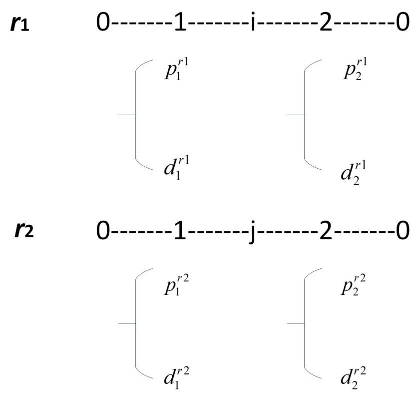
Appendix A. Proof of Corollary 2 and Corollary 3

1. Proof of Corollary 2

PROOF. Considering two routes, r_1, and r_2, as illustrated in Fig. A.1 In this particular instance, both routes share two split customers, namely, customers 1 and 2. Suppose that the total delivery and pickup demands of customers 1 and 2 are represented by d_1, p_1, d_2, and p_2, respectively. In route r_1, the pickup and delivery quantities of vehicle 1 at customer 1 and 2 are denoted by $d_1^{r1}, p_1^{r1}, d_2^{r1}, p_2^{r1}$, respectively. Similarly, in route r_2, the pickup and delivery quantities of vehicle 2 at customer 1 and 2 are denoted by $d_1^{r2}, p_1^{r2}, d_2^{r2}, p_2^{r2}$, respectively. If we can demonstrate that there is no feasible approach to reduce the overall number of visits to customers 1 and 2 from 4 to 3, we can establish the validity of **Corollary 1**.

Fig. A.1. An SDVRPSPD instance of two routes



$$\begin{cases} d_1 = d_1^{r1} + d_1^{r2} \\ d_2 = d_2^{r1} + d_2^{r2} \end{cases}$$

$$\begin{cases} p_1 = p_1^{r1} + p_1^{r2} \\ p_2 = p_2^{r1} + p_2^{r2} \end{cases}$$

Upon careful analysis, we can identify four strategies to reduce the overall number of visits to customers 1 and 2.

(1) Delete customer 1 from r_1, meaning vehicle 1 does not visit customer 1. Consequently, there is available space in r_1 and that can be utilized to accommodate an additional pickup and delivery demands of customer 2, denoted as $\Delta d_2^{r1}, \Delta p_2^{r1}$. Subsequently, in r_2, the pickup and delivery demands d_1^{r1}, p_1^{r1}, originally handled by vehicle 1 can now be handled by vehicle 2. Moreover, since $\Delta d_2^{r1}, \Delta p_2^{r1}$ is accommodated by vehicle 1 in r_1, they can be eliminated from d_2^{r2}, p_2^{r2}.

(2) Delete customer 2 from route r_1

(3) Delete customer 1 from route r_2

(4) Delete customer 2 from route r_2

Before employing the aforementioned strategies, the preceding Eq. (A.1) - Eq. (A.2) are observed to be valid. Where d_i and p_i denotes the total delivery and pickup demands between customers 1 and 2 in route 1, and d_j and p_j denotes the total delivery and pickup demands between customers 1 and 2 in route 2.

$$\begin{aligned} d_1^{r1} + d_i + d_2^{r1} &\le Q \\ p_1^{r1} + d_i + d_2^{r1} &\le Q \\ p_1^{r1} + p_i + d_2^{r1} &\le Q \\ p_1^{r1} + p_i + p_2^{r1} &\le Q \end{aligned} \qquad \text{Eq. (A.1)}$$

$$
\begin{aligned}
&d_1^{r2} + d_j + d_2^{r2} \le Q \\
&p_1^{r2} + d_j + d_2^{r2} \le Q \\
&p_1^{r2} + p_j + d_2^{r2} \le Q \\
&p_1^{r2} + p_j + p_2^{r2} \le Q
\end{aligned}
\qquad \text{Eq. (A.2)}
$$

Upon implementing strategy 1, subsequent Eq. (A.3) - Eq. (A.4) hold.

$$
\begin{aligned}
&d_i + d_2^{r1} + \Delta d \le Q \\
&p_i + d_2^{r1} + \Delta d \le Q \\
&p_i + p_2^{r1} + \Delta p \le Q
\end{aligned}
\qquad \text{Eq. (A.3)}
$$

$$
\begin{aligned}
&d_1^{r2} + d_1^{r1} + d_j + d_2^{r2} - \Delta d \le Q \\
&p_1^{r2} + p_1^{r1} + d_j + d_2^{r2} - \Delta d \le Q \\
&p_1^{r2} + p_1^{r1} + p_j + d_2^{r2} - \Delta d \le Q \\
&p_1^{r2} + p_1^{r1} + p_j + p_2^{r2} - \Delta p \le Q
\end{aligned}
\qquad \text{Eq. (A.4)}
$$

It can be inferred from Eq. (A.1) that the existence of inequalities $\Delta d_2^{r1} \le d_1^{r1}, \Delta d_2^{r1} \le p_1^{r1}, \Delta p_2^{r1} \le p_1^{r1}$ is a prerequisite for the preservation of Eq. (A.3). Similarly, Eq. (A.2) indicate that the preservation of inequalities $\Delta d_2^{r1} \ge d_1^{r1}, \Delta d_2^{r1} \ge p_1^{r1}, \Delta p_2^{r1} \ge p_1^{r1}$ is necessary for the continuation of Eq. (A.4). Thus, it can be deduced that strategy 1 can only be feasible when equation $\Delta d_2^{r1} = \Delta p_2^{r1} = d_1^{r1} = p_1^{r1}$ hold. Consequently, strategy 1 cannot be regarded as universally feasible.

Likewise, when equations $\Delta d_1^{r1} = \Delta p_1^{r1} = d_2^{r1} = p_2^{r1}$ and $\Delta d_2^{r2} = \Delta p_2^{r2} = d_2^{r2} = p_2^{r2}$, and $\Delta d_1^{r2} = \Delta p_1^{r2} = d_2^{r2} = p_2^{r2}$ hold, the feasibility of the other three strategies can only be assured. In other words, none of the aforementioned four strategies can be definitively feasible. Thus, there is no guarantee that an optimal solution exists in which no two vehicles have more than one split customer in common.

Thus, **Corollary 2** is thereby demonstrated.

2. Proof of Corollary 3

Proof. Considering two routes, r_1, and r_2, as illustrated in Fig. A.2 In this particular instance, both routes share two split customers, namely, customers 1 and 2. Suppose that the total delivery demands of customers 1 and 2 are represented by d_1, d_2 respectively. And assuming that each customer's delivery demand include two different items, namely, m_1 and m_2. In route r_1, the delivery quantities of m_1 and m_2 at customer 1 and 2 are denoted by $d_{m_1}^{1,r_1}, d_{m_2}^{1,r_1}, d_{m_1}^{2,r_1}, d_{m_2}^{2,r_1}$, respectively. Similarly, in route r_2, the delivery quantities of m_1 and m_2 at customer 1 and 2 are denoted by $d_{m_1}^{1,r_2}, d_{m_2}^{1,r_2}, d_{m_1}^{2,r_2}, d_{m_2}^{2,r_2}$, respectively. If we can demonstrate that there is no feasible approach to reduce the overall number of visits to customers 1 and 2 from 4 to 3, we can establish the validity of **Corollary 3**.

Similarly, there are four ways to reduce the total number of visits to customers 1 and 2.

Firstly, we provide the condition required to remove customer 1 from r_1 and merge it into r_2 (set as **condition 1**).

Condition 1, Only when inequalities $d_{m_1}^{1,r_1} \le d_{m_1}^{2,r_2}$ and $d_{m_2}^{1,r_1} \le d_{m_2}^{2,r_2}$ hold can customer 1 in r_1 be deleted and merged into r_2 without violating any constraints, thereby reducing the number of vehicle visits to customer 1.

Secondly, we provide the condition required to remove customer 1 from r_2 and merge it into r_1 (set as **condition 2**).

Condition 2, Only when inequalities $d_{m_1}^{1,r_2} \le d_{m_1}^{2,r_1}$ and $d_{m_2}^{1,r_2} \le d_{m_2}^{2,r_1}$ hold can customer 1 in r_2 be deleted and merged into r_1 without violating any constraints, thereby reducing the number of vehicle visits to customer 1.

Thirdlly, we provide the condition required to remove customer 2 from r_1 and merge it into r_2 (set as **condition 3**).

Condition 3, Only when inequalities $d_{m_1}^{2,r_1} \le d_{m_1}^{1,r_2}$ and $d_{m_2}^{2,r_1} \le d_{m_2}^{1,r_2}$ hold can customer 2 in r_1 be deleted and merged into r_2 without violating any constraints, thereby reducing the number of vehicle visits to customer 2.

Finally, we provide the condition required to remove customer 2 from r_2 and merge it into r_1 (set as **condition 4**).

Condition 4, Only when inequalities $d_{m_1}^{2,r_2} \le d_{m_1}^{1,r_1}$ and $d_{m_2}^{2,r_2} \le d_{m_2}^{1,r_1}$ hold can customer 2 in r_2 be deleted and merged into r_1 without violating any constraints, thereby reducing the number of vehicle visits to customer 2.

Due to the fact that at least one of the above conditions must be met in order to ensure a reduction of the number of visits to customers (those split customers in common). Thus, Corollary 3 is demonstrated.

In summary, in SDVRP, since customers only have demand for one type of items, when two routes have more than one split customer in common, there is always a customer among them which has the smallest total delivery quantities can be safely deleted form its route and merged it into another route (In other words, for a single-commodity SDVRP, at least one of the four conditions mentioned above will always be satisfied.). By using this merging method, it is certain that there exists an optimal solution property in the single-commodity SDVRP as shown in Theorem 1. However, when the demand from single-commodity shifts to multi-commodity, the situation changes because the total delivery quantities for a customer transitions from the sum of single items to the sum of multiple items. As a result, the smallest total delivery quantities do not necessarily ensure that its components are also the corresponding smallest delivery quantities. Therefore, Theorem 1 no longer applies to the SDVRP with multi-commodity. Thus, **Corollary 3** is thereby demonstrated.

Appendix B Example

The given example is composed of three delivery and pick-up sites (No. 1-3), three urban customers (No. 4-6), six rural customers (No. 7-12), and one depot (No.0). The location information is shown in Table A.1, the demand information is shown in Table A.2, including industrial demand (IND) and three different agricultural demand (AG_1-AG_3). The maximum load of the vehicle is 50. The maximum capacity of the delivery and pick-up site is 100. Gurobi gives the optimal demand allocation plan for this example as follows:{1: [9, 10], 2: [8, 11], 3: [7, 12]}, and the optimal allocation cost is 20.73. The optimal routing plan under this allocation plan is: [[0, 3, 2, 5, 0], [0, 1, 2, 4, 0], [0, 1, 6, 5, 0]], the route cost is 109.99, and the total cost is 130.72. However, the allocation plan corresponding to the optimal solution of the problem is {1: [9, 10], 2:[8, 12], 3: [7, 11},allocation cost is 23.35, routing plan is [[0, 3, 2, 4, 0], [0, 3, 1, 6, 5, 0], [0, 1, 5, 0]], ravel cost of vehicles is 103.04, and the total cost is 126.39, which is the optimal solution for this example.

Table B.1 Location information

No.	x	y
0	10	10
1	1	17
2	4	16
3	7	4
4	19	4
5	18	5
6	14	16
7	2	11
8	5	3
9	0	5
10	3	18
11	8	19
12	6	0

Table B.2 Demand information

	delivery	delivery	delivery	delivery	pick-up	pick-up	pick-up
No.	IND	AG_1	AG_2	AG_3	AG_1	AG_2	AG_3
4	*	19	28	15	*	*	*
5	*	18	16	8	*	*	*
6	*	6	10	8	*	*	*
7	30	*	*	*	6	11	3
8	14	*	*	*	14	16	6
9	35	*	*	*	3	7	5
10	24	*	*	*	9	4	8
11	20	*	*	*	7	12	4
12	5	*	*	*	4	4	5

Appendix C. Detailed numerical results

The time for solving each small instance by Gurobi is limited to 3600s, and the lower and upper bounds of the solutions obtained within the limited time are reported in columns *LB* and *UB*, respectively. *indicates that Gurobi cannot obtain any feasible solution within the limited time. For three heuristic algorithms, each solves each small instance 10 times and we report the optimal cost in column *Best_c*, the average cost in column *Avg_c*, and the average computation time in column *Avg_t*. For PRTTA and HHA, we limit their computation time to ensure that their computing time is not less than that of the T-ALNS.

Table C.1 The performance of algorithms in instance S_3_3_6

Instance	T-ALNS			Gurobi			$Gap^1(\%)$	PRTTA			$Gap^2(\%)$	HHA			$Gap^3(\%)$
	Best_c	*Avg_c*	*Avg_t(s)*	*LP*	*UP*	*t(s)*		*Best_c*	*Avg_c*	*Avg_t(s)*		*Best_c*	*Avg_c*	*Avg_t(s)*	
S_3_3_6-1	118.5	118.5	3.0	118.5	118.5	13.3	0.0	126.4	126.5	7.6	6.6	124.5	126.9	5.5	5.0
S_3_3_6-2	130.0	130.0	3.9	130.0	130.0	3.0	0.0	132.5	133.8	6.7	1.9	132.5	133.8	5.7	1.9
S_3_3_6-3	130.7	130.7	4.2	130.7	130.7	6.1	0.0	133.4	137.8	8.3	2.1	145.6	148.7	6.2	11.3
S_3_3_6-4	123.6	124.2	3.8	123.6	123.6	5.2	0.0	126.5	129.3	8.3	2.3	128.8	131.9	7.7	4.2
S_3_3_6-5	124.5	124.7	3.4	124.5	124.5	4.7	0.0	127.3	127.7	7.1	2.2	127.3	128.5	5.4	2.2
S_3_3_6-6	139.7	139.7	3.5	139.7	139.7	6.2	0.0	142.6	144.0	7.9	2.0	144.8	147.2	6.8	3.6
S_3_3_6-7	124.1	124.1	3.5	124.1	124.1	19.5	0.0	125.7	126.8	7.2	1.3	125.7	128.2	6.1	1.3
S_3_3_6-8	139.2	139.2	4.1	139.2	139.2	71.8	0.0	140.9	141.5	7.5	1.2	140.9	141.8	6.3	1.2
S_3_3_6-9	118.3	118.3	3.7	118.3	118.3	3.4	0.0	118.3	118.8	7.2	0.0	118.3	121.8	6.6	0.0
S_3_3_6-10	142.1	142.1	3.8	142.1	142.1	19.9	0.0	146.0	147.8	7.8	2.8	146.7	149.2	6.7	3.2
S_3_3_6-11	88.6	88.6	3.5	88.6	88.6	4.2	0.0	88.6	88.6	7.3	0.0	88.6	90.3	5.7	0.0
S_3_3_6-12	126.6	127.5	3.6	126.6	126.6	32.4	0.0	127.4	127.9	7.1	0.6	127.4	129.0	5.0	0.6
S_3_3_6-13	117.1	117.1	3.7	117.1	117.1	35.3	0.0	120.9	121.5	8.2	3.3	121.6	123.5	6.8	3.9
S_3_3_6-14	92.5	92.5	3.3	92.5	92.5	3.6	0.0	92.5	92.5	6.9	0.0	92.5	94.5	6.0	0.0
S_3_3_6-15	122.2	122.2	3.2	122.2	122.2	7.0	0.0	122.3	122.3	5.7	0.1	122.3	122.8	5.0	0.1
S_3_3_6-16	129.2	129.2	3.2	129.2	129.2	3.1	0.0	138.3	140.8	7.9	7.1	138.3	143.7	6.1	7.1
S_3_3_6-17	115.2	115.2	3.6	115.2	115.2	12.7	0.0	115.2	117.3	7.3	0.0	116.7	119.0	6.1	1.3
S_3_3_6-18	117.4	117.7	3.3	117.4	117.4	8.3	0.0	117.4	119.5	6.8	0.0	117.4	119.5	5.8	0.0
S_3_3_6-19	113.6	113.6	3.6	113.6	113.6	2.9	0.0	113.6	116.1	7.8	0.0	113.6	125.8	7.1	0.0
S_3_3_6-20	122.5	122.8	3.8	122.5	122.5	12.4	0.0	125.9	127.2	8.3	2.8	127.1	129.4	6.1	3.8
S_3_3_6-21	146.6	146.6	2.7	146.6	146.6	4.4	0.0	146.6	151.4	7.3	0.0	152.0	158.4	6.6	3.7
S_3_3_6-22	122.4	122.4	2.6	122.4	122.4	4.4	0.0	130.3	139.9	8.0	6.5	142.1	143.6	5.7	16.1
S_3_3_6-23	111.0	111.7	3.4	111.0	111.0	4.6	0.0	113.7	117.7	8.2	2.5	113.7	120.8	6.9	2.5
S_3_3_6-24	137.5	137.5	3.6	137.5	137.5	4.3	0.0	139.0	139.9	6.6	1.1	139.0	141.8	5.7	1.1
S_3_3_6-25	102.6	102.6	3.4	102.6	102.6	3.0	0.0	103.8	105.8	6.7	1.2	103.8	107.8	6.4	1.2
S_3_3_6-26	120.5	120.5	3.1	120.5	120.5	3.4	0.0	122.5	124.2	7.7	1.7	122.5	124.5	6.9	1.7
S_3_3_6-27	120.3	121.1	2.9	120.3	120.3	8.7	0.0	123.9	126.8	7.0	3.0	127.6	129.9	6.3	6.1
S_3_3_6-28	126.5	126.6	4.0	126.5	126.5	29.7	0.0	127.3	128.5	6.6	0.6	127.3	128.8	5.1	0.6
S_3_3_6-29	100.5	100.5	3.4	100.5	100.5	2.2	0.0	102.0	107.7	7.7	1.5	102.0	108.6	6.3	1.5
S_3_3_6-30	116.4	116.4	3.3	116.4	116.4	7.4	0.0	117.5	119.0	6.8	0.9	117.5	121.2	5.9	0.9
Avg.			3.5			11.6	0.0			7.4	1.8			6.1	2.9

Table C.2 The performance of algorithms in instance S_3_5_8

Instance	T-ALNS			Gurobi			$Gap^1(\%)$	PRTTA			$Gap^2(\%)$	HHA			$Gap^3(\%)$
	Best_c	*Avg_c*	*Avg_t(s)*	*LP*	*UP*	*t(s)*		*Best_c*	*Avg_c*	*Avg_t(s)*		*Best_c*	*Avg_c*	*Avg_t(s)*	
S_3_5_8-1	183.4	183.5	6.9	183.4	183.4	165.7	0.0	184.9	188.6	11.6	0.8	184.9	189.4	8.7	0.8
S_3_5_8-2	139.1	141.8	8.8	139.1	139.1	59.7	0.0	139.1	142.7	11.5	0.0	143.1	145.8	8.3	2.9
S_3_5_8-3	154.5	156.8	7.9	154.5	154.5	180.3	0.0	154.5	155.1	11.6	0.0	157.1	158.3	8.4	1.7
S_3_5_8-4	174.8	174.8	10.5	174.7	174.7	60.6	0.0	174.7	175.0	11.4	0.0	174.7	175.8	9.7	0.0
S_3_5_8-5	154.2	154.5	8.8	154.2	154.2	358.2	0.0	154.2	159.3	12.1	0.0	155.0	164.4	9.9	0.5

S_3_5_8-6	186.0	187.8	7.9	186.0	186.0	312.5	0.0	187.5	195.3	10.6	0.8	196.9	199.8	10.9	5.9
S_3_5_8-7	170.7	170.9	8.7	170.7	170.7	219.1	0.0	170.7	172.8	11.1	0.0	170.7	175.1	9.6	0.0
S_3_5_8-8	146.7	146.9	9.3	146.7	146.7	142.4	0.0	151.5	155.5	11.5	3.2	154.5	159.9	9.1	5.3
S_3_5_8-9	173.5	174.9	7.8	173.5	173.5	695.1	0.0	175.9	175.9	10.5	1.4	175.9	176.2	9.2	1.4
S_3_5_8-10	188.6	190.2	6.7	188.6	188.6	125.8	0.0	190.1	192.8	11.2	0.8	190.0	193.6	8.7	0.8
S_3_5_8-11	181.9	183.5	8.4	181.9	181.9	50.7	0.0	184.0	184.5	10.4	1.1	184.0	185.9	8.8	1.1
S_3_5_8-12	152.7	152.7	7.7	152.7	152.7	71.1	0.0	155.5	164.7	11.6	1.8	155.5	170.3	11.3	1.8
S_3_5_8-13	172.7	175.4	8.3	172.7	172.7	369.5	0.0	174.5	177.1	11.4	1.0	176.0	178.7	9.8	1.9
S_3_5_8-14	133.9	135.1	8.5	133.9	133.9	83.6	0.0	133.9	137.8	11.4	0.0	136.2	140.5	9.4	1.8
S_3_5_8-15	162.7	163.1	8.3	162.7	162.7	61.5	0.0	162.7	163.3	11.3	0.0	163.4	167.3	8.5	0.4
S_3_5_8-16	159.8	160.0	7.5	159.8	159.8	42.6	0.0	166.8	171.8	10.0	4.4	167.0	174.3	9.0	4.5
S_3_5_8-17	208.2	209.6	7.2	208.2	208.2	1362.2	0.0	211.3	213.1	11.7	1.5	212.1	214.5	9.7	1.9
S_3_5_8-18	189.3	190.5	7.0	189.3	189.3	50.4	0.0	190.4	191.0	11.2	0.6	190.4	192.6	8.8	0.6
S_3_5_8-19	156.8	157.6	9.2	156.8	156.8	53.2	0.0	158.4	160.9	11.9	1.0	163.8	168.5	9.4	4.4
S_3_5_8-20	149.4	150.8	9.1	149.4	149.4	37.3	0.0	149.4	150.1	11.0	0.0	149.4	155.7	8.8	0.0
S_3_5_8-21	159.4	159.7	8.8	159.4	159.4	194.5	0.0	161.5	166.7	11.0	1.3	168.5	170.5	9.9	5.7
S_3_5_8-22	215.5	215.8	8.4	215.5	215.5	471.1	0.0	216.0	219.2	9.8	0.3	216.0	221.1	9.4	0.3
S_3_5_8-23	159.5	160.1	8.8	159.5	159.5	92.3	0.0	164.1	167.2	11.6	2.9	164.1	169.4	9.5	2.9
S_3_5_8-24	158.4	159.1	8.7	158.4	158.4	537.3	0.0	158.4	160.3	11.9	0.0	158.8	161.5	9.9	0.2
S_3_5_8-25	174.9	176.4	8.3	174.9	174.9	77.0	0.0	174.9	176.7	9.9	0.0	177.0	179.6	9.7	1.2
S_3_5_8-26	160.5	160.8	8.1	160.5	160.5	37.8	0.0	160.5	160.7	10.6	0.0	160.5	162.8	8.4	0.0
S_3_5_8-27	167.4	167.7	7.8	167.4	167.4	74.4	0.0	167.4	170.2	11.7	0.0	167.4	177.4	9.4	0.0
S_3_5_8-28	157.1	158.5	8.1	157.1	157.1	202.0	0.0	159.1	161.9	10.4	1.3	163.4	163.9	9.0	4.0
S_3_5_8-29	164.2	165.2	9.1	164.2	164.2	286.6	0.0	164.2	167.6	11.6	0.0	164.6	171.9	9.5	0.3
S_3_5_8-30	154.5	154.6	6.3	154.5	154.5	139.0	0.0	154.5	155.0	12.3	0.0	156.9	162.1	9.1	1.6
Avg.			8.2			220.5	0.0			11.2	0.8			9.3	1.8

Table C.3 The performance of algorithms in instance S_5_10_15

Instance	T-ALNS			Gurobi			*Gap[1](%)*	PRTTA			*Gap[2](%)*	HHA			*Gap[3](%)*
	Best_c	*Avg_c*	*Avg_t(s)*	*LP*	*UP*	*t(s)*		*Best_c*	*Avg_c*	*Avg_t(s)*		*Best_c*	*Avg_c*	*Avg_t(s)*	
S_5_10_15-1	432.7	439.0	35.3	344.0	440.2	3600.0	1.7	445.7	450.4	51.5	3.0	444.2	450.7	53.0	2.7
S_5_10_15-2	502.5	512.0	30.3	395.1	519.9	3600.0	3.5	535.1	553.4	56.5	6.5	537.2	559.9	59.7	6.9
S_5_10_15-3	482.4	486.7	30.3	400.8	498.4	3600.0	3.3	503.7	528.6	53.9	4.4	529.2	539.8	57.9	9.7
S_5_10_15-4	428.4	434.7	25.9	331.9	442.1	3600.0	3.2	454.9	459.8	55.4	6.2	457.3	470.1	60.1	6.8
S_5_10_15-5	418.7	425.9	28.5	300.1	433.1	3600.0	3.5	431.4	436.8	55.6	3.0	434.0	444.2	59.0	3.7
S_5_10_15-6	399.7	409.3	34.5	302.9	409.3	3600.0	2.4	415.6	423.8	55.9	4.0	412.1	421.1	52.7	3.1
S_5_10_15-7	486.5	496.1	35.3	351.5	517.2	3600.0	6.3	497.8	504.7	58.0	2.3	499.3	510.8	63.3	2.6
S_5_10_15-8	400.2	404.5	44.4	345.9	430.5	3600.0	7.6	432.0	437.2	59.4	7.9	427.3	438.4	54.4	6.8
S_5_10_15-9	406.9	415.5	24.6	311.6	417.4	3600.0	2.6	413.6	417.2	52.4	1.7	420.1	428.0	55.1	3.2
S_5_10_15-10	501.3	513.1	46.7	389.7	528.3	3600.0	5.4	533.6	540.7	52.3	6.4	546.1	552.2	57.8	8.9
S_5_10_15-11	433.5	438.9	24.7	359.6	458.1	3600.0	5.7	463.8	488.4	57.2	7.0	458.0	488.6	65.1	5.7
S_5_10_15-12	522.9	526.1	45.6	417.5	532.5	3600.0	1.8	529.0	541.2	53.9	1.2	539.1	551.4	55.1	3.1

S_5_10_15-13	450.1	458.7	40.1	341.2	465.6	3600.0	3.4	469.2	477.6	55.5	4.2	472.2	479.4	54.9	4.9
S_5_10_15-14	480.6	489.1	29.1	334.7	501.1	3600.0	4.3	494.1	511.6	50.3	2.8	507.7	517.4	55.6	5.6
S_5_10_15-15	418.8	426.0	28.6	337.8	430.2	3600.0	2.7	435.3	443.0	61.3	3.9	437.6	442.8	58.4	4.5
S_5_10_15-16	494.1	498.5	33.8	359.6	504.9	3600.0	2.2	510.3	515.8	57.6	3.3	511.0	517.2	54.0	3.4
S_5_10_15-17	485.2	490.1	26.0	351.6	507.1	3600.0	4.5	495.4	506.0	57.3	2.1	492.7	504.1	58.5	1.5
S_5_10_15-18	509.5	513.4	29.2	393.0	527.9	3600.0	3.6	543.5	551.1	59.0	6.7	539.9	554.7	68.9	6.0
S_5_10_15-19	493.8	499.4	30.6	354.6	500.7	3600.0	1.4	523.5	530.0	57.4	6.0	524.0	535.0	57.9	6.1
S_5_10_15-20	435.0	439.1	37.8	373.2	457.0	3600.0	5.0	442.8	457.0	51.2	1.8	454.1	465.7	51.2	4.4
Avg.			33.1			3600.0	3.7			55.6	4.2			57.6	5.0

Table C.4 The performance of algorithms in instance S_5_30_50

Instance	T-ALNS			Gurobi			*Gap[1](%)*	PRTTA			*Gap[2](%)*	HHA			*Gap[3](%)*
	Best_c	*Avg_c*	*Avg_t(s)*	*LP*	*UP*	*t(s)*		*Best_c*	*Avg_c*	*Avg_t(s)*		*Best_c*	*Avg_c*	*Avg_t(s)*	
M_5_30_50-1	2788.3	2810.7	81.5	2337.3	*	10800.0	*	2923.8	2972.4	103.8	4.9	3002.2	3019.7	106.4	7.7
M_5_30_50-2	2119.5	2138.1	87.4	1631.1	*	10800.0	*	2068.1	2103.2	117.7	-2.4	2083.6	2113.4	100.2	-1.7
M_5_30_50-3	2461.0	2496.5	78.9	1903.6	*	10800.0	*	2444.8	2494.5	114.3	-0.7	2512.5	2531.2	106.1	2.1
M_5_30_50-4	2043.5	2070.9	80.8	1503.6	*	10800.0	*	2021.2	2030.5	103.3	-1.1	2036.0	2048.5	91.7	-0.4
M_5_30_50-5	2104.5	2118.5	70.7	1645.5	*	10800.0	*	2125.9	2164.1	96.9	1.0	2108.9	2151.6	100.5	0.2
M_5_30_50-6	2136.7	2172.3	82.9	1684.9	*	10800.0	*	2119.8	2131.2	91.3	-0.8	2132.4	2159.1	89.7	-0.2
M_5_30_50-7	2294.6	2323.2	79.4	1937.0	*	10800.0	*	2418.3	2446.2	98.9	5.4	2414.2	2444.4	106.2	5.2
M_5_30_50-8	2155.3	2170.4	78.9	1728.7	*	10800.0	*	2169.4	2180.7	88.2	0.7	2181.6	2195.7	87.4	1.2
M_5_30_50-9	2134.9	2153.7	95.0	1720.2	*	10800.0	*	2072.0	2113.1	98.7	-2.9	2084.6	2113.8	93.8	-2.4
M_5_30_50-10	2182.1	2191.6	79.9	1706.4	*	10800.0	*	2202.4	2250.8	96.6	0.9	2188.4	2242.1	98.1	0.3
M_5_30_50-11	2667.2	2678.2	67.1	2044.5	*	10800.0	*	2820.5	2838.6	106.2	5.7	2836.0	2852.2	90.9	6.3
M_5_30_50-12	2329.8	2361.9	77.6	1790.0	*	10800.0	*	2379.5	2436.3	99.7	2.1	2408.9	2453.1	102.7	3.4
M_5_30_50-13	2078.0	2103.3	81.4	1494.8	*	10800.0	*	2096.1	2162.8	108.9	0.9	2115.9	2158.2	110.5	1.8
M_5_30_50-14	2003.6	2043.0	87.4	1598.5	*	10800.0	*	2065.6	2076.5	91.6	3.1	2041.6	2088.5	93.5	1.9
M_5_30_50-15	1940.7	1949.8	76.8	1538.8	*	10800.0	*	1936.0	2001.1	114.7	-0.2	1982.7	2017.0	109.7	2.2
M_5_30_50-16	2264.4	2302.2	85.1	1719.7	*	10800.0	*	2427.4	2438.1	90.2	7.2	2398.1	2430.7	92.0	5.9
M_5_30_50-17	1945.5	1977.2	72.1	1719.7	*	10800.0	*	2107.2	2137.3	112.9	8.3	2087.9	2148.0	114.9	7.3
M_5_30_50-18	2244.0	2264.0	66.3	1513.2	*	10800.0	*	2304.0	2321.5	97.6	2.7	2311.9	2334.8	92.0	3.0
M_5_30_50-19	2328.0	2342.5	79.1	1748.4	*	10800.0	*	2412.4	2418.8	103.2	3.6	2348.0	2376.8	97.0	0.9
M_5_30_50-20	1970.2	2008.8	88.6	1687.4	*	10800.0	*	1939.1	1995.5	115.9	-1.6	1946.0	1992.5	101.8	-1.2
M_5_30_50-21	2083.5	2107.8	81.0	1621.3	*	10800.0	*	1977.4	2065.5	112.7	-5.1	2064.2	2076.1	103.3	-0.9
M_5_30_50-22	2049.9	2092.4	80.3	1607.0	*	10800.0	*	2114.3	2151.4	109.4	3.1	2157.3	2176.4	100.9	5.2
M_5_30_50-23	2183.4	2198.6	72.9	1734.7	*	10800.0	*	2199.6	2205.1	102.0	0.7	2209.0	2220.6	91.0	1.2
M_5_30_50-24	2213.6	2223.4	78.6	1726.3	*	10800.0	*	2243.2	2269.5	103.4	1.3	2271.4	2295.7	93.8	2.6
M_5_30_50-25	1939.1	1965.2	70.6	1573.1	*	10800.0	*	2024.5	2056.4	102.9	4.4	2060.0	2097.1	94.2	6.2
M_5_30_50-26	2004.9	2028.7	81.9	1414.0	*	10800.0	*	2051.8	2094.9	112.3	2.3	1965.8	2044.7	106.3	-1.9
M_5_30_50-27	3034.8	3056.9	65.1	2159.0	*	10800.0	*	3148.6	3176.4	104.1	3.7	3124.7	3150.5	98.1	3.0
M_5_30_50-28	2067.0	2096.6	85.7	1737.2	*	10800.0	*	1998.7	2027.0	104.0	-3.3	2025.0	2062.8	99.1	-2.0
M_5_30_50-29	2223.0	2231.9	76.8	1592.1	*	10800.0	*	2308.0	2316.6	90.9	3.8	2290.1	2309.7	89.1	3.0

M_5_30_50-30	3012.8	3055.7	68.8	2359.7	*	10800.0	*	3156.6	3183.8	98.0	4.8	3164.9	3192.8	90.8	5.0
Avg.			78.6			10800.0	*			103.0	1.8			98.4	2.2

Table C.5 The performance of algorithms in instance L_12_50_80

Instance	T-ALNS			Gurobi			*Gap¹(%)*	PRTTA			*Gap²(%)*	HHA			*Gap³(%)*
	Best_c	*Avg_c*	*Avg_t(s)*	*LP*	*UP*	*t(s)*		*Best_c*	*Avg_c*	*Avg_t(s)*		*Best_c*	*Avg_c*	*Avg_t(s)*	
L_ 12_ 50_ 80-1	16426.1	16692.3	327.5	9647.6	*	10800.0	*	17649.9	17812.0	1169.8	7.5	17613.5	17726.5	1195.0	7.3
L_ 12_ 50_ 80-2	16541.8	16671.5	336.3	9928.7	*	10800.0	*	17312.1	17526.5	1274.1	6.2	17335.4	17484.6	1257.0	6.4
L_ 12_ 50_ 80-3	15653.6	15922.3	286.1	8832.2	*	10800.0	*	15602.3	15775.6	1252.3	1.8	15891.6	16073.0	1024.3	3.7
L_ 12_ 50_ 80-4	19244.7	19423.2	279.6	13041.1	*	10800.0	*	19510.4	19718.7	1134.8	2.6	19578.1	19743.4	972.4	2.9
L_ 12_ 50_ 80-5	17242.5	17477.8	344.3	11094.3	*	10800.0	*	18236.7	18482.7	1242.3	6.7	18319.0	18422.9	1119.3	7.2
L_ 12_ 50_ 80-6	19255.2	19416.0	306.7	11387.9	*	10800.0	*	20390.0	20477.9	1208.8	7.2	20203.5	20438.0	1089.9	6.2
L_ 12_ 50_ 80-7	16944.1	17031.6	314.1	10504.4	*	10800.0	*	17349.4	17638.3	1190.7	4.8	17372.6	17484.5	1086.4	4.9
L_ 12_ 50_ 80-8	19570.5	19684.1	289.2	13545.7	*	10800.0	*	20427.7	20547.2	1087.9	6.0	20350.0	20483.1	1074.7	5.6
L_ 12_ 50_ 80-9	16507.4	16714.8	292.5	10593.1	*	10800.0	*	17953.7	18291.7	1327.5	10.2	17722.9	17809.6	1332.7	8.8
L_ 12_ 50_ 80-10	17514.2	17570.0	287.9	10882.6	*	10800.0	*	18374.3	18573.8	1210.5	7.9	18441.7	18515.2	1060.5	8.3
L_ 12_ 50_ 80-11	15035.6	15228.7	349.9	9283.4	*	10800.0	*	15548.3	15780.2	1013.0	4.9	15804.8	15924.4	1109.8	6.7
L_ 12_ 50_ 80-12	17337.3	17485.7	331.1	10487.1	*	10800.0	*	17476.9	17738.1	1025.4	2.8	18039.2	18234.1	1102.3	6.1
L_ 12_ 50_ 80-13	19442.5	19660.2	295.0	13470.6	*	10800.0	*	20428.8	20797.6	981.9	6.1	20815.1	20943.3	1138.6	8.1
L_ 12_ 50_ 80-14	24122.9	24430.4	296.8	15469.2	*	10800.0	*	25651.4	25766.4	1033.9	6.5	25751.5	25950.1	1178.1	6.9
L_ 12_ 50_ 80-15	16321.6	16384.8	278.6	9842.6	*	10800.0	*	17738.8	17899.0	967.0	10.7	18093.5	18430.4	1141.0	13.0
L_ 12_ 50_ 80-16	16493.5	16642.3	326.7	9409.4	*	10800.0	*	17353.5	17895.0	1062.6	6.7	17840.3	18135.7	1182.5	9.7
L_ 12_ 50_ 80-17	19985.1	20308.9	298.0	12968.8	*	10800.0	*	21327.4	21438.7	1042.8	6.4	21467.1	21568.5	1145.4	7.1
L_ 12_ 50_ 80-18	17386.0	17512.7	326.5	10171.2	*	10800.0	*	18433.0	18500.6	1063.8	9.2	18730.2	18826.6	1153.8	11.0
L_ 12_ 50_ 80-19	23446.6	23618.7	303.6	15702.1	*	10800.0	*	23936.6	24081.6	962.3	2.9	24176.0	24352.1	1054.9	3.9
L_ 12_ 50_ 80-20	20490.9	20532.8	311.9	12281.5	*	10800.0	*	22301.5	22516.3	1214.5	11.2	22817.2	22972.6	1204.0	13.8
L_ 12_ 50_ 80-21	22771.8	22915.8	341.4	14673.6	*	10800.0	*	24248.3	24539.7	1093.3	8.0	24445.0	24692.1	1207.4	8.9
L_ 12_ 50_ 80-22	18402.2	18583.9	370.6	11809.9	*	10800.0	*	19943.4	20099.0	1062.1	8.9	20227.5	20318.6	1211.2	10.4
L_ 12_ 50_ 80-23	18848.8	19083.3	311.7	12683.2	*	10800.0	*	19802.2	19882.8	918.4	9.5	19887.4	20026.5	1160.9	10.0
L_ 12_ 50_ 80-24	15979.2	16419.9	320.2	9956.8	*	10800.0	*	17159.2	17650.0	1050.5	8.4	17833.5	18368.5	1193.5	12.6
L_ 12_ 50_ 80-25	22969.0	23047.7	286.5	14271.9	*	10800.0	*	23809.5	24190.1	957.5	4.1	24372.8	24478.1	1107.6	6.5
L_ 12_ 50_ 80-26	25365.7	25487.9	303.8	16859.7	*	10800.0	*	26590.8	26882.4	1012.7	4.6	26822.6	26937.6	1131.2	5.6
L_ 12_ 50_ 80-27	17953.9	18118.9	323.0	11490.2	*	10800.0	*	18852.0	19202.4	989.1	6.3	19401.1	19694.3	1184.3	9.4
L_ 12_ 50_ 80-28	18162.5	18278.1	354.5	11241.2	*	10800.0	*	19643.3	20049.5	1146.3	9.0	19998.4	20255.5	1233.2	11.0
L_ 12_ 50_ 80-29	21579.2	21819.5	325.3	14062.4	*	10800.0	*	23541.4	23909.7	1113.9	8.5	24012.4	24242.4	1151.6	10.7
L_ 12_ 50_ 80-30	19357.0	19429.6	355.4	12174.1	*	10800.0	*	20694.2	20993.7	1113.4	7.8	21002.3	21100.3	1179.0	9.4
Avg.			315.8			10800.0	*			1097.4	5.4			1146.1	6.7