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Cheapest Insertion Constructive Heuristic based on Two Combination Seed Customer Criterion for the Capacitated Vehicle Routing Problem

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***Abstract*— The heuristic method is a well-known constructive method for initialize trail quality solutions in capacitated vehicle routing problem. Cheapest insertion heuristic is a popular construction heuristic known for being fast, producing decent solutions, simple to implement and easy to extend handling complicated constraints. However, in previous work, there was less focus on diverse initial quality solutions. Therefore, this study proposed an extension to the cheapest insertion heuristic which consider various combinations of seed customer criteria (the first customer inserted on a route) to preserve solutions diversification. Three seed customer criteria proposed which based on the combination of two criteria based on (farthest, nearest and random criteria). The best performing criteria selected and tested on benchmark dataset, later compared with Clarke and Wright saving heuristic. The results shown that the combination of (farthest and random) criteria obtained the best initial solution which preserve balance between the quality and diversity, with less time when compared to Clarke and wright saving heuristic. This approach is for generating diverse and quality starting solutions for the capacitated vehicle routing problem.**

***Keywords*— insertion heuristic; capacitated vehicle; routing problem; initial solution construction.**

I. INTRODUCTION

The vehicle routing problem (VRP) and its extensions is one of the most widely studied optimization combinatorial problems (COPs) in the transportation domain. One of its basic variant is the Capacitated VRP (CVRP), which may be stated as follows: generate a sequence of deliveries for each vehicle in a homogeneous fleet based on a single depot so that all customers are serviced and the total distance travelled by the fleet is minimised. Each vehicle has a fixed capacity and must leave from and return to the depot. Each customer has a known demand serviced by exactly one visit of a single vehicle [1]. Up to date, many efforts made to construct the initial quality solutions for the CVRP. Generally, these solution methods are either randomly constructed or by a classical heuristics often name as (greedy methods). The aim of the constructive heuristics is to obtain fast quality solutions, not necessarily the best one [2]. However, when the solution is not final and need to be further improved by other methods such as the upper level heuristic (metaheuristic). The need for a diverse solutions pool is become critical [3]. Diversity is referred to as the key to preventing stagnation in local optima (The diversity in this context means that each solution properties are different from each other). Mainly, the constructive heuristics for CVRP is categorised into two categories: (i) saving and (ii) insertion heuristics. The popular saving heuristics is similar to Clarke and Wright's heuristic (CW) [4] which categorized for obtain near to optimal solutions [5]. On other hand, the insertion heuristic is similar to the cheapest insertion heuristic (CIH) which known for being fast, producing decent solutions, simple to implement and easy to extend handling complicated constraints [6]. The CIH firstly introduced for the traveling salesman problem and then later extended to solve the VRP and its extension [7]. Generally, most of the basic construction heuristics are categorised as deterministic such as the CIH, where each execution produces the same solution, which later causes the lack of diversity between the solutions if the solutions are not final. This research aimed to propose a CIH by considering various combinations of Seed Customer Criteria (SCC) to ensure solution pool diversify. Three different seed customer criteria combinations investigated to acquire the best one for CIH. The target was to have a construction heuristics that demonstrates a suitable balance between the quality and diversity of the generated solution using relative simple approach, which can be seen as one of the CIH characteristics [8]. Experiment conducted to compare the three extensions between each other, and later with the well-known CW. The remainder of this paper was organised as follows: (Section 2) material and method provided, the proposed CIH heuristic and how it applied to CVRP demonstrated. In (Section 3) an experimental setup and result presented. Finally, (Section 4) concluded the study.

II. Material and Method

Literature reviews have shown that the use of SCC has significantly influenced the behaviour of various CIH extensions [9]. The most popular SCC for CVRP is known as the nearest, farthest, biggest demand and random [10], classified as the fixed criteria. However, the most popular one among them would be the cheapest. The use of the cheapest SCC classified the CIH as a deterministic, which always obtains the same quality solution. On the other hand, the use of random SCC classified as a non-deterministic, which has less quality solutions but preserve high solution diversifications [11]. Solution diversity is referred to as a key in preventing premature convergence and stagnation in local optima [3]. It is generally believed that diversity is beneficial in heuristic and metaheuristic to efficiently explore the given search space [12]. In the iterative stage, which usually tackled using metaheuristics, the diversification defines the amount of variety in the population pool. The diverse of initial solutions and how to maintain it is considered as one of the fundamental issues in iterative stage. Latest literature indirectly addressed the importance of solution diversify by adopting a non-deterministic two-phase construction heuristic (construction of the initial solution, followed by an improvement phase using other heuristic such as 2-opt), it is identified as always produces a different solution in each execution [6, 11, 13, 14]. Moreover, the simple deterministic CIH were enhanced by the two-phase heuristics such as in [6, 9, 15]. How-ever, the limitation of this mechanism is that incur additional configuration of adding extra computationally cost heuristics. The diversity of the solutions according to the literature can be categorised into two categories: Burke, Gustafson [3], some diversity measurement methods are intended to quantify the variety in a population (behavioural diversity), such as the common approach to measure diversity based on fitness values without measure the structural of the solutions [16]. On other hand, other methods used to measure the difference between individuals (structural diversity) which is attempting to maintain high diversity during a run by compare the solution characteristic. In this study, a structural diversity measurement is used which is presented by Maquera, Laguna [17].

A. review of the basic insertion heuristic

The cheapest insertion heuristic was defined by Solomon [7]. It begins by initialising the route under consideration with a seed customer (the first customer inserted on a route) this process named as the (initialization criteria). After initialization of each route by the selected initial criteria is finished, other customers then selected for addition to the current route, if they satisfy the problem constraint (capacity constraint in this study). However, this process is known as (insertion criterion) which is fixed in this study to (cheapest to previous customer). When no more un-routed customers can be 'feasibly' inserted in the current route, and as long as adding this customer does not exceed the capacity of this route, the process is repeated for a new route until either all the routes are full or all customers have been served. However, different variants of CIH rise as result of how the two key decisions that are made at every iteration are selected: Firstly, which un-routed customer to insert as stated before (initialization criteria), secondly, where to insert it in the partial solution (insertion criteria).

B. Initialization Criteria

The basic initial criteria can be identified as follow: for each SCC (whether it is farthest, nearest or random), the distance between the depot d and the seed customer k in the customer list (CL) is computed and evaluated. This SCC selection can obtained by the function g in Eq. 1.

$$g\ (k) = c_{dk} \tag{1}$$

The selection associated with the nearest k to d is performed as:

$$\min \{g(k)|\ k \in \text{CL}\} \tag{2}$$

while the farthest is performed as:

$$\max \{g(k)|\ k \in \text{CL}\} \tag{3}$$

and random customers are performed as:

$$k \sim U([1, n])\ \{g(k)|\ k \in \text{CL}\} \tag{4}$$

where n is the number of customers.

C. Insertion Criteria

A simple insertion 'greedy' approach used in the proposed CIH, known as Cheapest Insertion Criterion (CIC). CIC directly computes the distance between a customer k in available CL and every customer i that has been already included into the partial solution; as can be observed by function g in Eq. 5. It assumed that the insertion of k is always performed after i.

$$g\ (k) = c_{ik} \tag{5}$$

The insertion associated with the cheapest-cost (the minimum distance between the current previous inserted customer and newly suggested customer) is performed as the one presented in Eq. 2.

D. CIH Drawbacks

In practice, CIH has two drawbacks. These drawbacks strongly related to the greedy nature of the heuristic, which can be outlined as: (1) when the CIH has ended, either all the customers have been served, or there are still some customers left that have not been served. The latter can happen more frequently if the tightness of the problem is very high. The tightness of a CVRP defined as the relation between the sum of the demands of all customers and the total capacity of all the vehicles, which presented in Table 3. (2) The way in which the CIH travelled back to the depot not taken into account, and usually that travel distance is too costly. Because of these two drawbacks, either an unfeasible solution is constructed which may need a repairing procedure, or a high cost solution is obtained which contradicts to the using of the heuristic. These problems strongly attracted when fixed criteria is begin used; either fixed initialization criteria or fixed insertion criteria or both criteria are begin used. A practical solution to consider in this situation is to incorporate some degree of randomness to overcome these drawbacks.

E. diversity measurement method

In order to calculate the diversity of the solutions, this study employs a structural diversity, which presented by Maquera, Laguna [17]. This structural diversity measurement considers the differences in properties between the compared solutions. This method works as follows: The difference value between the two solutions x and y is calculated by creating a two-dimensional matrix CustomerCount of size *r x r*, where r is the maximum number of routes in either *x* or *y* (in this case, the number of routes in the solution was fixed). Then, the matrix will be filled up in such a way that CustomerCount (x_i,y_j) include the number of customers that match route (i_{th}) in solution *x* with route (j_{th}) in solution *y*. After the above process is complete, either the total number of customers is computed in the solution, *x* or *y*, then the largest CustomerCount value is found. This value is then summed and the corresponding column and row is thus eliminated. The process will finish when CustomerCount becomes empty. The sum value will be subtracted from the total number of customers and the difference between two solutions x and y is obtained. Here, an example demonstrated the above-mentioned technique to obtain the diversity between solutions *x* and *y*:

X= (3, 7) (4, 5, 8, 6) (10, 2, 9, 1)
Y= (7, 9, 6, 8, 5) (1, 2, 3, 4, 10)

TABLE I
EXAMPLE OF CUSTOMERCOUNT MATRIX WITH R=3

	Y1	Y2	Y3
X1	1	1	0
X2	3	1	0
X3	1	3	0

The CustomerCount matrix is filled as in **Error! Reference source not found.**, where the value of *r* is 3. However, the first value (x_1, y_1) in the matrix in table, the number of customers that are mutual between route x_1 and route y_1. This operation is repeated until the entire CustomerCount matrix is filled. The maximum number in the matrix will saved, and then all values in the same column and row will deleted. This operation repeated until there are no more values in the matrix. Next, the sum of all saved values is calculated to detect the average number of customers in both solutions. For example, after filling up CustomerCount matrix with the number of customers that are mutual between routes, the values (x_2, y_1) selected as maximum value *3* in the matrix; then, the corresponding column and row will deleted. The same procedure repeated for the values (x_3, y_2). Therefore, the sum of the maximum values in CustomerCount matrix is *6*. After that, the average of the total customers in both solutions are found by dividing it by *2*, (20/2=10). Finally, the difference value between solution *x* and *y* is given by 10-6=4. The difference value (diversity) is calculated for each solution *x* in population *P*, with the remaining solution in *P*; next, the average is found for each solution corresponding to other solutions in *P*.

F. The proposed cheapest insertion heuristic based on two-seed customer criteria

The proposed CIH is similar to the basic previously presented CIH in insertion criteria but differ in terms of the initialisation criteria of the seed customer. The basic CIH uses one type of SCC; either nearest, farthest or random [18]. On other hand, the proposed CIH uses a combination of two types of SCC from the three types shown in Table 2. Which named as CIH based Two-Seed Customer Criteria (Two-CIH). This combination aims to make a balance between the solution quality and diversity. Since the proposed criterion is a combination of two criteria, only one type of SCC selected during the assignment of the seed customer. Therefore, a random selection used to select the type of SCC in each route SCC assignment.

TABLE II
THE BASIC AND TWO-SEED CUSTOMER CRITERIA

Abbreviation	Seed customer criteria		Category
	Type	Distance measure	
N	Single	Nearest	Deterministic
F	Single	Farthest	
R	Single	Random	Non-deterministic
NF	Combined	nearest or farthest	
NR	Combined	nearest or random	
FR	Combined	Farthest or random	

The proposed Two-CIH was based on the heuristic presented by [18]. The pseudo code of the proposed CIH presented in **Error! Reference source not found.**.

```
1  Procedure GenerateInitialSolution( s, MaxIter, seedCustomerCriteria);
2  ConsecutiveTrials ← 0;
3  Initialize the CL;
4  Initialize s by v empty routes
5  for v' = 1 . . . v do
6  Evaluate the value of each k ∈ CL based on seedCustomerCriteria
7  s^v' ← k
8  Update CL; {CL ← CL - {k}}
9  InsertionCriterion ← CIC as in Eq. 2.
10 while CL ≠ ∅ and at least one customer k ∈ CL can be added to s do
11 for v' = v0 . . . v and CL ≠ ∅ do
12 if at least one customer k ∈ CL can be inserted into the vehicle v' then
13 Evaluate the value of each cost g(k) for k ∈ CL;
14 g^Min. ← InsertionCriterion
15 k' ← customer k associated to g^Min.;
16 if capacity of k' + demand of v' ≤ vehicle demand do
17 s^v' ← s^v' ∪ {k'};
18 Update CL;
19 Update v';
20 End while
21 if s is infeasible and ConsecutiveTrials ≠ MaxIter then
22 ConsecutiveTrials ← ConsecutiveTrials + 1;
23 Go to line 3;
24 if ConsecutiveTrials = MaxIter then
25 report unable to construct feasible solution
26 return s
27 end GenerateInitialSolution;
```

Fig. 1. The CIH pseudo code

The heuristic began by randomly selecting one criteria from the proposed SCC (line 4) which differed from Subramanian [18] original pseudocode. An initial costumer list and empty solution was generated (line 3-4). Each route filled with a seed customer *k* from the Customer List (*CL*); it selected based on the proposed combined criteria (lines 5-8), this step illustrated as in **Error! Reference source not found.**. (a). An insertion criterion was fixed as cheapest insertion criteria (CIC) in line 9. Iteratively, each remaining customer assigned to its respective routes (lines 10-20). Only a single route considered for insertion in each iteration these steps are illustrated as in **Error! Reference source not found.**. (b, c, and d). While the *CL* is not empty and there was at least one customer $k \in CL$ that can be added to the current partial solution without violating any constraints (lines 11-19), each route was filled with a selected customer using CIC (lines 13-15) these steps is illustrated as in **Error! Reference source not found.**. (f). If an infeasible solution has been found, the procedure restarts from line 3 (line 23). In this case, an infeasible solution necessarily corresponded to an incomplete solution, which meant that the selected insertion procedure was not capable of including all customers using v vehicles. However, the returned solution may not have visited all customers because of the earlier stated problem of high tightness value.

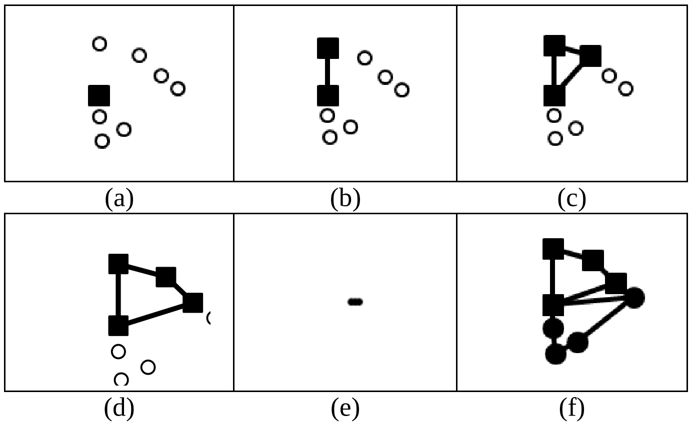

Fig. 2. The CIH steps.

III. Results and Discussion

Experiments were conducted to test the performance of the proposed CIH on the benchmark datasets of Augerat, Belenguer [19]. There were 16 CVRP instances; the total number of clients varied from 30 to 135 clients, and the total number of vehicles varied from 3 to 10 vehicles. Details of these instances were presented in **Error! Reference source not found.** and obtained from [20] .

TABLE III
CVRP instances charastratics.

Instances	Vehicle	Customer	Capacity	Tightness	BKS
A-n33-k5	5	32	100	0.82	661
A-n46-k7	7	45	100	0.86	914
A-n60-k9	9	59	100	0.92	1354
B-n35-k5	5	34	100	0.87	955
B-n45-k5	5	44	100	0.97	751
B-n68-k9	9	67	100	0.93	1272
B-n78-k10	10	77	100	0.94	1221
E-n30-k3	3	29	4500	0.94	534
E-n51-k5	5	50	160	0.97	521
E-n76-k7	7	75	220	0.89	682
F-n72-k4	4	71	30000	0.96	237
F-n135-k7	7	134	2210	0.95	1162
M-n101-k10	10	100	200	0.91	820
M-n121-k7	7	120	200	0.98	1034
P-n76-k4	4	75	350	0.97	593
P-n101-k4	4	100	400	0.91	681

All experiments performed on a 2.4 GHz Intel core i5 laptop computer, 4 gigabyte of ram; and the heuristics coded using C++. The mini-mum (Min.), maximum (Max.), average (Avg.), standard deviation (Std.) and average result of all instances (Avg. All) computed over 31 independent runs with 30 solutions on each problem instances and the results were summarised in the following subsection. The best results showed in bold. The following subsection also displayed two experiments, which conducted based on two factors: the quality and diversity of the solutions. The best one obtained from the two experiments compared with the fixed seed customer criteria, such as the farthest and nearest, which demonstrate the drawback of using the fixed criteria. A statistical test also conducted to prove the significant difference among them. Later, the results compared with the benchmark CW heuristic.

A. *The Proposed CIH Based on Solution Quality*

In order to estimate the benefit of using the CIH with different SCCs in terms of solution quality, three extensions of CIH heuristics applied to the basic CIH. The results showed in **Error! Reference source not found.**. The table presented the min, max, average and standard deviation for various type Two-SCC-CIHs such as NF-SCC-CIH, NR-SCC-CIH and FR-SCC-CIH.

TABLE IV
SOLUTION QUALITY COMPARISON RESULT BASED ON THE TWO-SCC-CIH TYPES

Instances	*NF*				*NR*				*FR*			
	Min.	Max.	Avg.	Std.	Min.	Max.	Avg.	Std.	Min	Max	Avg.	Std.
A-n33-k5	757	895	805.8	48.7	746	899	821.0	45.1	**744**	**882**	**789.6**	33.7
A-n46-k7	1160	**1235**	1180.1	19.0	1142	1287	1213.0	46.2	**1083**	1258	**1177.8**	43.8
A-n60-k9	**1507**	**1631**	**1574.2**	37.7	1519	1681	1605.5	42.4	1514	1703	1618.8	47.5
B-n35-k5	1016	**1067**	1039.0	19.3	1034	1161	1065.6	29.2	**1005**	1134	**1030.8**	30.5
B-n45-k5	-	-	-	-	**802**	941	875.2	38.0	824	**932**	**861.8**	27.0
B-n68-k9	1366	**1409**	**1379.8**	12.8	1360	1493	1415.6	36.4	**1349**	1480	1406.8	38.0
B-n78-k10	-	-	-	-	**1310**	**1437**	**1351.6**	30.6	1375	1504	1443.5	35.5
E-n30-k3	598	618	609.2	10.1	**588**	**629**	**605.4**	11.3	**588**	687	625.2	24.2
E-n51-k5	660	686	669.5	9.1	**651**	**752**	692.1	26.7	663	764	705.1	25.1
E-n76-k7	876	**981**	**918.8**	30.9	**857**	983	921.2	35.6	895	982	945.0	25.1
F-n72-k4.	-	-	-	-	**275**	342	**300.7**	18.8	283	**318**	301.4	11.5
F-n135-k7	1404	**1478**	**1423.8**	23.7	1371	1606	1473.6	62.5	**1336**	1502	1449.2	35.4
M-n101-k10	1007	1148	1084.4	32.0	1019	1200	1130.7	48.3	**988**	**1086**	**1021.4**	26.9
M-n121-k7	1186	**1240**	**1219.9**	21.2	**1151**	1322	1245.5	48.8	1189	1297	1223.7	27.6
P-n76-k4	767	866	828.2	29.8	**711**	**836**	**782.8**	25.4	746	903	841.2	35.2
P-n101-k4	923	**1020**	959.5	29.3	**879**	1024	**952.7**	34.5	882	1035	975.2	31.7
Average	1017.5	1098	1053.2	24.9	**963.4**	1099.6	1028.3	36.2	966.5	**1091.7**	**1026.0**	31.2

In Table 4, the ''NR" SCC performed slightly better than the "FR" criteria, and much better than "NF" criteria when tested on capacitated vehicle routing problem. This comparison was based on the Min value, where 9 out of 16 instances were better when using "NR" than other criteria. In addition, it was slightly bigger in the overall Average when compared to its competitor "FR" SCC. However, the overall Average result of all instances was better when using the "FR" where the results showed that the best result of overall Average of (Max and Avg.) obtained by "FR". Furthermore, it is worth mentioning that the "NF" criteria were unable to construct initial solutions for some instances (B-n45-k5, B-n78-k10, and F-n72-k4, F-n135-k7). This was mainly due to the tightness of the instances being very high (0.97, 0.94, 0.96 and 0.95, respectively). Moreover, the results also demonstrated that the two combination criteria with random criteria, "FR" and "NR", performed better solution quality and were able to construct initial solutions for all instances compared to "FN". The results illustrated that "FN" was unable to construct initial solutions for some instances, which was marked as a dashed line in the table. It clearly indicated that the CIH is able to overcome one of the known drawbacks of fixed criteria when random SCC criteria are combined with fixed criteria.

B. *The Proposed CIH Based on Solution Quality*

Table 5 displayed the results of solution diversity for the three CIH extensions. The Min and Max values described the similarity of solutions. The Min value indicated how far the solutions are similar to each other; while the Max value indicated how far the solutions are diversified or different. The Avg. described the average diversifying value for current instance, while the SD indicated the standard deviation for Min and Max. The solution diversity of the proposed CIH evaluated based on the max value. Table 5 also presented the diversity values of the three criteria. The "FR" criterion obtained the best Max value for 9 out of 16, which indicated that the solution was much diversified in those 9 instances, followed by "NR" with 7 out of 16 and, lastly, NF with zero instances. Moreover, the overall Average of the Min, Max and Avg. values for all instances was better when using the "FR" criteria. One may say that when the quality is compared to the diversity in the initial stage of the combinatorial problem, then clearly one can choose the diversifying solutions rather than the quality ones since the solutions are not final and the differences in quality is not that much. The solutions, for now, are in a preliminary stage of whole methodology of designing a better solution, and the quality of both "NR" and "FR" SCC criteria is slightly different. Therefore, the diversifying solution using the "FR" SCC selected to carry out next experiments.

TABLE V
SOLUTION DIVERSITY COMPARISON RESULT OF THE THREE CIH TYPES

instances	*NF*				*NR*				*FR*			
	min	Max	Avg.	SD	min	Max	Avg.	SD	min	max	Avg.	SD
A-n33-k5	3.1	7.0	4.7	1.7	**5.2**	**16.9**	**7.7**	2.5	4.7	16.6	7.2	3.0
A-n46-k7	7.2	15.5	10.3	2.8	12.0	**22.0**	16.1	3.2	**14.4**	19.8	**16.4**	1.5
A-n60-k9	7.7	12.7	9.3	1.1	14.2	**27.0**	**19.7**	3.1	**16.1**	23.0	19.6	2.2
B-n35-k5	5.4	9.0	6.4	1.1	**6.5**	**14.1**	**8.9**	2.3	4.5	10.8	6.4	1.6
B-n45-k5	-	-	-	-	**12.2**	**23.2**	**15.3**	2.6	10.2	21.7	13.6	2.9
B-n68-k9	4.4	17.3	6.4	3.3	**13.9**	23.2	**18.3**	2.9	13.2	**24.5**	17.0	3.3
B-n78-k10	-	-	-	-	15.8	25.2	19.2	2.8	**24.3**	**34.4**	**28.0**	2.9
E-n30-k3	0.0	0.0	0.0	0.0	1.1	8.4	1.9	2.0	**2.8**	**12.2**	**4.0**	2.3
E-n51-k5	3.4	3.6	3.5	0.1	**16.6**	**29.0**	**20.5**	3.0	13.8	22.8	17.4	2.6
E-n76-k7	20.2	30.5	25.0	3.5	**25.7**	37.4	**29.7**	3.3	23.3	**38.2**	28.6	3.8
F-n72-k4.	-	-	-	-	**12.3**	27.2	16.2	4.2	11.4	**40.2**	**21.6**	6.8
F-n135-k7	11.5	29.9	16.4	7.5	24.7	**65.9**	36.9	11.1	**40.9**	58.9	**48.7**	4.7
M-n101-k10	14.0	25.6	17.4	4.0	**15.0**	29.0	**20.5**	3.9	12.4	**29.9**	19.0	5.1
M-n121-k7	2.5	7.2	3.4	1.3	8.8	23.3	12.8	4.4	**12.2**	**23.5**	**15.3**	2.4
P-n76-k4	13.1	22.7	17.1	3.4	22.0	38.9	27.9	5.3	**23.2**	**40.0**	**28.6**	4.8
P-n101-k4	20.8	34.7	23.3	3.6	**23.2**	45.2	**30.2**	5.7	18.0	**45.3**	26.7	8.8
Average	8.7	16.6	11.0	2.6	14.3	28.5	18.9	3.9	**15.3**	**28.9**	**19.9**	3.7

The results revealed that the best criteria used for constructing the initial solution for the CVRP was “FR”. Furthermore, the results also showed that “FR” is different from the other criteria employed for the CVRP; thus, a statistical t-test among the “FR” with other Two-SCCs executed. Table 6 displayed the p-value results. The p-value results that showed ($p<0.05$) were a significant difference between “FR” compared to the used “NF” and “NR”.

TABLE VI
P-VALUE RESULTS FOR THE “FR” PAIRED WITH OTHER CRITERIA

Instances	*p*-Value	
	FR & NF	FR & NR
A-n33-k5	**0.0**	**0.0**
A-n46-k7	**0.0**	**0.0**
A-n60-k9	**0.0**	**0.0**
B-n35-k5	**0.0**	**0.0**
B-n45-k5	-	**0.0**
B-n68-k9	**0.0**	**0.0**
B-n78-k10	-	**0.0**
E-n30-k3	**0.047**	**0.006**
E-n51-k5	**0.0**	**0.0**
E-n76-k7	0.470	**0.0**
F-n72-k4.	-	**0.001**
F-n135-k7	0.073	**0.0**
M-n101-k10	**0.006**	**0.0**
M-n121-k7	**0.0**	**0.0**
P-n76-k4	**0.0**	**0.027**
P-n101-k4	0.110	0.170

Table 6 presented the p-values for the best criteria paired with two other criteria for all instances. With such results, it can be concluded that a CIH with different SCC criterion has different impact, where the criteria used in the CVRP are different from each other.

C. Performance of the FR-SCC-CIH Compared to Other Fixed CIH Criteria

Table 7 demonstrated the difference between the “FR” SCC-CIH, the fixed “N” SCC-CIH and the fixed “F” SCC-CIH from the solution quality prospective. It can be seen that the N and F based CIH were unable to construct feasible solutions for some instances, representing 37% and 43% of the overall instances, respectively. While the proposed combined, “FR” SCC was able to overcome this drawback and successfully construct solutions for all instances. Moreover, the fixed “N” and “F” SCC were always constructing the exact solutions. Therefore, they drove the solutions to the same area in the problem search space which affected the solution diversity in later stages.

D. Performance of the FR-SCC-CIH with CW Heuristic

Furthermore, a comparison made between the “FR” and CW to demonstrate the difference, with different prospective, regarding the solution quality and computational time presented in **Error! Reference source not found.**. The CW heuristic was able to obtain the best solution for all instances, but with high computational cost ranging from 5 seconds for small instances and up to 15 minutes for larger ones. Whilst using the “FR” based CIH, the solution quality was acceptable since the diversity was the important factor in this study. This solution quality of the proposed method came with small computational costs compared to CW with less than 5 seconds for even larger instances.

TABLE VII
DIFFERENCE BETWEEN RANDOM GENERATION METHOD AND CIH BASED METHOD

instances	*N*					*F*					*FR*				
	min	Max	Avg.	SD	T(s)	min	Max	Avg.	SD	T(s)	min	Max	Avg.	SD	T(s)
A-n33-k5	829	829	829	0	0.10	-	-	-	-	-	**744**	882	**789.6**	33.7	0.14
A-n46-k7	1201	1201	1201	0	0.18	1161	1161	1161	0	0.2	**1083**	1258	1177.8	43.8	0.16
A-n60-k9	-	-	-	-	-	1590	1590	1590	0	0.24	**1514**	1703	1618.8	47.5	0.25
B-n35-k5	1024	1024	1024	0	0.06	1016	1016	1016	0	0.1	**1005**	1134	1030.8	30.5	0.09
B-n45-k5	-	-	-	-	-	-	-	-	-	-	**824**	932	**861.8**	27.0	3.98
B-n68-k9	1360	1360	1360	0	0.1	1371	1371	1371	0	0.37	**1349**	1480	1406.8	38.0	0.30
B-n78-k10	-	-	-	-	-	-	-	-	-	-	**1375**	1504	**1443.5**	35.5	2.09
E-n30-k3	598	598.0	598.0	0	1.11	-	-	-	-	-	**588**	687	**625.2**	24.2	1.47
E-n51-k5	-	-	-	-	-	-	-	-	-	-	**663**	764	**705.1**	25.1	0.31
E-n76-k7	**869**	869	869	0	0.30	943	943	943	0	0.1	895	982	945.0	25.1	0.25
F-n72-k4.	-	-	-	-	-	-	-	-	-	-	**283**	318	**301.4**	11.5	4.79
F-n135-k7	1477	1477	1477	0	1.76	-	-	-	-	-	**1336**	1502	**1449.2**	35.4	1.51
M-n101-k10	1147	1147	1147	0	0.44	995	995	995	0	0.29	**988**	1086	1021.4	26.9	0.37
M-n121-k7	-	-	-	-	-	1205	1205	1205	0	1.5	**1189**	1297	1223.7	27.6	1.06
P-n76-k4	797	797	797	0	0.67	849	849	849	0	0.55	**746**	903	841.2	35.2	0.34
P-n101-k4	944	944	944	0	0.32	984	984	984	0	0.41	**882**	1035	975.2	31.7	0.44

TABLE VIII
COMPARISON BETWEEN "FN" BASED CIH WITH CW HEURISTIC

Instances	*CW*					*FR*				
	Min	max	Avg.	SD	T(s)	min	max	Avg.	SD	T(s)
A-n33-k5	**691**	691	691	0.0	7.3	744	882	789.6	33.7	**0.14**
A-n46-k7	**939**	939	939	0.0	24.6	1083	1258	1177.8	43.8	**0.16**
A-n60-k9	**1428**	1428	1428	0.0	70.6	1514	1703	1618.8	47.5	**0.25**
B-n35-k5	**978**	978	978	0.0	10.3	1005	1134	1030.8	30.5	**0.09**
B-n45-k5	**758**	758	758	0.0	21.4	824	932	861.8	27.0	**3.98**
B-n68-k9	**1322**	1322	1322	0.0	92.1	1349	1480	1406.8	38.0	**0.30**
B-n78-k10	**1268**	1268	1268	0.0	165.6	1375	1504	1443.5	35.5	**2.09**
E-n30-k3	**538**	538	538	0.0	5.7	588	687	625.2	24.2	**1.47**
E-n51-k5	**588**	588	588	0.0	29.9	663	764	705.1	25.1	**0.31**
E-n76-k7	**738**	738	738	0.0	116.3	895	982	945.0	25.1	**0.25**
F-n72-k4.	**256**	256	256	0.0	106.5	283	318	301.4	11.5	**4.79**
F-n135-k7	**1214**	1214	1214	0.0	935.5	1336	1502	1449.2	35.4	**1.51**
M-n101-k10	**830**	830	830	0.0	245.2	988	1086	1021.4	26.9	**0.37**
M-n121-k7	**1076**	1076	1076	0.0	804.3	1189	1297	1223.7	27.6	**1.06**
P-n76-k4	**655**	655	655	0.0	119	746	903	841.2	35.2	**0.34**
P-n101-k4	**766**	766	766	0.0	295.5	882	1035	975.2	31.7	**0.44**

IV. CONCLUSION

This study proposed two combinations of seed customer criterion to improve CIH for CVRP solution quality (Two-SCC-CIH) as FR, NR and NF. The proposed methods had proven their ability to establish diversification of the solution method for the CIH as they presented better results in comparison to the basic CIH. The used random combination SCC (FR and NR) obtained better solutions compared to the fixed combination (NF). However, the farthest and random (FR) to depot as seed customer criteria obtained better performance based on the balance between quality and diversity. The use of FR seed customer criterion for CIH also obtained better solution quality compared to the fixed SCC, along with better time com-pared to the CW heuristic. The proposed Two-SCC-CIH was developed based on the one-phase approach, as the quality solution can be improved using the 2-phase approach.

REFERENCES

[1] Gendreau, M., et al., Metaheuristics for the Vehicle Routing Problem and Its Extensions: A Categorized Bibliography, in The Vehicle Routing Problem: Latest Advances and New Challenges, B. Golden, S. Raghavan, and E. Wasil, Editors. 2008, Springer US. p. 143-169.J. Breckling, Ed., *The Analysis of Directional Time Series: Applications to Wind Speed and Direction*, ser. Lecture Notes in Statistics. Berlin, Germany: Springer, 1989, vol. 61.

[2] Talbi, E.-G., Metaheuristics: from design to implementation. Vol. 74. 2009: John Wiley & Sons.

[3] Burke, R., S.M. Gustafson, and G. Kendall. A Survey And Analysis Of Diversity Measures In Genetic Programming. in GECCO. 2002.

[4] Clarke, G. and J.W. Wright, Scheduling of Vehicles from a Central Depot to a Number of Delivery Points. Operations Research, 1964. 12(4): p. 568-581.

[5] Pichpibul, T. and R. Kawtummachai, New enhancement for Clarke-Wright savings algorithm to optimize the capacitated vehicle routing problem. 2012.

[6] Mester, D. and O. Bräysy, Active-guided evolution strategies for large-scale capacitated vehicle routing problems. Computers & Operations Research, 2007. 34(10): p. 2964-2975.

[7] Solomon, M.M., Algorithms for the vehicle routing and scheduling problems with time window constraints. Operations Research, 1987. 35(2): p. 254-265.

[8] Cordeau, J.F., et al., A guide to vehicle routing heuristics. Journal of the Operational Research society, 2002: p. 512-522.

[9] Hosny, M.I. and C.L. Mumford, Constructing initial solutions for the multiple vehicle pickup and delivery problem with time windows. Journal of King Saud University - Computer and Information Sciences, 2012. 24(1): p. 59-69.

[10] Carić, T., et al., A modelling and optimization framework for real-world vehicle routing problems. Vehicle Routing Problem, 2008. 15.

[11] Campbell, A.M. and M. Savelsbergh, Efficient insertion heuristics for vehicle routing and scheduling problems. Transportation science, 2004. 38(3): p. 369-378.

[12] Berg, H., Viewing the problem from different angles: a new diversity measure based on angular distances. Journal of Artificial Evolution and Applications, 2009. 2009: p. 3.

[13] Stålhane, M., et al., A construction and improvement heuristic for a liquefied natural gas inventory routing problem. Computers & Industrial Engineering, 2012. 62(1): p. 245-255.

[14] Csiszár, S., Two-Phase Heuristic for the Vehicle Routing Problem with Time Windows. Acta Polytechnica Hungarica, 2007. 4(2): p. 143-156.

[15] Joubert, J. and S. Claasen, A sequential insertion heuristic for the initial solution to a constrained vehicle routing problem. ORiON: The Journal of ORSSA, 2006. 22(1): p. 105-116.

[16] Rosca, J.P. Genetic Programming Exploratory Power and the Discovery of Functions. in Evolutionary Programming. 1995. Citeseer.

[17] Maquera, G., et al., Scatter Search Applied to the Vehicle Routing Problem with Simultaneous Delivery and Pickup. Int. J. Appl. Metaheuristic Comput., 2011. 2(2): p. 1-20.

[18] Subramanian, A., Heuristic, exact and hybrid approaches for vehicle routing problems. 2012, Ph. D. thesis, Universidade Federal Fluminense, Niterói, Brazil.

[19] Augerat, P., et al., Computational results with a branch and cut code for the capacitated vehicle routing problem. Rapport de recherche-IMAG, 1995.

[20] Chen, Yang, and Wu, Hybrid discrete particle swarm optimization algorithm for capacitated vehicle routing problem. Journal of Zhejiang University SCIENCE A, 2006. 7(4): p. 607-614.