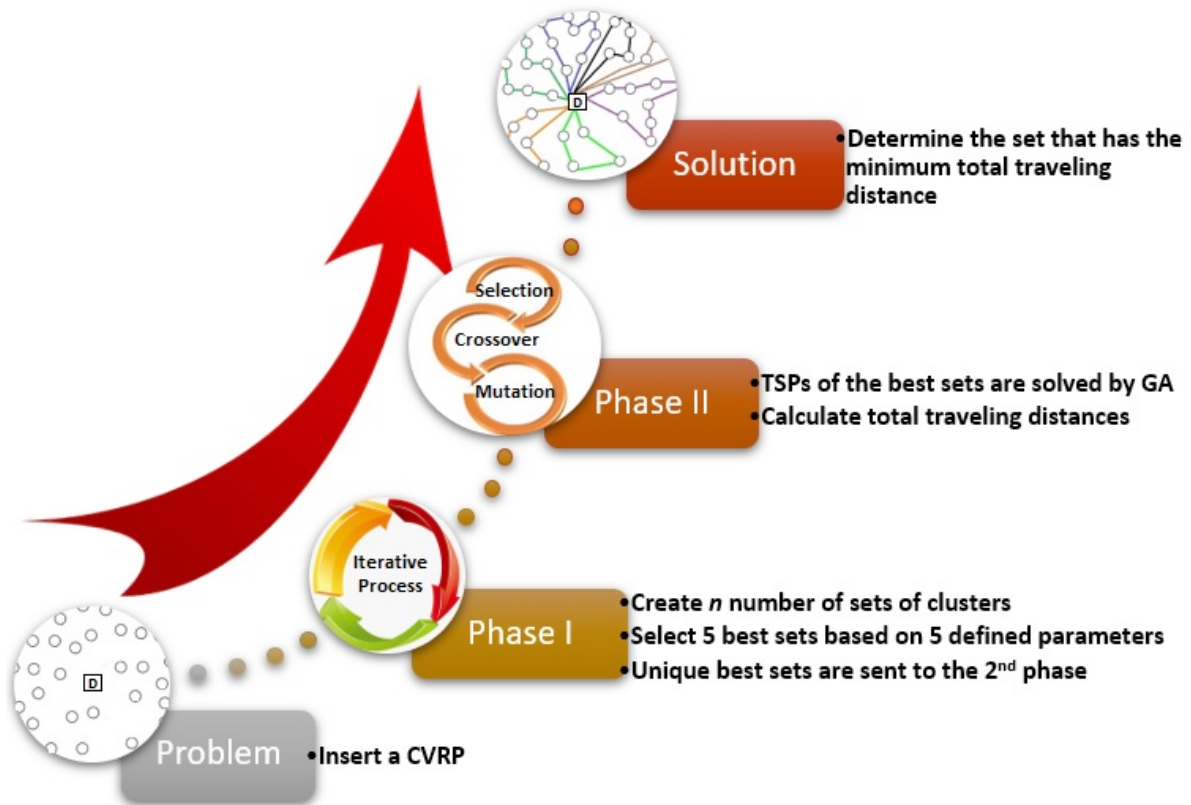# An improved two-phased heuristic algorithm for the capacitated vehicle routing problem and a case study

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Highlights

- The improved heuristic algorithm is more efficient than the prominent algorithms
- Better solutions than BKS were discovered for two benchmarked instances
- An optimal distribution schedule for the case study problem was developed

An improved two-phased heuristic algorithm for the capacitated vehicle routing problem and a case study

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Abstract: The Capacitated Vehicle Routing Problem (CVRP) is a special variant of the Vehicle Routing Problem which has been extensively addressed in the literature of Operations Research. Since CVRP is a NP-hard problem, only heuristic algorithms are capable of solving relatively large-scale problems. In this research paper, a new Improved Two-phased Heuristic algorithm is presented for solving CVRP. The Improved Two-phased Heuristic algorithm is comprised of two phases and cluster-first rout-second approach is used. In the first phase, best sets (≤ five) of clusters are obtained using an iterative procedure based on five parameters. In the second phase, the Traveling Salesman Problem (TSP) of each cluster of the obtained sets of clusters is separately solved by applying the standard Genetic algorithm (GA). Subsequently, the best set of clusters with the minimum total traveling distance is selected as the final solution. The performance of the improved algorithm was compared with three prominent algorithms find in the literature: Efficient Two-phased Heuristic algorithm, Savings algorithm and GA, using thirty well-known benchmarked instances. The computational results of the comparison revealed that the Improved Two-phased Heuristic algorithm finds the least total traveling distance within a reasonable CPU time, compared to the three stated prominent algorithms. To illustrate the proposed algorithm and its applicability, the algorithm was applied for a food manufacturing company located in Sri Lanka. The results showed that there was a significant impact in reducing the transportation cost in distributing the company products by reducing the total traveling distance.

Keywords: CVRP; savings algorithm; two-phased heuristic; genetic algorithm; comparison of heuristics.

INTRODUCTION

The Vehicle Routing Problem (VRP) is one of the most studied combinatorial optimization problems in the field of Operations Research. The VRP is directly related to the economically valued sections of almost all the businesses of the current world such as transportation and logistics. In VRP, an optimal set of routes is determined for a fleet of vehicles to satisfy the demands of geographically dispersed customers from one or more depots. Many variants of VRP have been introduced in the literature by imposing additional requirements and operational constraints for the route construction. A comprehensive literature review on the classification of the VRP was conducted by Hoff *et al.* (Hoff *et al.*, 2010). The CVRP is more important among these variants due to the higher practical relevance.

The objective of CVRP is to minimize the total traveling cost which directly depends on the total traveling distance. In the CVRP, all customers have known deterministic demands, the operation is deliveries only, customer locations are known, the capacities of vehicles are identical and based at a single depot. The operational constraints of the CVRP are; each customer is visited exactly once by exactly one vehicle to satisfy the demand, the routes of vehicles are initiated and terminated at the prime depot, and summation of customer demands of each route does not exceed the vehicle capacity.

Since the CVRP was initially formulated (Dantzig and Ramser, 1959), numerous solving techniques have been introduced. Basically, these techniques are classified into exact algorithms, heuristic algorithms, and metaheuristic algorithms. The exact algorithms solve CVRP optimally by examining all the feasible solutions in the search space such as Branch and Bound algorithm (Christofides *et al.*, 1981), and Branch and Cut algorithm (Augerat *et al.*, 1995; Lysgaard *et al.*, 2004). The CVRP is a NP-hard problem which means the complexity of the problem grows exponentially as the number of customers increases. Therefore, heuristic and metaheuristic algorithms are generally used to solve CVRP. The heuristic algorithms are reached to a near-optimal solution by examining a limited area of the search space, for examples, Savings algorithm (Clarke and Wright, 1964), Sweep algorithm (Gillett and Miller, 1971), Cluster-first Route-second algorithms (Fisher and Jaikumar, 1981; Sandaruwan *et al.*, 2019). The metaheuristic algorithms are mechanisms which iteratively improve a feasible solution of the search space and find a near-optimal solution. These mechanisms can be used to solve many optimization problems by modifying the objective function and constraints accordingly. The GA (Holland, 1995), Tabu Search algorithm (Glover, 1986) and Ant Colony algorithm (Bullnheimer *et al.*, 1997) are a few examples for the metaheuristic algorithms.

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In this research paper, an Improved Cluster-first Route-second Two-phased Heuristic algorithm is presented for solving CVRP and the performance of the presented heuristic algorithm is compared with another three prominent heuristic algorithms find in the literature: Efficient Two-phased Heuristic algorithm, Savings algorithm and GA, using thirty well-known benchmarked problem instances. To illustrate the performance of the algorithm, a CVRP of a reputed spices and allied food manufacturing company was considered as a case study.

MATERIAL AND METHODS

Mathematical formulation of the CVRP

The CVRP can be clearly represented by a weighted directed complete graph. Let G = (V, A), where V = {v_1, v_2, …, v_n} is a set of vertices that denotes the prime depot and customers, and A is a set of arcs that connects the vertices. For each arc (v_i, v_j) there is a non-negative associated weight which represents the traveling cost between v_i and v_j. The mathematical model of the CVRP can be expressed as follows:

Minimize

$$\sum_{r=1}^{p}\sum_{i=1}^{n}\sum_{j=1,i\neq j}^{n} c_{ij}\,x_{rij}, \tag{1}$$

Subject to

$$\sum_{r=1}^{p}\sum_{i=1,i\neq j}^{n} x_{rij} = 1, \qquad \forall j \in \{2,…,n\}, \tag{2}$$

$$\sum_{j=2}^{n} x_{r1j} = 1, \qquad \forall r \in \{1,…,p\}, \tag{3}$$

$$\sum_{i=1,i\neq j}^{n} x_{rij} = \sum_{i=1}^{n} x_{rji}, \qquad \forall j \in \{1,…,n\}, r \in \{1,…,p\}, \tag{4}$$

$$\sum_{i=1}^{n}\sum_{j=2,i\neq j}^{n} d_{j}x_{rij} \leq Q, \qquad \forall r \in \{1,…,p\}, \tag{5}$$

$$\sum_{r=1}^{p}\sum_{i\in S}\sum_{j\in S,i\neq j} x_{rij} \leq |S| - 1, \qquad \forall S \subseteq \{1,…,n\}, \tag{6}$$

$$x_{rij} \in \{0,1\}, \qquad \forall r \in \{1,…,p\}, i,j \in \{1,…,n\}, i \neq j, \tag{7}$$

where d_i: demand of the ith customer,

c_{ij}: the distance between the vertices v_i and v_j,

v_1: the prime depot,

Q: the vehicle capacity,

x_{rij}: a binary variable which represents the vehicle *r* traverses from v_i to v_j.

The expression (1) represents the objective: minimizing the total traveling distance. The constraints, each customer is visited by exactly one vehicle, each vehicle initiates routing from the depot only once, and the number of vehicles arriving and leaving a particular vertex is equal are represented by equations (2) to (4) respectively. The vehicle capacity constraint is represented by the inequality (5) while the sub-tour elimination constraint is ensured by the inequality (6). The binary variable is stated in (7).

Two-phased heuristic algorithms

In two-phased heuristic algorithms, two separate consecutive phases are used to solve the CVRP. According to the literature, the two-phased heuristic algorithms are categorized into two approaches: route-first cluster-second approach and cluster-first rout-second approach. In the first approach, the first phase is used to create a large-scale TSP route disregarding the constraints of the CVRP. In the second phase, this TSP route is split into feasible vehicle routes. In the second approach, all the customers are clustered into several feasible clusters and subsequently, one of the TSP algorithms is used to construct the actual vehicle routes.

A recently proposed competitive cluster-first rout-second two-phased heuristic algorithm (Sandaruwan *et al.*, 2019) was considered for improvements. At the beginning of the considered two-phased heuristic, a distance matrix is formed which contained the distances among all the vertices including the depot. Subsequently, an iterative procedure is used to create *n* (number of customers) number of sets of clusters. In each iteration, all customer vertices are clustered depending on a repeatedly updating distance list without exceeding the vehicle capacity. The sets of clusters may have different number of clusters (*k*). At the end of the first phase, the best set of clusters is selected based on the parameter defined in equation (8):

$$\sum_{i=1}^{k} \frac{Area\ of\ the\ convex\ hull\ of\ i^{th}\ cluster}{Number\ of\ vertices\ in\ that\ cluster} \tag{8}$$

In the second phase of the algorithm, the GA is separately applied to create the TSP routes of each cluster of the selected best set of clusters. The size of the initial population of the used GA is set to 100. The number of generations and elitism rate are set to 400 and 0.25 respectively. A special procedure is used for creating new generations which consists of three mutation techniques, namely Flip, Swap and Shift instead of standard crossover and mutation operators.

The improved two-phased heuristic algorithm

In the improved two-phased heuristic algorithm, several enhancements were made to both phases of the aforementioned two-phased heuristic algorithm. The same method is used to construct *n* number of sets of feasible clusters at the beginning of the first phase in the improved algorithm. Then five parameters, including the parameter defined above by (8), are evaluated for each and every set of feasible clusters. The new four parameters are stated from (9) to (12) as follows:

$$\sum_{i=1}^{k} Area\ of\ the\ convex\ hull\ of\ i^{th}\ cluster \tag{9}$$

$$\sum_{i=1}^{k} \frac{Area\ of\ the\ convex\ hull\ of\ i^{th}\ cluster}{Total\ demand\ of\ the\ vertices\ in\ that\ cluster} \tag{10}$$

$$\sum_{i=1}^{k} Mean\ distance\ of\ vertices\ in\ the\ i^{th}\ cluster\ from\ the\ centroid\ of\ that\ cluster \tag{11}$$

$$\sum_{i=1}^{k} \frac{Mean\ distance\ of\ vertices\ in\ the\ i^{th}\ cluster\ from\ the\ centroid\ of\ that\ cluster}{Total\ demand\ of\ the\ vertices\ in\ that\ cluster} \tag{12}$$

1. Set parameters
2. Generate an initial population
3. While stopping criteria is reached
4.   Evaluate fitness of population members
5.   Select individuals according to their fitness values
6.   Perform crossover to create new offspring
7.   Mutate the new offspring with mutation probability
8.   Add the new offspring to the new population
9. End while

Figure 1: The pseudocode of the standard GA.

At the end of the first phase, the five best sets of clusters are selected with regard to the above five parameters such that each set of clusters corresponds to a minimum value of the five parameters. Several parameters may take the minimum value for a selected set of clusters. Therefore, the unique sets of clusters are chosen from the five selected best sets and initiate the second phase of the heuristic.

In the second phase of the Improved Heuristic algorithm, only the chosen best unique sets of clusters ($\leq$ 5) are considered. The TSP of each cluster is separately solved by applying the standard GA and the total traveling distance of each unique best set of clusters is evaluated. The pseudocode of the standard GA is mentioned in Figure 1. Then the set of clusters that has the minimum total traveling distance is selected as the final solution for the considered CVRP. The used configurations of the GA to solve the TSP are briefly explained here: The population size is set to 100 and the Tournament Selection is used as the selection operator of the Genetic algorithm with tournament size 4. The well-known Ordered Crossover operator is applied to generate new offspring. The Swap mutation operator is applied under the mutation probability 0.9. The best 10% chromosomes of the current population are directly sent to the next generation without any change (Elitism rate = 0.1). The stopping criterion is reaching 1000 number of generations or fitness value is not improved within 300 number of generations.

Since four additional parameters are evaluated in the first phase and the GA is applied to solve TSP of more than one set of clusters in the second phase of the improved heuristic algorithm, more CPU time is consumed by the improved heuristic algorithm than the original algorithm for solving CVRP. And also, the lower boundary of the solution generated by the Improved Heuristic algorithm is the optimal solution of the original heuristic algorithm.

The Clarke and Wright heuristic algorithm (Savings algorithm)

In the literature, the Clarke and Wright heuristic is the most frequently used algorithm for solving CVRP (Clarke and Wright, 1964). This heuristic is widely known as 'Savings algorithm' due to the fact that the heuristic is based on the notion of saving distance. The heuristic is initiated with an infeasible solution in which each customer is served by a separate vehicle which means n vehicles are used to serve n customers. Subsequently, saving distances S_{ij} are calculated by the equation (13) for each pair of customers i and j, $i \neq j$, where the cost of traveling between customers i and j is represented by C_{ij}.

$$S_{ij} = C_{i0} + C_{0j} - C_{ij} \tag{13}$$

Then customer pairs are arranged in descending order of the saving distances and merging starts from the top. Two routes are merged if i and j are belonging to separate routes, subject to the vehicle capacity is not exceeded and, either i or j is the first or last customer on their routes. In the literature, there are two versions of the heuristic: Parallel version and Sequential version. In the Sequential version, the same route is expanded until no more merging is feasible but in the Parallel version the highest saving yielding pair is always merged. According to the literature, the Parallel version of the Clarke and Wright heuristic is

more efficient (Volna and Kotyrba, 2016). Therefore, the Parallel version of the Clarke and Wright heuristic is used for this study.

The genetic algorithm

Among the various available metaheuristic algorithms for solving NP-hard optimization problems in the literature, the GA is considered to be more prominent and extensively used. The GA was derived based on the Charles Darwin's theory of biological evolution (Holland, 1995). The parameters and other configurations used for the GA to solve the CVRP are the same as the GA in the second phase of the Improved Heuristic which is applied to solve the TSP, except the following changes: The well-known Partially Mapped Crossover operator is applied to generate new offspring instead of the Ordered Crossover. The mutation probability is changed to 0.5 and the stopping criterion is

changed to 5000 number of generations or fitness value does not improve within 500 number of generations. The fitness function and the operational constraints are changed accordingly.

The case study

The distribution schedule of a prominent Sri Lankan manufacturing company of spices and allied products was considered as a case study. The main manufacturing plant of the company is located in the Southern Province of Sri Lanka and it has 81 sub-distribution centers that are widely spread across the country. The demands of all the sub-distribution centers are obtained by the Logistics Department of the company and it schedules the weekly distribution routes. The transportation cost of this CVRP mainly depends on the total traveling distance. The company has a fleet of mini trucks, each having a capacity of 3,500

Table 1: Weekly predefined demands of the sub-distribution centers.

No	Center	Demand	No	Center	Demand	No	Center	Demand
1	Matara	0	28	Thissamaharama	1610.04	55	Walapane	1495.6
2	Katunayaka	625.8	29	Alawwa	704.56	56	Peradeniya	1345.61
3	Divulapiyiya	765.12	30	Kegalle	960.88	57	Welimada	1199.4
4	Mirigama	1103.76	31	Mawanella	1080.14	58	Badulla	1369.48
5	Gampaha	1061.26	32	Kandy	943.47	59	Passara	1134.86
6	Kalaniya	1373.88	33	Digana	1111.52	60	Mawathagama	512.4
7	Homagama	1439.08	34	Gampola	939.25	61	Yatiyanthota	693.15
8	Piliyandala	1878.58	35	Ruwanwella	530.11	62	Pannala	723.08
9	Panadura	1256.14	36	Hatton	2671.52	63	Negambo	620.15
10	Horana	857.56	37	Kuruwita	613.73	64	Borella	1075.28
11	Kaluthara	675.07	38	Ratnapura	1111.89	65	Maradana	548.69
12	Mathugama	867.67	39	Balngoda	1391.83	66	Anuradhapura	703.85
13	Awissawella	790.3	40	Godakawela	1138.58	67	Eppawala	622.72
14	Ambalangoda	1250.66	41	Embilipitiya	1436.76	68	Higurakgoda	847.19
15	Elpitiya	147.78	42	Dankotuwa	834.69	69	Kurunegala	408.16
16	Neluwa	842.2	43	Ahangama	1448.5	70	Matale	1019.3
17	Baddegama	724.72	44	Kiridiwela	1515.95	71	Polonnaruwa	964.61
18	Deniyaya	1335.38	45	Wattala	333.31	72	Thabuttegama	533.19
19	Urubokka	731.02	46	Maharagama	1121.82	73	Trincomale	837.91
20	Akuressa	1019.83	47	Mahiyanganaya	2270.21	74	Vavuniya	550.76
21	Weligama	1066.09	48	Ampara	1805.25	75	Chilaw	582.31
22	Kaburupitiya	1256.83	49	Meegoda	788.14	76	Dambulla	828.74
23	Walasmulla	1177	50	Monaragala	1986.85	77	Galenbinduna-wewa	472.63
24	Beliatta	817.75	51	Biyagama	750.89	78	Ambanpola	449.85
25	Dikwalle	670.25	52	Bandarawela	1818.84	79	Jaffna	1461.2
26	Agunukola-palassa	428.34	53	Wellawaya	1430.38	80	Wariyapola	49.37
27	Ambalanthota	1193.32	54	Kaduwela	780.3	81	Puttalama	457.33
						82	Padaviya	244.14

kg, to distribute the products which are assigned multiple trips in a week to satisfy the demands. For this study, demands of all the sub-distribution centers of a particular week, and the geographical locations of the distribution centers and the manufacturing plant were obtained from the Logistics Department of the company. The distances between all vertices were obtained from Google Maps. The predefined demands of the sub-distribution centers and the reference numbers are exhibited in the Table 1.

The objective of this case study was to determine a better distribution schedule to satisfy the weekly demands of all the sub-distribution centers while minimizing the total traveling distance.

RESULTS AND DISCUSSION

The performance comparison

To compare the performance of the Improved Two-Phased Heuristic algorithm with the prominent heuristic algorithms find in the literature for solving the CVRP, thirty well-known benchmarked problem instances (22 instances of Augerat *et al*. 1995 and 8 instances of Christofides and Eilon 1969) were considered. All the used benchmarked problem instances and their Best-Known Solutions (BKS) are available online at Capacitated Vehicle Routing Problem Library (CVRPLIB) ("CVRPLIB - All Instances", n.d.). Subsequently, all four heuristic algorithms including the Improved Two-Phased Heuristic algorithm were implemented in MATLAB 2014a (8.3.0.532) environment and run on a 1.60 GHz Intel Core i5 with 8.0 GB of RAM computer with the previously mentioned configurations. All the benchmarked problem instances were solved by applying these four heuristic algorithms. The total traveling distance, the CPU time required for execution and Relative Percentage Deviation (RPD) of the four heuristic algorithms for solving each benchmarked problem instance are presented in the following Table 2:

To compare the significance of the optimal total traveling distances obtained by the considered four algorithms, a one-way ANOVA test ($\alpha = 0.05$) was conducted by using RPD values. The results of the one-way ANOVA test revealed that there is a significant difference ($p = 0.026$). Therefore, the Fisher's Least Significant Difference (LSD) test was applied to perform the pairwise comparisons among the algorithms. The results of the Fisher's LSD test are shown in the Figure 2.

According to the results of the Fisher's LSD test, the optimal solutions reached by the Improved Two-Phased Heuristic is significantly better than the solutions found by the GA ($p = 0.005$) and the Savings algorithm ($p = 0.038$). According to the results of the Fisher's LSD test, the difference between the Two-phased Heuristic and the Improved Two-phased Heuristic is not statistically significant ($p = 0.357$). But, when comparing the obtained total traveling distance for each benchmarked problem instance alone as it is seen in Table 2, better optimal solutions are found by the Improved Two-phased Heuristic for 15 out of 30 instances which are highlighted in the Table 2 and for the remaining 15 instances, both algorithms have

reached to the same near-optimal solutions. Therefore, from the optimal solutions point of view, the Improved Two-phased Heuristic algorithm has performed better than the counter three algorithms considered in the study.

For each algorithm, a line graph of CPU time against 30 benchmarked problem instances is given in the Figure 3 below. The line graph exhibits that marginally more CPU time is consumed by the Improved Heuristic algorithm than the original Two-phased Heuristic and Savings algorithms. However, when compared to the CPU time consumed by the GA, the Improved Heuristic algorithm is moderately better.

Moreover, Table 2 shows that there are three negative values for RPD correspond to problem instance P-n22-k8 and E-n30-k3 which indicate that the related solutions have reached better solutions than the BKS. Therefore, in this study, the BKS of the benchmarked problem instances P-n22-k8 and E-n30-k3 are improved to 588.79 and 520.20 units respectively.

The case study

To illustrate the proposed Improved Two-phased Heuristic algorithm and its applicability, the distribution schedule of a reputed food manufacturing company was considered as a case study. The considered case study problem was solved by applying the aforementioned four heuristic algorithms separately. As the solution of each heuristic algorithm: set of routes, corresponding load and distance of the routes, total traveling distance, number of required vehicles and CPU time taken for the execution were observed. The summary of the results obtained by all four heuristic algorithms is stated in Table 3.

The main objective of the considered CVRP is to minimize the total traveling distance of the weekly distribution schedule. According to the Table 3, the minimum total traveling distance (10567 km) was determined by the Improved Two-phased Heuristic algorithm. Compared to the GA, less CPU time was consumed by the improved algorithm and requires 26 vehicles to distribute the products to all the sub-distribution centers. The details of the routes generated by the improved algorithm are exhibited in Table 4. In the table, routes are denoted by reference numbers of the sub-distribution centers which represent the sequence of routing, where number 1 referred to the manufacturing plant.

The solutions found by the heuristic algorithms clearly show that the manufacturing company prepares the distribution schedule not using any logical or analytical reasoning, but based only on its experience. The optimum distribution schedule generated by the improved heuristic algorithm has proven that the total traveling distance for distributing the manufactured products of the company to the sub-distribution centers is significantly reduced. In addition, the proposed algorithm has simplified and eased the process of preparing the weekly distribution schedules of the company.

Table 2: Computational results of four heuristic algorithms.

No	Instance	BKS	Two-Phased Heuristic			Improved Two-Phased Heuristic			Savings Algorithm			Genetic Algorithm		
			Total traveling distance	CPU time (s)	RPD (%)	Total traveling distance	CPU Time (s)	RPD (%)	Total traveling distance	CPU time (s)	RPD (%)	Total traveling distance	CPU time (s)	RPD (%)
1	P-n16-k8	450	492.28	1.35	9.40	492.28	5.56	9.40	478.77	0.03	6.39	451.34	97.20	0.30
2	P-n19-k2	212	252.19	0.5	18.96	**229.91**	3.45	8.45	248.85	0.04	17.38	212.66	59.36	0.31
3	P-n20-k2	216	218.31	0.36	1.07	218.31	1.41	1.07	252.79	0.04	17.03	217.42	85.59	0.66
4	P-n21-k2	211	212.71	0.36	0.81	212.71	2.79	0.81	253.16	0.05	19.98	212.71	121.89	0.81
5	P-n22-k2	216	217.85	0.36	0.86	217.85	2.75	0.86	260.53	0.06	20.62	217.87	92.68	0.87
6	P-n22-k8	603	724.51	1.67	20.15	**689.71**	13.01	14.38	590.62	0.05	-2.05	588.79	118.15	-2.36
7	E-n22-k4	375	385.29	0.66	2.74	385.29	5.84	2.74	388.77	0.08	3.67	375.28	150.36	0.07
8	E-n23-k3	569	592.87	0.51	4.20	**581.04**	3.96	2.12	660.93	0.07	16.16	643.95	60.90	13.17
9	E-n30-k3	534	613.68	0.68	14.92	**563.77**	9.84	5.57	603.40	0.14	13.00	520.20	126.93	-2.58
10	P-n40-k5	458	511.60	0.88	11.70	511.60	6.68	11.70	507.05	0.35	10.71	493.76	272.05	7.81
11	P-n45-k5	510	526.74	0.91	3.28	526.74	3.47	3.28	572.78	0.56	12.31	619.76	121.24	21.52
12	P-n50-k7	554	597.58	1.25	7.87	597.58	9.19	7.87	604.25	0.88	9.07	606.37	240.89	9.45
13	P-n50-k8	631	747.50	1.54	18.46	**683.63**	22.98	8.34	676.16	0.90	7.16	702.63	233.65	11.35
14	P-n50-k10	696	753.99	1.85	8.33	753.99	13.40	8.33	739.84	0.86	6.30	770.53	302.37	10.71
15	P-n51-k10	741	839.24	2.02	13.26	**798.93**	21.40	7.82	776.10	1.03	4.74	827.44	302.99	11.67
16	E-n51-k5	521	609.06	1.1	16.90	**607.64**	7.42	16.63	650.36	1.11	24.83	591.05	308.09	13.44
17	P-n55-k7	568	616.12	1.3	8.47	**614.62**	9.29	8.21	629.27	1.59	10.79	719.45	221.81	26.66
18	P-n55-k8	588	623.66	1.28	6.06	**607.26**	14.49	3.28	630.77	1.53	7.27	639.64	306.77	8.78
19	P-n55-k10	694	738.54	1.74	6.42	738.54	12.91	6.42	746.76	1.38	7.60	784.79	322.90	13.08
20	P-n60-k10	744	822.94	1.82	10.61	822.94	19.80	10.61	807.25	2.47	8.50	891.45	305.17	19.82
21	P-n60-k15	968	1097.09	2.83	13.34	**1071.57**	20.97	10.70	1005.54	2.46	3.88	1060.65	303.04	9.57
22	P-n65-k10	792	939.71	1.98	18.65	**858.13**	13.67	8.35	839.48	2.37	6.00	922.45	297.45	16.47
23	P-n70-k10	827	925.61	2.04	11.92	**918.68**	35.58	11.09	888.27	3.32	7.41	961.40	315.33	16.25
24	P-n76-k4	593	638.91	1.08	7.74	638.91	12.99	7.74	792.13	4.63	33.58	714.07	310.66	20.42
25	P-n76-k5	627	726.67	1.38	15.90	**723.21**	7.95	15.35	792.13	4.54	26.34	904.30	242.76	44.23
26	E-n76-k7	682	747.40	1.5	9.59	747.40	14.51	9.59	799.11	5.13	17.17	851.58	270.27	24.87
27	E-n76-k8	735	855.10	1.65	16.34	**802.68**	10.88	9.21	827.11	5.13	12.53	905.17	307.32	23.15
28	E-n76-k14	1021	1098.54	2.69	7.59	1098.54	29.36	7.59	1086.34	5.68	6.40	1180.55	313.55	15.63
29	P-n101-k4	681	752.88	1.49	10.56	**745.18**	6.71	9.42	926.98	15.51	36.12	1125.02	306.87	65.20
30	E-n101-k8	815	897.27	2.08	10.09	897.27	18.05	10.09	1007.16	22.21	23.58	1217.33	328.70	49.37

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Fisher Individual Tests for Differences of Means

                        Difference       SE of                          Adjusted
Difference of Levels    of Means      Difference      95% CI     T-Value  P-Value
Improved - Two-phased     -2.31          2.49     (-7.25,  2.63)  -0.92    0.357
Savings  - Two-phased      2.94          2.49     (-2.00,  7.88)   1.18    0.240
Genetic  - Two-phased      4.82          2.49     (-0.12,  9.76)   1.93    0.056
Savings  - Improved        5.25          2.49     ( 0.31, 10.19)   2.10    0.038
Genetic  - Improved        7.12          2.49     ( 2.18, 12.06)   2.86    0.005
Genetic  - Savings         1.87          2.49     (-3.07,  6.81)   0.75    0.454

Simultaneous confidence level = 79.87%
```

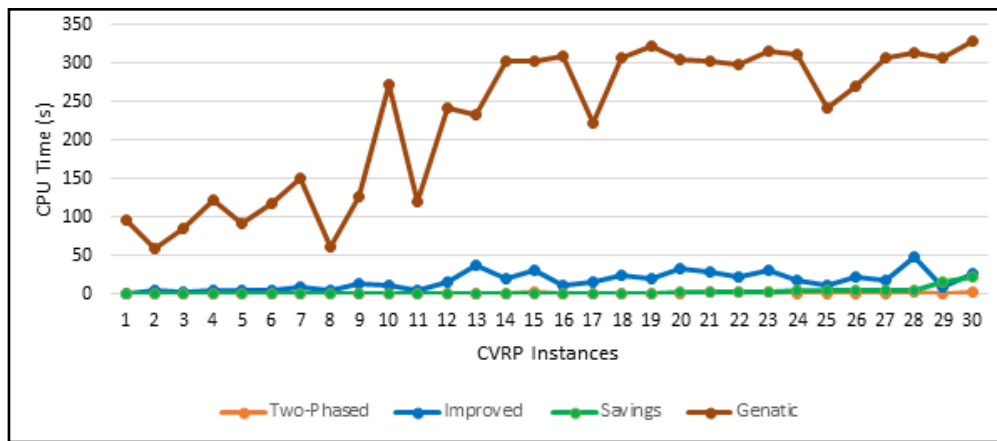**Figure 2:** Results of the Fisher's LSD test.

Figure 3: Consumed CPU time for execution.

Table 3: Results of the four heuristic algorithms.

Heuristic Algorithm	Total Distance (km)	CPU time (s)	No. of Vehicles Required
Two-Phased Heuristic	11905	5.61	27
Improved Two-Phased Heuristic	10567	44.02	26
Savings Algorithm	10984	13.04	27
Genetic Algorithm	11096	1177.10	26

Table 4: Details of the routes generated by the improved two-phased heuristic.

Route No	Route								Load (kg)	Distance (km)
1	1	73	82	74	79	1			3094	1194.4
2	1	68	71	76	60	1			3152.9	724.3
3	1	80	78	81	72	67	66	77 1	3288.9	802.2
4	1	32	33	70	69	1			3482.4	577.3
5	1	34	56	31	1				3365	520.7
6	1	55	57	1					2695	524.7
7	1	42	75	62	4	1			3243.8	492.9
8	1	5	3	29	30	1			3491.8	456
9	1	51	35	61	13	15	1		2912.2	387.4
10	1	44	2	63	45	1			3095.2	404.8
11	1	52	58	1					3188.3	404.3
12	1	37	38	39	1				3117.4	379
13	1	6	65	64	1				2997.9	323.9
14	1	50	53	1					3417.2	358.8
15	1	46	54	7	1				3341.2	304.5
16	1	8	49	17	1				3391.4	293.2
17	1	11	9	10	1				2788.8	277
18	1	47	59	1					3405.1	371.9
19	1	28	48	1					3415.3	534
20	1	40	41	24	1				3393.1	212
21	1	16	12	14	1				2960.5	244
22	1	20	18	19	1				3086.2	156
23	1	23	26	27	25	1			3468.9	152
24	1	21	43	1					2514.6	59.8
25	1	22	1						1256.8	38
26	1	36	1						2671.5	374

CONCLUSION

In this research paper, an improved cluster-first route-second two-phased heuristic algorithm was presented for solving CVRP. At the completion of solving 30 well-known benchmarked problem instances, it was revealed that the Improved Two-phased Heuristic algorithm finds the least total traveling distance, compared to the Two-phased Heuristic algorithm, GA, and Savings algorithm. Also, in this study, the BKSs of two benchmarked problem instances were improved. The case study of the food manufacturing company was solved satisfactorily. The distribution schedule recommended by the proposed algorithm has reduced the total traveling distance and also optimized the company resources. As a future direction, optimizing the route distance balancing and reducing the travel time of the CVRP could be investigated.

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DECLARATION OF CONFLICT OF INTEREST

Authors declare no conflict of interest.

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