area.

When new item loaded into the container, there will be a new *posList*. Let *posList* denote a list of available loading positions for the items. In the beginning, the only available loading position lies in the front left corner (0, 0) of the vehicle, so *posList* = {(0, 0)}. Whenever an item is inserted, its loading position is erased from the *posList*, while new loading positions are generated and added into the *posList*. In this way, the positions of holes that may be created between the placed items are stored into the *posList* and may be later filled by the subsequent items.

The position for the placement of an item is selected from the list of available positions *posList* and must not lead to any loading constraint violation (overlapping or sequential constraint). As later explained, it is determined by the packing heuristic currently employed. If all items are packed onto the loading surface, the route is considered to be feasible in terms of the loading constraints of the problem. If, on the other hand, the insertion of an item into any available position leads to loading constraint violations, the method empties the loading surface, *posList* is set equal to {(0, 0)}, and the next packing heuristic is employed from the beginning. If none of the five available packing heuristics manages to produce a feasible loading, the heuristic bundle is applied to the second ordering of the items. If again, no feasible loading is obtained, the examined route is considered to be infeasible regarding the loading constraints.

As mentioned earlier, the loading position of an inserted item is determined by the packing heuristic currently in use. This position must be feasible, i.e., it must not lead to any overlaps or sequence constraint violations. Each of the proposed five packing heuristics $Heur_i$(i =1...5) employs a different criterion for selecting the loading position of an item:

$Heur_1$: *Bottom-Left Fill (W-axis)* [31]

From the *feasible* available loading positions of *posList*, the position selected is the one with the minimum W-axis coordinate, breaking ties by minimum L-axis coordinate. Using this heuristic, the packing tends to evolve in the form of strips parallel to the L-axis.

$Heur_2$: *Bottom-Left Fill (L-axis)* [31]

From the *feasible* available loading positions of *posList*, the position selected is the one with the minimum L-axis coordinate, breaking ties by minimum W-axis coordinate. Using this heuristic, the packing tends to evolve in the form of strips parallel to the W-axis.

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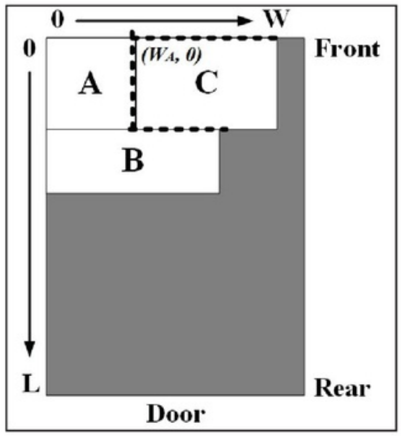

Figure 3. Calculating the perimeter for Maximum Touching Perimeter heuristic.

$Heur_3$: *Maximum Touching Perimeter* [32]

For each of the *feasible* available positions of *posList*, the total touching perimeter of the inserted item is calculated. The total touching perimeter is evaluated as the sum of the common edges of the inserted item with the edges of the already inserted items, and the edges of the loading surface of the vehicle as seen in figure 3: the total touching perimeter of item C placed in position $(w_A, 0)$ is demonstrated by the bold dotted lines, and is equal to $l_C + w_C + (w_B - w_A)$. Term l_C corresponds to the common edges of items C and A, term w_C corresponds to the common edges of item C and the loading surface, and term $(w_B - w_A)$ corresponds to the common edges of items C and B. The item is placed into the loading position that maximises the value of touching perimeter.

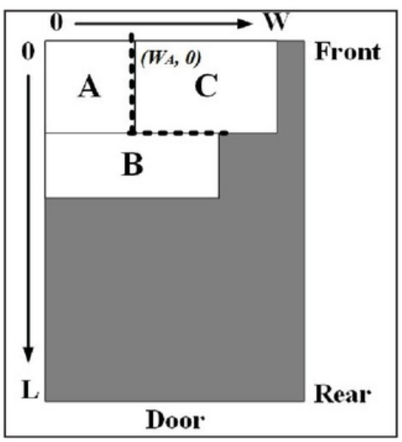

Figure 4. Calculating the perimeter for Maximum Touching Perimeter No Walls heuristic.

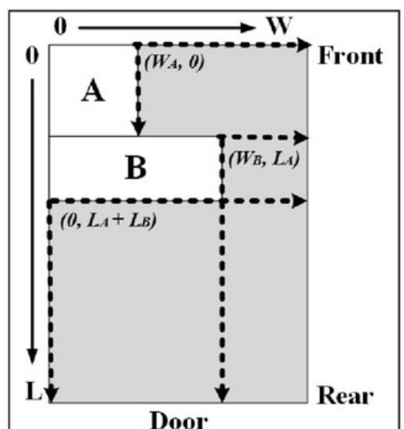

Figure 5. Calculating the rectangular areas of the loading positions.

$Heur_4$: *Maximum Touching Perimeter No Walls* [32]

As in the case of the Max Touching Perimeter heuristic, for each of the *feasible* available positions of *posList*, the total touching perimeter of the inserted item is calculated. In this case, the total touching perimeter is evaluated as the sum of the common edges of the inserted item with the edges of the already inserted items. The common edges of the item and the loading surface are not taken into account. The evaluation of the touching perimeter is presented in figure 4: the total touching perimeter of item C placed in position $(w_A, 0)$ is demonstrated by the bold dotted lines, and is equal to $l_C + (w_B - w_A)$. Term l_C corresponds to the common edges of items C and A and term $(w_B - w_A)$ corresponds to the common edges of items C and B. The item is placed into the loading position that maximises the value of touching perimeter.

$Heur_5$: *Minimum Area* [30]

For each of the *feasible* available positions of *posList*, the area of its corresponding rectangular surface is calculated, as demonstrated in figure 5. The area of the rectangular surface determined by the loading position $(w_A, 0)$ equal to $(W - w_A) \times l_A$, the area corresponding to loading position (w_B, l_A) is equal to $(W - w_B) \times (L - l_A)$, and the area of the surface corresponding to position $(0, l_A + l_B)$ is equal to $W \times (L - l_A - l_B)$. The loading position selected is the one yielding the minimum surface area.

4. Computational results

4.1. Benchmark instances characteristics

All algorithms were implemented and tested on benchmark instances from the literature. In order to verify the performance of the proposed algorithm, the proposed algorithm was tested by 180 sequential 2L-CVRP benchmark problem instances that was used in [26], [28], [29], and [30]. The datasets are available at http://www.or.deis.unibo.it/research.html. These instances were derived from 36 CVRP instances, whose the description can be found in [33], by expressing the customer demand as a set of two-dimensional, weighted and rectangular items. To generate the aforementioned item sets, five classes of the item demand characteristics are introduced

```
Instance: E016-03m.dat
Class:  3
   15 --- number of customers (no depot)
    3 --- number of vehicles
   31 --- number of items
Capacity - height - width of vehicles
    90     40     20
Node - x - y - demand
     0    30.0    40.0     0.0
     1    37.0    52.0     7.0
     2    49.0    49.0    30.0
     3    52.0    64.0    16.0
     4    20.0    26.0     9.0
     5    40.0    30.0    21.0
     6    21.0    47.0    15.0
     7    17.0    63.0    19.0
     8    31.0    62.0    23.0
     9    52.0    33.0    11.0
    10    51.0    21.0     5.0
    11    42.0    41.0    19.0
    12    31.0    32.0    29.0
    13     5.0    25.0    23.0
    14    12.0    42.0    21.0
    15    36.0    16.0    10.0
Node - number of items - h - w for each item
     0   0
     1   2    4   11   13    6
     2   2    9    5    5   15
     3   2   13    8   26    2
     4   1   10    5
     5   2   13    7   31    2
     6   2   12    8    6   11
     7   1    5   10
     8   3    9    7    7    8   12    3
     9   2   22    2    7   13
    10   3   11    5    6   12   29    2
    11   3    9    6   15    8   10    5
    12   1   13    3
    13   3   17    3   14    5    5    9
    14   1    6    9
    15   3    7    6    8    5   16    7
```

Figure 6. Data set contents

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- Class 1: with each customer is associated a single item of width and length equal to nil. The problems of Class 1 are in fact pure CVRP instances, as every customer sequence is feasible in terms of the loading constraints of the problem examined. They are used to test the algorithmic effectiveness in terms of the routing aspects of the problem examined.
- Classes 2–5: with each customer i, a set of m_i is uniformly distributed within a given range (see table 1, column 2). Each item is classified into one of the three shape categories, with equal probability. The three categories are *vertical* (the relative lengths are greater than the relative widths), *homogeneous* (the relative lengths and widths are generated in the same intervals), and *horizontal* (the relative lengths are smaller than the relative widths). The dimensions (width and length) of an item are uniformly distributed into the ranges determined by this item's shape category (see table 1, column 3-8).

Table 1. The characteristics of items of classes 2-5 instances

		Vertical		Homogenous		Horizontal	
Class	m_i	Length	Width	Length	Width	Length	Width
2	[1, 2]	[0.4L, 0.9L]	[0.1W, 0.2W]	[0.2L, 0.5L]	[0.2W, 0.5W]	[0.1L, 0.2L]	[0.4W, 0.9W]
3	[1, 3]	[0.3L, 0.8L]	[0.1W, 0.2W]	[0.2L, 0.4L]	[0.2W, 0.4W]	[0.1L, 0.2L]	[0.3W, 0.8W]
4	[1, 4]	[0.2L, 0.7L]	[0.1W, 0.2W]	[0.1L, 0.4L]	[0.1W, 0.4W]	[0.1L, 0.2L]	[0.2W, 0.7W]
5	[1, 5]	[0.1L, 0.6L]	[0.1W, 0.2W]	[0.1L, 0.3L]	[0.1W, 0.3W]	[0.1L, 0.2L]	[0.1W, 0.6W]

Table 2. The characteristics of classes of 2-5 instances

		Number of items of classes 2-5						Number of items of classes 2-5			
Inst	n	2	3	4	5	Inst	n	2	3	4	5
1	15	24	31	37	45	19	50	82	103	134	157
2	15	25	31	40	48	20	71	104	151	178	226
3	20	29	46	44	49	21	75	114	164	168	202
4	20	32	43	50	62	22	75	112	154	198	236
5	21	31	37	41	57	23	75	112	155	179	225
6	21	33	40	57	56	24	75	124	152	195	215
7	22	32	41	51	55	25	100	157	212	254	311
8	22	29	42	48	52	26	100	147	198	247	310
9	25	40	61	63	91	27	100	152	211	245	320
10	29	43	49	72	86	28	120	183	242	299	384
11	29	43	62	74	91	29	134	197	262	342	422
12	30	50	56	82	101	30	150	225	298	366	433
13	32	44	56	78	102	31	199	307	402	513	602
14	32	47	57	65	87	32	199	299	404	497	589
15	32	48	59	84	114	33	199	301	407	499	577
16	35	56	74	93	114	34	240	370	490	604	720
17	40	60	73	96	127	35	252	367	507	634	762
18	44	66	87	112	122	36	255	387	511	606	786

n number of customer

The values $L = 40$ and $W = 20$ were chosen for the dimensions of the loading area. The numbers of customers and items, in the instances for Classes 2–5, are shown in table 2. For details of the datasets, the reader is referred to Gendreau et al. [7] and Zachariadis et al. [8]. As the aforementioned characteristics of data set, each data set contains number of customers, number of items, vehicle's capacity, length & width of container, depot coordinate, customers coordinate, number of items/customer, and length & width of each items that different with the other data set, as we can see in figure 6.

Figure 6 shows that on that data set, there are 15 customers to be served and total items from those customers are 31 item. To know the location for each vertices (depot and customers), X and Y coordinate are used on the data set, for example, depot are in (30,40) position, customer 1 are in (37,52) position, et cetera. Customer 1 have 2 items that should be delivered which each item have length and width 4×11 and 13×6, respectively, with total weight for those two item are 7. Total weight capacity for the container are 90 with container area is 40×20.

4.2. Results on benchmark instances

There are ten algorithms combination for this research, first five algorithms combination are the combination between general cutting NN and five loading heuristics, while last five algorithms combination are the combination between skip cutting NN and five loading heuristics. From all combination of algorithms, the best algorithm combination will be found in accordance with the performance measurements that has been stated. There are 3 performance measurement that will be used to find the best algorithm combination: K (the number of vehicles needed), D (total vehicle's mileage), and U (containers utility). Good performance are indicated from those three performance measurements value, the smaller K and D value, the better performance are achieved, same as the bigger U value will achieve the better performance.

4.2.1. Loading heuristic methods comparison. Main program which is the combination between nearest neighbor and five loading heuristic algorithms can be used to solve sequential 2L-CVRP problem properly. Summary of data test results for algorithm combination between regular cutting NN and five loading heuristics can be ssen on table 3. SUM row indicated as the total of all results from performance measurements for each methods from 180 data. While AVERAGE row indicated as the average of all results from performance measurements for each methods from 180 data.

Table 3. Data test results summary for algorithm combination between regular cutting NN and five loading heuristics

		Regular Cutting NN				
		Heuristic 1	**Heuristic 2**	**Heuristic 3**	**Heuristic 4**	**Heuristic 5**
SUM	**K**	4352	3954	**3860**	3995	4316
	D	374742	352806	**347892**	354842	372566
	U	68,2	76,04	**77,84**	75,44	69,75
AVERAGE	**K**	24,18	21,97	**21,44**	22,19	23,98
	D	2082	1960	**1933**	1971	2070
	U	38%	42%	**43%**	42%	39%

Table 3 shows that from five algorithm combination between regular cutting NN and five loading heuristics, heuristic 3 (maximum touching perimeter) have the best solution from the other heuristics. Because of that, to prove that these heuristic methods is the best method, five loading heuristics are also combined with skip cutting NN algorithm that can be seen in table 4 which produce the same result as before.

Table 4. Data test results summary for algorithm combination between skip cutting NN and five loading heuristics

		Skip Cutting NN				
		Heuristic 1	**Heuristic 2**	**Heuristic 3**	**Heuristic 4**	**Heuristic 5**
SUM	**K**	3420	3055	**3030**	3077	3348
	D	434026	416526	**410276**	414222	430344
	U	85,12	95,79	**97,08**	96,03	86,95
AVERAGE	**K**	19	16,97	**16,83**	17,09	18,6
	D	2411	2314	**2279**	2301	2391
	U	47%	53%	**54%**	53%	48%

Table 4 shows that from five algorithm combination between skip cutting NN and five loading heuristics, heuristic 3 (maximum touching perimeter) have the best solution from the other heuristics. Maximum touching perimeter are said as the best loading heuristics because have the smallest value of *K* (the number of vehicles needed) and *D* (total vehicle's mileage), and have the biggest value of *U* (containers utility).

4.2.2. Route determination methods comparison. There are two route determination methods, namely regular and skip cutting NN. The comparison between these two methods are summarized in table 5. For each methods of nearest neighbor, averaging five loading results are done for doing this comparison.

Table 5. Data test results summary for route determination methods

		Regular Cutting NN	Skip Cutting NN
SUM	**K**	4095	**3186**
	D	**360569.6**	421078.8
	U	73.45	**92.19**
AVERAGE	**K**	22.75	**17.7**
	D	**2003**	2339
	U	0.408	**0.512**

If viewed from the value of *K* (the number of vehicles needed) and *U* (containers utility), skip cutting NN has the better performance than regular cutting NN. But, if viewed from the value of *D* (total vehicle's mileage), regular cutting NN has the better performance than skip cutting NN.

4.2.3. Algorithms combination comparison. From comparisons above, loading heuristics have been compared at each NN, regular and skip cutting NN. Because of that, last comparison is needed, which is will compare all algorithms combination that used to solve sequential 2L-CVRP problem in this research. The comparison results between those ten algorithms combination for each performance measurement, *K* (the number of vehicles needed), *D* (total vehicle's mileage), and *U* (containers utility), can be seen in table 6.

Table 6 shows that if viewed from performance measurement *K* (the number of vehicles needed) and *U* (containers utility), then combination of algorithm between skip cutting nearest neighbor and maximum touching perimeter have a better performance from the others. Whereas, if viewed from performance measurement *D* (total vehicle's mileage), then combination of algorithm between regular-cutting nearest neighbor and maximum touching perimeter have a better performance from the others.

Table 6. Data test results summary for sequential 2L-CVRP

		Regular Cutting NN					Skip Cutting NN				
		Heuristic 1	Heuristic 2	Heuristic 3	Heuristic 4	Heuristic 5	Heuristic 1	Heuristic 2	Heuristic 3	Heuristic 4	Heuristic 5
SUM	K	4352	3954	3860	3995	4316	3420	3055	**3030**	3077	3348
	D	374742	352806	**347892**	354842	372566	434026	416526	410276	414222	430344
	U	68.20	76.04	77.84	75.44	69.75	85.12	95.79	**97.08**	96.03	86.95
AVERAGE	K	24.18	21.97	21.44	22.19	23.98	19.00	16.97	**16.83**	17.09	18.60
	D	2082	1960	**1933**	1971	2070	2411	2314	2279	2301	2391
	U	38%	42%	43%	42%	39%	47%	53%	**54%**	53%	48%

Comparison results from those combination of algorithms depicts that the less container is needed will affect the bigger container utility. Beside, for performance measurement *K* and *U*, skip cutting NN method have a better performance because all customers are checked, so, the container can be used more optimal than regular cutting NN method which directly cut off the route if one of two loading constraints are not fulfilled. Otherwise, for performance measurement *D*, regular cutting NN method have a better performance because this method directly do the cut off if one of two loading constraints are not fulfilled.

5. Conclusions

In this paper, we study a generalisation of the VRP, in which the demand of customers consists of weighted, two-dimensional, rectangular items. This problem is called sequential two dimensional loading constraints capacitated vehicle routing problem (sequential 2L-CVRP) and have three performance measurements to choose the best combination of algorithms that used to test the instances. The 2L-CVRP is of particular theoretical interest as it combines two frequently studied combinatorial optimisation problems, namely the Vehicle Routing Problem, and the two-dimensional bin packing problem. Although 2L-CVRP has several real-life applications in the field of transportation logistics.

Regarding the packing features of the problem examined, our algorithm makes use of a bundle of packing heuristics, producing diverse packing structures in order to increase the probability of obtaining a feasible loading. Those bundle of packing heuristics consist of Bottom Left Fill, Maximum Touching Perimeter, and Minimum area heuristics. The routing aspects of the problem are handled by a Nearest Neighbor method that divided into two cluster, namely regular and skip cutting nearest neighbor.

The conclusion for this research is that from 10 combination algorithms, if viewed from performance measurement *K* (the number of vehicles needed) and *U* (containers utility), then combination of algorithm between skip cutting nearest neighbor and maximum touching perimeter have a better performance from the others. Whereas, if viewed from performance measurement *D* (total vehicle's mileage), then combination of algorithm between regular-cutting nearest neighbor and maximum touching perimeter have a better performance from the other method.

References

[1] Chopra S and Meindl P 2007 *Supply Chain Management Strategy, Planning, and Operation, 3rd edition* (New Jersey: Prentice Hall)

[2] Miltenburg J 2005 *Manufacturing Strategy : How to Formulate and Implement a Winning Plan, 2nd edition* (Oregon: Productivity Press)

[3] Pujawan I N and Mahendrawati E R 2010 *Supply Chain Management*, *edisi 2* (Surabaya: Guna Widya)

[4] Miao L, Ruan Q, Woghiren K and Ruo Q 2012 A hybrid genetic algorithm for the vehicle routing problem with three-dimensional loading constraints *RAIRO-Operations Research* **46(01)** 63-82

[5] Leung S C, Zheng J, Zhang D and Zhou X 2010 Simulated annealing for the vehicle routing problem with two-dimensional loading constraints *Flexible services and manufacturing journal* **22(1-2)** 61-82

[6] Laporte G and Semet F 2001 Classical heuristics for the capacitated VRP *The vehicle routing problem - Society for Industrial and Applied Mathematics* 109-128

[7] Gendreau M, Laporte G and Potvin J Y 2001 Metaheuristics for the capacitated VRP *The vehicle routing problem - Society for Industrial and Applied Mathematics* 129-154

[8] Cordeau J F, Gendreau M, Laporte G, Potvin J Y and Semet F 2002 A guide to vehicle routing heuristics *Journal of the Operational Research society* 512-522

[9] Cordeau J F, Gendreau M, Hertz A, Laporte G and Sormany J S 2005 New heuristics for the vehicle routing problem *Logistics systems: design and optimization - Springer US* 279-297

[10] Gendreau M, Iori M, Laporte G and Martello S 2006 A tabu search algorithm for a routing and container loading problem *Transportation Science* **40(3)** 342-350

[11] Fuellerer G, Doerner K F, Hartl R F and Iori M 2009 Ant colony optimization for the two-dimensional loading vehicle routing problem *Computers and Operations Research* **36(3)** 655-673

[12] Toth P and Vigo D 2001 Branch-and-bound algorithms for the capacitated VRP *The vehicle routing problem - Society for Industrial and Applied Mathematics* 29-51

[13] Fukasawa R, Longo H, Lysgaard J, Aragão M P D, Reis M, Uchoa E and Werneck R F 2006 Robust branch-and-cut-and-price for the capacitated vehicle routing problem *Mathematical programming* **106(3)** 491-511

[14] Baldacci R, Christofides N and Mingozzi A 2008 An exact algorithm for the vehicle routing problem based on the set partitioning formulation with additional cuts *Mathematical Programming* **115(2)** 351-385

[15] Martello S and Vigo D 1998 Exact solution of the two-dimensional finite bin packing problem *Management science* **44(3)** 388-399

[16] Fekete S P and Schepers J 2001 New classes of fast lower bounds for bin packing problems *Mathematical programming* **91(1)** 11-31

[17] Fekete S P and Schepers J 2004 A general framework for bounds for higher-dimensional orthogonal packing problems *Mathematical Methods of Operations Research* **60(2)** 311-329

[18] Fekete S P, Schepers J and Van der Veen J C 2007 An exact algorithm for higher-dimensional orthogonal packing *Operations Research* **55(3)** 569-587

[19] Boschetti M A and Mingozzi A 2003a The two-dimensional finite bin packing problem. Part I: New lower bounds for the oriented case *Quarterly Journal of the Belgian, French and Italian Operations Research Societies* **1(1)** 27-42

[20] Boschetti M A and Mingozzi A 2003b The two-dimensional finite bin packing problem. Part II: New lower and upper bounds *Quarterly Journal of the Belgian, French and Italian Operations Research Societies* **1(2)** 135-147

[21] Pisinger D and Sigurd M 2007 Using decomposition techniques and constraint programming for solving the two-dimensional bin-packing problem *INFORMS Journal on Computing* **19(1)** 36-51

[22] Lodi A, Martello S and Vigo D 1999 Heuristic and metaheuristic approaches for a class of two-dimensional bin packing problems *INFORMS Journal on Computing* **11(4)** 345-357
[23] Alvarez-Valdes R, Parreño F and Tamarit J M 2005 A GRASP algorithm for constrained two-dimensional non-guillotine cutting problems *Journal of the Operational Research Society* **56(4)** 414-425
[24] Alvarez-Valdés R, Parreño F and Tamarit J M 2007 A tabu search algorithm for a two-dimensional non-guillotine cutting problem *European Journal of Operational Research* **183(3)** 1167-1182
[25] Khebbache S, Prins C and Yalaoui A 2008 Iterated local search algorithm for the constrained two-dimensional non-guillotine cutting problem *Journal of Industrial and Systems Engineering* **2(3)** 164-179
[26] Iori M 2004 *Metaheuristic algorithms for combinatorial optimization problems* PhD thesis DEIS (University of Bologna)
[27] Iori M 2005 Metaheuristic algorithms for combinatorial optimization problems *4OR* **3(2)** 163-166
[28] Iori M, Salazar-González J J and Vigo D 2007 An exact approach for the vehicle routing problem with two-dimensional loading constraints *Transportation Science* **41(2)** 253-264
[29] Gendreau M, Iori M, Laporte G and Martello S 2008 A Tabu search heuristic for the vehicle routing problem with two-dimensional loading constraints *Networks* **51(1)** 4-18
[30] Zachariadis E E, Tarantilis C D and Kiranoudis C T 2009 A guided tabu search for the vehicle routing problem with two-dimensional loading constraints *European Journal of Operational Research* **195(3)** 729-743
[31] Chazelle B 1983 The bottomn-left bin-packing heuristic: An efficient implementation *Computers, IEEE Transactions on* **100(8)** 697-707
[32] Lodi A, Martello S and Vigo D 1999 Heuristic and metaheuristic approaches for a class of two-dimensional bin packing problems *INFORMS Journal on Computing* **11(4)** 345-357
[33] Toth P and Vigo D 2002 The vehicle routing problem. Monographs on discrete mathematics and applications SIAM (Philadelphia)

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Appendix

Table A1
Results obtained for the regular cutting nearest neighbor

Instance	Class	Kontainer 1			Kontainer 2			Kontainer 3			Kontainer 4			Kontainer 5		
		K	D	U	K	D	U	K	D	U	K	D	U	K	D	U
	1	4	432	0%	4	432	0%	4	432	0%	4	432	0%	4	432	0%
	2	5	498	47%	5	462	47%	5	480	47%	5	492	47%	5	444	47%
	3	5	468	49%	5	492	49%	5	470	49%	5	464	49%	5	460	49%
	4	6	500	47%	5	446	56%	6	472	47%	5	446	56%	6	520	47%
1	5	0	0	0%	0	0	0%	0	0	0%	0	0	0%	0	0	0%
	1	6	494	0%	6	494	0%	6	494	0%	6	494	0%	6	494	0%
	2	6	500	44%	5	480	52%	6	506	44%	5	480	52%	6	484	44%
	3	7	540	42%	6	496	49%	7	540	42%	6	502	49%	6	490	49%
	4	6	442	44%	5	416	53%	5	416	53%	5	416	53%	5	444	53%
2	5	5	456	39%	4	444	49%	3	374	65%	4	424	49%	3	400	65%
	1	5	584	1%	5	584	1%	5	584	1%	5	584	1%	5	584	1%
	2	8	676	43%	7	650	49%	7	618	49%	7	650	49%	7	636	49%
	3	9	730	43%	7	650	55%	7	650	55%	7	616	55%	8	736	48%
	4	7	584	44%	7	638	44%	7	638	44%	7	622	44%	8	644	39%
3	5	6	570	45%	5	566	54%	5	552	54%	5	566	54%	6	580	45%
	1	7	626	0%	7	626	0%	7	626	0%	7	626	0%	7	626	0%
	2	8	698	43%	6	586	58%	6	590	58%	6	586	58%	7	624	49%
	3	8	690	44%	6	578	58%	6	562	58%	7	620	50%	8	714	44%
	4	10	742	38%	9	702	42%	9	718	42%	9	704	42%	9	714	42%
4	5	8	666	35%	7	664	40%	8	666	35%	7	664	40%	7	664	40%
	1	5	640	1%	5	640	1%	5	640	1%	5	640	1%	5	640	1%
	2	6	620	48%	6	680	48%	5	642	58%	6	650	48%	6	692	48%
	3	6	672	50%	5	698	60%	5	664	60%	5	628	60%	5	652	60%
	4	7	800	43%	5	618	61%	5	670	61%	6	698	50%	5	652	61%
5	5	8	820	33%	5	608	53%	5	614	53%	6	680	44%	6	660	44%
	1	7	678	0%	7	678	0%	7	678	0%	7	678	0%	7	678	0%
	2	8	798	40%	8	810	40%	8	794	40%	8	810	40%	8	798	40%
	3	6	672	63%	8	764	47%	7	712	54%	7	706	54%	10	890	38%
	4	9	832	48%	8	754	54%	8	808	54%	8	754	54%	8	728	54%
6	5	6	670	46%	5	588	56%	5	546	56%	5	590	56%	5	572	56%
	1	4	1030	1%	4	1030	1%	4	1030	1%	4	1030	1%	4	1030	1%
	2	7	1376	51%	7	1418	51%	7	1376	51%	7	1418	51%	7	1376	51%
	3	7	1354	47%	6	1216	55%	6	1264	55%	6	1250	55%	6	1294	55%
	4	8	1418	42%	7	1222	48%	7	1214	48%	9	1340	37%	7	1200	48%
7	5	7	1248	42%	5	1144	58%	5	1132	58%	5	1082	58%	6	1254	49%

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Table A1 continued

Instance	Class	Kontainer 1			Kontainer 2			Kontainer 3			Kontainer 4			Kontainer 5		
		K	D	U	K	D	U	K	D	U	K	D	U	K	D	U
	1	4	1030	1%	4	1030	1%	4	1030	1%	4	1030	1%	4	1030	1%
	2	7	1236	45%	6	1298	52%	7	1380	45%	6	1170	52%	6	1164	52%
	3	7	1370	50%	7	1372	50%	7	1372	50%	7	1372	50%	7	1372	50%
	4	6	1128	57%	7	1368	49%	6	1224	57%	7	1334	49%	7	1364	49%
8	5	5	1108	45%	4	1096	56%	4	1086	56%	3	964	75%	4	1046	56%
	1	9	886	0%	9	886	0%	9	886	0%	9	886	0%	9	886	0%
	2	10	874	45%	9	882	50%	10	874	45%	9	882	50%	9	882	50%
	3	10	976	49%	11	966	44%	10	940	49%	10	960	49%	12	1086	41%
	4	9	826	53%	9	888	53%	7	748	69%	9	868	53%	9	926	53%
9	5	9	936	47%	8	880	53%	7	800	61%	8	838	53%	8	856	53%
	1	4	792	1%	4	792	1%	4	792	1%	4	792	1%	4	792	1%
	2	10	1470	44%	8	1316	55%	8	1254	55%	8	1240	55%	10	1464	44%
	3	8	1172	49%	7	1078	56%	7	1166	56%	7	1092	56%	8	1222	49%
	4	10	1438	51%	10	1548	51%	11	1544	46%	10	1466	51%	10	1518	51%
10	5	9	1348	49%	8	1294	55%	7	1168	63%	8	1260	55%	8	1254	55%
	1	4	792	1%	4	792	1%	4	792	1%	4	792	1%	4	792	1%
	2	9	1390	51%	8	1208	57%	7	1168	66%	8	1240	57%	9	1400	51%
	3	11	1418	47%	12	1532	43%	10	1416	52%	11	1520	47%	13	1598	40%
	4	12	1640	48%	12	1580	48%	11	1594	53%	12	1700	48%	12	1570	48%
11	5	9	1296	49%	8	1166	55%	8	1196	55%	8	1156	55%	9	1262	49%
	1	10	874	0%	10	874	0%	10	874	0%	10	874	0%	10	874	0%
	2	11	900	51%	9	840	62%	10	872	56%	9	840	62%	11	900	51%
	3	9	794	52%	8	798	58%	8	784	58%	9	796	52%	9	798	52%
	4	14	1026	42%	12	946	49%	11	948	54%	13	980	45%	11	920	54%
12	5	12	966	44%	9	836	58%	9	850	58%	10	914	52%	12	944	44%
	1	3	3166	1%	3	3166	1%	3	3166	1%	3	3166	1%	3	3166	1%
	2	10	4832	48%	9	4546	54%	10	4646	48%	9	4526	54%	10	4488	48%
	3	9	4566	53%	9	4560	53%	9	4700	53%	9	4620	53%	9	4732	53%
	4	12	5134	45%	10	5398	54%	9	4726	60%	9	4740	60%	9	4680	60%
13	5	9	4940	52%	7	4390	67%	7	4224	67%	8	4548	59%	9	4678	52%
	1	5	1214	1%	5	1214	1%	5	1214	1%	5	1214	1%	5	1214	1%
	2	9	2028	51%	9	2074	51%	9	1998	51%	9	1978	51%	9	2086	51%
	3	9	2052	51%	9	1974	51%	9	1944	51%	11	2262	42%	11	2286	42%
	4	10	2140	43%	8	1874	53%	7	1700	61%	7	1746	61%	9	2110	47%
14	5	7	1594	56%	6	1480	65%	6	1488	65%	7	1660	56%	7	1668	56%

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Table A1 continued

Inst ance	Class	Kontainer 1			Kontainer 2			Kontainer 3			Kontainer 4			Kontainer 5		
		K	D	U	K	D	U	K	D	U	K	D	U	K	D	U
	1	5	1214	1%	5	1214	1%	5	1214	1%	5	1214	1%	5	1214	1%
	2	9	2062	50%	8	1768	57%	9	2022	50%	8	1866	57%	11	2332	41%
	3	12	2570	42%	9	2016	56%	10	2234	50%	9	2090	56%	11	2364	46%
	4	11	2264	52%	10	2120	57%	10	2068	57%	10	2172	57%	12	2532	48%
15	5	11	2374	52%	11	2178	52%	10	2118	57%	11	2220	52%	10	2198	57%
	1	13	1030	0%	13	1030	0%	13	1030	0%	13	1030	0%	13	1030	0%
	2	15	1128	41%	16	1168	38%	15	1148	41%	16	1194	38%	16	1168	38%
	3	16	1186	39%	15	1134	42%	16	1166	39%	15	1134	42%	16	1166	39%
	4	15	1120	47%	15	1136	47%	16	1198	44%	16	1190	44%	18	1308	39%
16	5	13	1032	41%	13	1030	41%	13	1030	41%	13	1030	41%	13	1030	41%
	1	16	1216	0%	16	1216	0%	16	1216	0%	16	1216	0%	16	1216	0%
	2	18	1310	36%	18	1302	36%	18	1310	36%	17	1262	38%	20	1374	32%
	3	17	1252	34%	16	1216	37%	16	1206	37%	16	1216	37%	17	1266	34%
	4	18	1336	40%	16	1216	45%	16	1216	45%	16	1216	45%	19	1390	38%
17	5	17	1280	33%	16	1216	35%	16	1240	35%	16	1240	35%	16	1210	35%
	1	5	1484	1%	5	1484	1%	5	1484	1%	5	1484	1%	5	1484	1%
	2	14	2034	46%	12	1836	54%	13	1838	50%	12	1822	54%	14	1996	46%
	3	16	2056	47%	14	2044	54%	14	2042	54%	13	1986	58%	17	2302	44%
	4	17	2374	46%	14	2042	55%	14	2010	55%	15	2032	52%	15	2112	52%
18	5	12	1886	49%	10	1734	58%	8	1434	73%	10	1748	58%	11	1906	53%
	1	6	1020	1%	6	1020	1%	6	1020	1%	6	1020	1%	6	1020	1%
	2	18	1522	47%	17	1438	50%	17	1462	50%	16	1432	53%	19	1552	45%
	3	18	1528	50%	15	1356	61%	16	1506	57%	16	1404	57%	19	1560	48%
	4	19	1544	50%	20	1662	47%	19	1606	50%	19	1612	50%	19	1570	50%
19	5	16	1448	46%	13	1306	56%	13	1268	56%	13	1310	56%	13	1308	56%
	1	5	390	2%	5	390	2%	5	390	2%	5	390	2%	5	390	2%
	2	22	1034	54%	22	1020	54%	22	1020	54%	24	1104	49%	24	1088	49%
	3	24	1022	52%	23	1002	54%	22	954	57%	24	992	52%	25	1098	50%
	4	24	1038	54%	26	1120	50%	21	956	62%	24	1066	54%	26	1140	50%
20	5	22	970	50%	19	886	58%	18	868	61%	17	822	65%	20	948	55%
	1	7	1070	1%	7	1070	1%	7	1070	1%	7	1070	1%	7	1070	1%
	2	26	2168	45%	24	2110	49%	24	2042	49%	23	2060	51%	27	2180	44%
	3	29	2336	48%	27	2348	51%	26	2342	53%	28	2392	50%	27	2244	51%
	4	25	2096	48%	23	1998	52%	21	1808	57%	22	1988	54%	25	2132	48%
21	5	22	1914	47%	18	1704	57%	18	1726	57%	19	1772	54%	19	1752	54%

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Table A1 continued

Instance	Class	Kontainer 1			Kontainer 2			Kontainer 3			Kontainer 4			Kontainer 5		
		K	D	U	K	D	U	K	D	U	K	D	U	K	D	U
	1	8	1184	1%	8	1184	1%	8	1184	1%	8	1184	1%	8	1184	1%
	2	26	2142	47%	22	1930	56%	23	1974	53%	21	1832	59%	25	1964	49%
	3	26	2082	50%	26	2148	50%	23	2012	57%	23	2024	57%	30	2332	43%
	4	31	2376	45%	25	2018	56%	26	2082	54%	27	2122	52%	28	2274	50%
22	5	23	2130	49%	19	1750	59%	19	1770	59%	18	1738	63%	22	1940	51%
	1	11	1294	1%	11	1294	1%	11	1294	1%	11	1294	1%	11	1294	1%
	2	26	2188	46%	26	2274	46%	24	2088	50%	25	2178	48%	27	2308	44%
	3	25	2168	53%	24	2068	55%	24	2050	55%	23	2048	58%	27	2210	49%
	4	27	2228	49%	25	2138	53%	25	2088	53%	24	2132	56%	28	2156	48%
23	5	23	1928	50%	22	1864	52%	20	1792	57%	21	1882	55%	25	2036	46%
	1	16	1658	1%	16	1658	1%	16	1658	1%	16	1658	1%	16	1658	1%
	2	26	2196	53%	26	2184	53%	27	2194	51%	27	2216	51%	27	2204	51%
	3	28	2198	47%	24	2042	54%	24	2052	54%	24	2042	54%	30	2372	44%
	4	31	2468	45%	24	2006	58%	24	2082	58%	26	2140	54%	30	2366	46%
24	5	22	1948	51%	19	1808	59%	18	1816	62%	20	1878	56%	22	1984	51%
	1	8	1478	2%	8	1478	2%	8	1478	2%	8	1478	2%	8	1478	2%
	2	35	2894	50%	34	2820	51%	34	2798	51%	35	2888	50%	38	3030	46%
	3	39	2944	46%	37	3028	48%	32	2700	56%	37	2952	48%	38	2962	47%
	4	37	3022	49%	36	3038	51%	31	2710	59%	36	2990	51%	38	3126	48%
25	5	29	2572	49%	25	2354	57%	24	2256	60%	27	2462	53%	28	2448	51%
	1	10	1362	1%	10	1362	1%	10	1362	1%	10	1362	1%	10	1362	1%
	2	34	2784	47%	29	2574	55%	32	2800	50%	30	2684	53%	33	2704	48%
	3	33	2942	50%	28	2564	59%	28	2582	59%	28	2512	59%	33	2880	50%
	4	34	2868	51%	33	2858	53%	32	2914	55%	32	2710	55%	38	3222	46%
26	5	30	2540	50%	26	2368	58%	22	2058	68%	24	2192	62%	29	2572	52%
	1	15	1830	1%	15	1830	1%	15	1830	1%	15	1830	1%	15	1830	1%
	2	35	2790	46%	32	2668	50%	31	2624	52%	34	2718	47%	37	2940	43%
	3	40	2974	45%	35	2798	51%	34	2734	53%	36	2786	50%	42	3146	43%
	4	34	2748	50%	34	2742	50%	29	2524	59%	31	2590	55%	36	2866	47%
27	5	31	2782	50%	27	2462	58%	26	2384	60%	28	2490	56%	32	2790	49%
	1	8	1700	2%	8	1700	2%	8	1700	2%	8	1700	2%	8	1700	2%
	2	34	5114	56%	34	5096	56%	33	5084	58%	36	5404	53%	38	5494	50%
	3	45	6082	46%	41	5580	51%	38	5290	55%	39	5542	53%	43	6098	48%
	4	42	5694	50%	40	5510	52%	38	5422	55%	42	5630	50%	41	5668	51%
28	5	40	6070	45%	30	4678	60%	29	4668	62%	32	4988	57%	33	5000	55%

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Table A1 continued

Inst ance	Class	Kontainer 1			Kontainer 2			Kontainer 3			Kontainer 4			Kontainer 5		
		K	D	U	K	D	U	K	D	U	K	D	U	K	D	U
	1	8	1972	2%	8	1972	2%	8	1972	2%	8	1972	2%	8	1972	2%
	2	39	4366	52%	36	4210	57%	38	4294	54%	38	4272	54%	38	4376	54%
	3	47	4650	46%	39	4280	55%	40	4292	54%	41	4470	52%	43	4388	50%
	4	47	4732	51%	42	4580	57%	44	4858	54%	44	4410	54%	51	5194	47%
29	5	46	4794	45%	33	3918	63%	34	4130	61%	36	4100	58%	38	4224	55%
	1	12	1730	2%	12	1730	2%	12	1730	2%	12	1730	2%	12	1730	2%
	2	48	3782	50%	47	3812	51%	45	3674	54%	45	3632	54%	50	3888	48%
	3	53	4126	49%	52	4110	50%	49	3828	53%	49	3864	53%	53	4064	49%
	4	51	4052	51%	49	3826	53%	45	3624	57%	50	3908	52%	52	4102	50%
30	5	41	3422	51%	34	3014	62%	33	3024	64%	35	3134	60%	40	3334	52%
	1	17	2072	1%	17	2072	1%	17	2072	1%	17	2072	1%	17	2072	1%
	2	67	4930	48%	58	4296	55%	61	4652	53%	58	4394	55%	67	4984	48%
	3	69	4940	49%	63	4764	54%	62	4626	55%	65	4826	52%	71	5146	48%
	4	70	5194	52%	68	4998	53%	63	4744	57%	67	4904	54%	75	5468	48%
31	5	61	4638	48%	50	3988	59%	52	4312	56%	49	4042	60%	55	4364	53%
	1	17	2072	1%	17	2072	1%	17	2072	1%	17	2072	1%	17	2072	1%
	2	68	4984	47%	63	4690	51%	61	4718	53%	65	4782	49%	66	4788	49%
	3	65	4916	51%	61	4612	54%	59	4504	56%	64	4800	52%	64	4820	52%
	4	68	5060	50%	63	4650	53%	62	4686	54%	64	4800	53%	72	5258	47%
32	5	57	4492	50%	48	3958	59%	44	3740	65%	49	4026	58%	53	4222	54%
	1	17	2112	1%	17	2112	1%	17	2112	1%	17	2112	1%	17	2112	1%
	2	64	4944	49%	62	4606	51%	61	4530	52%	65	4896	49%	67	5010	47%
	3	71	5228	49%	63	4746	55%	62	4696	56%	64	4824	54%	69	5182	50%
	4	75	5470	47%	68	5018	52%	62	4638	57%	68	5034	52%	70	5214	51%
33	5	58	4480	50%	48	3922	61%	46	3772	63%	47	3868	62%	56	4330	52%
	1	23	1074	1%	23	1074	1%	23	1074	1%	23	1074	1%	23	1074	1%
	2	82	2542	48%	73	2302	54%	75	2388	52%	76	2456	52%	81	2458	48%
	3	87	2742	48%	77	2428	54%	74	2366	57%	81	2590	52%	86	2668	49%
	4	86	2626	50%	80	2448	54%	77	2390	56%	81	2504	53%	84	2560	51%
34	5	76	2384	48%	64	2060	57%	62	2010	58%	65	2084	56%	70	2176	52%
	1	27	1128	1%	27	1128	1%	27	1128	1%	27	1128	1%	27	1128	1%
	2	79	2908	49%	73	2700	53%	74	2748	52%	75	2776	51%	84	3042	46%
	3	95	3362	45%	78	2876	54%	75	2738	57%	80	2900	53%	91	3204	47%
	4	91	3418	49%	86	3190	52%	80	2990	56%	90	3326	50%	96	3472	47%
35	5	73	2742	51%	63	2424	59%	63	2430	59%	61	2400	61%	68	2614	54%

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Table A1 continued

Inst ance	Class	Kontainer 1			Kontainer 2			Kontainer 3			Kontainer 4			Kontainer 5		
		K	D	U	K	D	U	K	D	U	K	D	U	K	D	U
	1	14	918	2%	14	918	2%	14	918	2%	14	918	2%	14	918	2%
	2	87	3954	47%	79	3612	51%	79	3562	51%	79	3658	51%	86	3874	47%
	3	89	3976	49%	82	3770	53%	80	3598	55%	81	3704	54%	87	3928	50%
	4	86	3744	49%	78	3428	54%	72	3228	59%	78	3494	54%	88	3828	48%
36	5	78	3504	49%	63	2872	60%	64	2972	59%	67	3046	56%	71	3226	53%

Table A2
Results obtained for the skip cutting nearest neighbor

Inst ance	Class	Kontainer 1			Kontainer 2			Kontainer 3			Kontainer 4			Kontainer 5		
		K	D	U	K	D	U	K	D	U	K	D	U	K	D	U
	1	3	472	1%	3	472	1%	3	472	1%	3	472	1%	3	472	1%
	2	4	488	59%	4	550	59%	4	506	59%	3	506	78%	4	516	59%
	3	5	532	49%	4	500	61%	4	526	61%	4	474	61%	4	526	61%
	4	5	588	56%	5	596	56%	4	562	70%	4	576	70%	6	592	47%
1	5	0	0	0%	0	0	0%	0	0	0%	0	0	0%	0	0	0%
	1	5	504	0%	5	504	0%	5	504	0%	5	504	0%	5	504	0%
	2	5	590	52%	4	480	65%	5	590	52%	4	480	65%	5	592	52%
	3	6	544	49%	5	638	59%	5	574	59%	5	592	59%	6	520	49%
	4	5	584	53%	4	574	66%	5	588	53%	4	574	66%	5	536	53%
2	5	4	458	49%	3	424	65%	3	428	65%	3	448	65%	4	442	49%
	1	4	540	1%	4	540	1%	4	540	1%	4	540	1%	4	540	1%
	2	6	684	57%	6	708	57%	6	654	57%	6	718	57%	6	722	57%
	3	7	776	55%	6	672	64%	6	652	64%	6	670	64%	6	678	64%
	4	5	676	62%	5	722	62%	5	720	62%	5	766	62%	6	770	52%
3	5	5	738	54%	4	672	68%	4	558	68%	4	624	68%	5	714	54%
	1	6	654	0%	6	654	0%	6	654	0%	6	654	0%	6	654	0%
	2	6	680	58%	6	716	58%	6	670	58%	6	660	58%	5	702	69%
	3	7	770	50%	6	676	58%	5	650	70%	6	630	58%	7	714	50%
	4	10	810	38%	9	766	42%	7	676	54%	9	770	42%	9	752	42%
4	5	8	666	35%	7	664	40%	8	666	35%	7	664	40%	7	664	40%
	1	4	688	1%	4	688	1%	4	688	1%	4	688	1%	4	688	1%
	2	5	742	58%	5	876	58%	4	862	72%	5	782	58%	6	774	48%
	3	5	744	60%	5	760	60%	4	714	75%	5	752	60%	5	728	60%
	4	5	888	61%	5	740	61%	5	764	61%	4	742	76%	5	912	61%
5	5	6	732	44%	5	672	53%	5	614	53%	5	636	53%	6	702	44%

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Table A2 continued

Inst		Kontainer 1			Kontainer 2			Kontainer 3			Kontainer 4			Kontainer 5		
ance	Class	K	D	U	K	D	U	K	D	U	K	D	U	K	D	U
	1	6	750	0%	6	750	0%	6	750	0%	6	750	0%	6	750	0%
	2	8	752	40%	8	826	40%	8	842	40%	8	826	40%	8	808	40%
	3	6	864	63%	6	918	63%	7	898	54%	6	888	63%	7	888	54%
	4	7	790	61%	7	938	61%	7	926	61%	7	870	61%	7	938	61%
6	5	6	726	46%	5	856	56%	4	544	70%	4	726	70%	5	778	56%
	1	3	994	1%	3	994	1%	3	994	1%	3	994	1%	3	994	1%
	2	6	1630	59%	6	1642	59%	5	1606	71%	5	1594	71%	6	1642	59%
	3	6	1396	55%	5	1378	66%	5	1488	66%	5	1338	66%	6	1610	55%
	4	6	1442	56%	6	1296	56%	5	1326	67%	6	1404	56%	6	1502	56%
7	5	5	1402	58%	4	1296	73%	4	1306	73%	5	1276	58%	5	1224	58%
	1	3	994	1%	3	994	1%	3	994	1%	3	994	1%	3	994	1%
	2	5	1400	63%	5	1400	63%	4	1376	79%	5	1400	63%	5	1360	63%
	3	6	1254	59%	6	1402	59%	6	1532	59%	6	1120	59%	7	1446	50%
	4	6	1350	57%	5	1344	68%	5	1400	68%	5	1384	68%	6	1590	57%
8	5	4	1288	56%	4	1288	56%	4	1266	56%	3	1092	75%	4	1148	56%
	1	8	1020	0%	8	1020	0%	8	1020	0%	8	1020	0%	8	1020	0%
	2	8	1024	57%	8	1076	57%	8	1038	57%	8	1144	57%	8	1126	57%
	3	9	1126	54%	8	1140	61%	8	1098	61%	8	1122	61%	9	1070	54%
	4	7	1162	69%	7	1078	69%	7	1050	69%	7	1032	69%	8	1180	60%
9	5	8	1114	53%	6	972	71%	6	1038	71%	6	900	71%	6	1042	71%
	1	3	748	1%	3	748	1%	3	748	1%	3	748	1%	3	748	1%
	2	9	1688	49%	7	1486	63%	7	1486	63%	7	1390	63%	8	1596	55%
	3	7	1252	56%	7	1266	56%	6	1400	66%	6	1426	66%	7	1454	56%
	4	8	1684	64%	8	1596	64%	7	1498	73%	8	1612	64%	8	1680	64%
10	5	9	1590	49%	6	1328	73%	6	1146	73%	6	1394	73%	7	1666	63%
	1	3	748	1%	3	748	1%	3	748	1%	3	748	1%	3	748	1%
	2	7	1556	66%	7	1444	66%	6	1294	77%	7	1438	66%	8	1468	57%
	3	9	1562	58%	9	1862	58%	8	1562	65%	9	1772	58%	9	1604	58%
	4	10	1622	58%	9	1744	64%	9	1710	64%	9	1476	64%	10	1626	58%
11	5	8	1610	55%	7	1416	63%	7	1382	63%	7	1440	63%	7	1628	63%
	1	10	1122	0%	10	1122	0%	10	1122	0%	10	1122	0%	10	1122	0%
	2	10	1006	56%	8	1066	70%	9	898	62%	8	980	70%	10	1016	56%
	3	8	990	58%	7	1040	66%	7	984	66%	7	962	66%	8	982	58%
	4	10	1184	59%	9	1058	66%	10	1086	59%	10	1150	59%	10	1034	59%
12	5	9	1074	58%	8	1016	66%	8	1160	66%	8	1030	66%	9	1046	58%

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Table A2 continued

Inst ance	Class	Kontainer 1			Kontainer 2			Kontainer 3			Kontainer 4			Kontainer 5		
		K	**D**	**U**	**K**	**D**	**U**	**K**	**D**	**U**	**K**	**D**	**U**	**K**	**D**	**U**
	1	3	4106	1%	3	4106	1%	3	4106	1%	3	4106	1%	3	4106	1%
	2	8	6752	61%	8	6774	61%	7	6306	69%	7	5772	69%	9	6494	54%
	3	8	4706	59%	7	5814	68%	7	5576	68%	7	5324	68%	8	5570	59%
	4	9	5698	60%	9	6118	60%	8	6332	67%	8	5750	67%	8	5798	67%
13	**5**	8	5880	59%	7	6038	67%	7	6180	67%	7	6088	67%	8	5674	59%
	1	4	1242	1%	4	1242	1%	4	1242	1%	4	1242	1%	4	1242	1%
	2	8	1920	57%	7	1802	65%	7	1918	65%	7	2058	65%	7	2014	65%
	3	8	2354	57%	7	2080	65%	7	1972	65%	7	1892	65%	8	2220	57%
	4	7	2040	61%	6	1852	71%	6	1758	71%	6	1882	71%	8	2154	53%
14	**5**	7	1898	56%	6	1736	65%	6	1624	65%	6	1726	65%	6	1770	65%
	1	4	1242	1%	4	1242	1%	4	1242	1%	4	1242	1%	4	1242	1%
	2	8	2156	57%	6	1908	76%	7	1822	65%	6	1704	76%	8	2014	57%
	3	9	2514	56%	7	2086	72%	7	1984	72%	7	1988	72%	8	2078	63%
	4	10	2328	57%	9	2174	64%	9	2104	64%	9	2258	64%	10	2412	57%
15	**5**	9	2192	64%	8	2262	72%	9	2254	64%	8	2156	72%	9	2118	64%
	1	12	1182	0%	12	1182	0%	12	1182	0%	12	1182	0%	12	1182	0%
	2	13	1068	47%	14	1156	44%	14	1224	44%	13	1106	47%	14	1146	44%
	3	14	1092	45%	13	1050	48%	14	1082	45%	14	1112	45%	15	1154	42%
	4	15	1120	47%	14	1152	50%	15	1160	47%	14	1132	50%	16	1224	44%
16	**5**	13	1044	41%	12	1160	44%	12	1172	44%	12	1138	44%	13	1206	41%
	1	14	1346	0%	14	1346	0%	14	1346	0%	14	1346	0%	14	1346	0%
	2	17	1350	38%	15	1356	43%	17	1390	38%	16	1344	40%	17	1280	38%
	3	15	1258	39%	15	1352	39%	15	1414	39%	15	1398	39%	16	1362	37%
	4	18	1464	40%	15	1286	48%	15	1280	48%	16	1350	45%	18	1470	40%
17	**5**	15	1286	37%	15	1350	37%	14	1298	40%	15	1350	37%	14	1298	40%
	1	4	1728	1%	4	1728	1%	4	1728	1%	4	1728	1%	4	1728	1%
	2	11	2184	59%	10	2388	64%	10	2202	64%	11	2190	59%	11	2184	59%
	3	12	2868	63%	11	2476	68%	11	2480	68%	11	2366	68%	12	2724	63%
	4	13	2400	60%	12	2476	64%	11	2384	70%	12	2614	64%	13	2618	60%
18	**5**	9	2194	65%	8	2156	73%	8	1882	73%	9	2396	65%	8	2110	73%
	1	5	902	1%	5	902	1%	5	902	1%	5	902	1%	5	902	1%
	2	13	1602	65%	13	1570	65%	13	1768	65%	14	1664	61%	14	1704	61%
	3	16	1860	57%	13	1656	70%	13	1558	70%	13	1628	70%	15	1680	61%
	4	16	2090	59%	14	1754	67%	13	1790	73%	14	2088	67%	15	2004	63%
19	5	13	1750	56%	10	1438	73%	11	1700	66%	10	1442	73%	11	1622	66%

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Table A2 continued

Inst		Kontainer 1			Kontainer 2			Kontainer 3			Kontainer 4			Kontainer 5		
ance	**Class**	**K**	**D**	**U**	**K**	**D**	**U**	**K**	**D**	**U**	**K**	**D**	**U**	**K**	**D**	**U**
	1	4	528	2%	4	528	2%	4	528	2%	4	528	2%	4	528	2%
	2	17	1252	69%	17	1178	69%	17	1152	69%	17	1276	69%	17	1186	69%
	3	20	1522	63%	17	1274	74%	17	1294	74%	17	1332	74%	19	1386	66%
	4	20	1260	65%	18	1246	72%	18	1310	72%	20	1374	65%	20	1348	65%
20	**5**	18	1206	61%	15	1110	73%	15	1050	73%	15	1140	73%	19	1182	58%
	1	7	1350	1%	7	1350	1%	7	1350	1%	7	1350	1%	7	1350	1%
	2	20	2602	59%	18	2452	65%	18	2302	65%	18	2354	65%	18	2712	65%
	3	24	2806	58%	20	2798	70%	20	2640	70%	20	2696	70%	22	2982	63%
	4	18	2842	66%	18	2838	66%	16	2418	74%	17	2622	70%	18	2608	66%
21	**5**	18	2616	57%	14	2390	74%	14	2250	74%	14	2352	74%	15	2378	69%
	1	8	1384	1%	8	1384	1%	8	1384	1%	8	1384	1%	8	1384	1%
	2	20	2608	61%	18	2314	68%	17	2418	72%	19	2280	65%	19	2456	65%
	3	20	3002	65%	18	2862	72%	17	2508	77%	19	2692	69%	21	2926	62%
	4	22	2968	63%	20	3084	70%	19	2764	73%	20	3034	70%	22	3088	63%
22	**5**	18	2694	63%	15	2444	75%	16	2504	71%	15	2410	75%	17	2380	66%
	1	10	1764	1%	10	1764	1%	10	1764	1%	10	1764	1%	10	1764	1%
	2	20	2752	60%	19	2668	63%	19	2672	63%	19	2580	63%	20	2904	60%
	3	20	2780	66%	18	2664	74%	18	2678	74%	18	2518	74%	20	2700	66%
	4	21	2800	64%	18	2742	74%	19	2790	70%	18	2494	74%	21	2674	64%
23	**5**	20	2600	57%	16	2296	72%	16	2234	72%	15	2276	76%	18	2412	64%
	1	14	1886	1%	14	1886	1%	14	1886	1%	14	1886	1%	14	1886	1%
	2	21	2726	65%	20	2516	69%	21	2580	65%	19	2652	72%	21	2806	65%
	3	21	2846	62%	18	2524	73%	19	2840	69%	18	2350	73%	21	2696	62%
	4	23	2688	61%	19	2814	73%	19	2476	73%	20	2746	70%	20	2802	70%
24	**5**	18	2460	62%	16	2642	70%	15	2410	75%	16	2762	70%	17	2678	66%
	1	8	1596	2%	8	1596	2%	8	1596	2%	8	1596	2%	8	1596	2%
	2	26	3416	67%	24	3334	73%	24	3230	73%	24	3338	73%	27	3476	65%
	3	29	3654	61%	25	3448	71%	24	3396	74%	26	3408	69%	28	3720	64%
	4	27	3652	67%	27	3762	67%	25	3486	73%	25	3240	73%	27	3596	67%
25	**5**	23	3538	62%	19	3186	76%	19	3080	76%	19	3118	76%	21	3110	68%
	1	10	1402	1%	10	1402	1%	10	1402	1%	10	1402	1%	10	1402	1%
	2	23	3274	69%	21	3274	76%	22	3580	72%	21	3326	76%	24	3554	66%
	3	26	2726	63%	24	2776	69%	24	2518	69%	24	2786	69%	26	2674	63%
	4	26	3692	67%	24	3546	73%	23	3370	76%	24	3806	73%	27	3802	65%
26	5	25	3098	60%	20	2894	75%	19	2856	79%	21	2986	71%	23	3192	65%

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Table A2 continued

Instance	Class	Kontainer 1			Kontainer 2			Kontainer 3			Kontainer 4			Kontainer 5		
		K	D	U	K	D	U	K	D	U	K	D	U	K	D	U
	1	14	2346	1%	14	2346	1%	14	2346	1%	14	2346	1%	14	2346	1%
	2	25	3444	64%	22	2918	73%	23	3254	70%	23	3330	70%	24	3366	67%
	3	29	3878	62%	25	3882	72%	25	3776	72%	25	3664	72%	30	3982	60%
	4	26	3478	66%	23	3658	74%	23	3580	74%	24	3796	71%	26	3702	66%
27	**5**	25	3256	63%	21	2934	74%	22	3432	71%	21	3116	74%	24	3422	65%
	1	7	1824	2%	7	1824	2%	7	1824	2%	7	1824	2%	7	1824	2%
	2	27	5574	71%	26	5296	74%	26	5320	74%	25	5000	76%	28	5980	68%
	3	33	6256	63%	28	5606	74%	29	6076	71%	28	6218	74%	32	6118	65%
	4	33	7532	63%	29	6982	72%	29	6642	72%	29	7026	72%	30	6682	70%
28	**5**	30	6310	60%	23	5064	79%	23	5178	79%	24	5826	75%	27	5920	67%
	1	7	2444	2%	7	2444	2%	7	2444	2%	7	2444	2%	7	2444	2%
	2	30	5244	68%	28	5272	73%	28	5686	73%	29	5262	70%	31	5654	66%
	3	34	6154	63%	29	5102	74%	28	4832	77%	29	5320	74%	33	5980	65%
	4	36	5952	66%	31	6114	77%	32	5438	75%	32	5800	75%	35	6126	68%
29	**5**	35	5470	60%	27	4362	77%	28	4868	74%	28	4602	74%	31	4732	67%
	1	12	2190	2%	12	2190	2%	12	2190	2%	12	2190	2%	12	2190	2%
	2	35	4728	69%	32	4170	75%	31	4044	78%	33	4290	73%	35	4722	69%
	3	39	4734	67%	34	4854	77%	37	4750	70%	35	4622	74%	38	4938	69%
	4	39	5102	66%	35	5044	74%	33	4720	78%	36	4778	72%	38	5346	68%
30	**5**	32	4308	66%	27	4026	78%	28	4172	75%	28	4370	75%	31	4432	68%
	1	16	2620	2%	16	2620	2%	16	2620	2%	16	2620	2%	16	2620	2%
	2	46	5624	70%	43	5282	75%	42	5300	76%	42	5412	76%	46	5542	70%
	3	51	6488	67%	46	5998	74%	45	6114	76%	46	5664	74%	49	5726	70%
	4	53	6484	68%	48	6242	75%	46	6094	78%	49	5892	74%	55	6240	66%
31	**5**	51	4770	57%	39	4104	75%	39	4232	75%	41	4264	71%	46	4684	64%
	1	16	2620	2%	16	2620	2%	16	2620	2%	16	2620	2%	16	2620	2%
	2	44	5348	73%	42	5488	76%	41	5326	78%	43	5908	75%	45	5668	71%
	3	49	6326	67%	43	5896	77%	43	5700	77%	43	5782	77%	48	6068	69%
	4	49	6218	69%	44	6044	77%	43	5814	78%	45	5810	75%	50	6102	67%
32	**5**	49	4894	58%	39	4308	73%	38	4004	75%	40	4142	71%	46	4532	62%
	1	17	2112	1%	17	2112	1%	17	2112	1%	17	2112	1%	17	2112	1%
	2	49	4574	64%	46	4488	69%	45	4560	70%	45	4412	70%	50	4782	63%
	3	53	6710	65%	46	5712	75%	46	5874	75%	46	5864	75%	51	5928	68%
	4	52	6662	68%	47	6588	76%	47	6038	76%	47	6656	76%	54	6524	66%
33	5	48	4612	61%	40	4260	73%	39	4220	75%	40	4178	73%	45	4350	65%

Table A2 continued

Instance	Class	Kontainer 1			Kontainer 2			Kontainer 3			Kontainer 4			Kontainer 5		
		K	**D**	**U**	**K**	**D**	**U**	**K**	**D**	**U**	**K**	**D**	**U**	**K**	**D**	**U**
	1	22	1192	1%	22	1192	1%	22	1192	1%	22	1192	1%	22	1192	1%
	2	62	2356	63%	58	2194	68%	57	2220	69%	58	2282	68%	63	2426	62%
	3	69	2538	61%	60	2266	70%	61	2360	69%	63	2400	67%	67	2546	63%
	4	68	2474	63%	62	2482	70%	61	2404	71%	63	2494	68%	67	2646	64%
34	**5**	62	2364	58%	51	2106	71%	49	2076	74%	52	2134	70%	57	2286	63%
	1	26	1354	1%	26	1354	1%	26	1354	1%	26	1354	1%	26	1354	1%
	2	57	3740	67%	50	3524	77%	51	3494	75%	51	3676	75%	55	3632	70%
	3	67	4222	63%	58	4138	73%	56	3830	76%	58	4178	73%	64	4062	66%
	4	64	4464	70%	59	4226	76%	56	4118	80%	60	4220	75%	67	4516	67%
35	**5**	58	3866	64%	46	3812	80%	47	3364	79%	46	3834	80%	54	3840	68%
	1	14	1062	2%	14	1062	2%	14	1062	2%	14	1062	2%	14	1062	2%
	2	59	3988	69%	53	3692	77%	53	3514	77%	54	3562	75%	56	3758	73%
	3	66	4188	66%	60	3858	73%	58	3840	75%	58	3906	75%	65	4126	67%
	4	64	4112	66%	55	3822	77%	55	3658	77%	56	3706	75%	63	4064	67%
36	**5**	64	3552	59%	51	2982	74%	50	2964	76%	53	3056	71%	58	3300	65%

Paper 17

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