Supplemental online material for "A genetic-algorithm-based approach to the two-echelon capacitated vehicle routing problem with stochastic demands"

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1. Description of Stochastic Simulation Method

Let n_{sim} be the number of simulation iterations and Q_t the total demand changed along the route. Function normrnd(μ, σ^2) returns a random value chosen from the normal distribution with mean μ and standard deviation σ. The stochastic simulation method for calculating the expected route failure cost for type-II routes is described in **Algorithm A1**. The number of simulation iterations n_{sim} is 10,000,000.

Algorithm A1: Stochastic Simulation Method for Calculating the Expected Failure Cost for Type-II Routes

$EQ_r \leftarrow 0$, $EFC_r \leftarrow 0$ // initialization
for $\tau = 1$ to n_{sim} **do**
  $Q_t \leftarrow 0$ // every simulation iteration begins
  for $i = 1$ to n_r **do** // calculate the failure cost at ith satellite
    $q_{v(i)} \leftarrow$ normrnd ($\mu_{v(i)}$, $\sigma_{v(i)}^2$)
    if $\mu_{v(i)} > Q$ **then** // the split delivery process
      $q_{v(i)} \leftarrow \max(0, q_{v(i)} - \text{floor}(\mu_{v(i)} / Q) \cdot Q)$
    end if
    $EQ_r \leftarrow EQ_r + q_{v(i)}$
    $Q_t \leftarrow Q_t + q_{v(i)}$
    repeat
      if $Q_t > Q$ **then** // the route failure occurs

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13	$Q_t \leftarrow Q_t - Q$
14	$EFC_r \leftarrow EFC_r + 2 \cdot c_{v(0),\, v(i)}$
15	**end if**
16	**until** $Q_t < Q$
15	**end for** // one simulation iteration ends
16	**end for**
17	$EQ_r \leftarrow EQ_r / n_{sim}$ // expected total demand of the route
18	$EFC_r \leftarrow EFC_r / n_{sim}$ // expected total route failure cost

2. Details of Solutions

The solution details of five sets of benchmark instances are demonstrated in Tables A1 to A6. The number of first- and second-level vehicles, the travel cost, the expected failure cost, and the total cost of the best known deterministic solutions are reported. The feasible route with split deliveries in the deterministic situation becomes infeasible in the stochastic situation. The solutions of eight instances in Set 5 are infeasible when considering stochastic demands. The expected excess quantity of vehicles is listed in Column "Over Capacity" of Table A5. Besides the number of first- and second-level vehicles, the travel cost, the expected failure cost, and the total cost of the best solution found by the proposed GA, the average and standard deviation of total cost in five runs, the relative gap of total cost between the best known deterministic solution and the best solution obtained by the GA, and the average computational time are also shown in the tables.

Table A1 Details of solutions of Set 2 by the GA

Subset	Instance	Best Known Deterministic Solution					GA								
		First-level Vehicles	Second-level Vehicles	Travel Cost	Expected Failure Cost	Total Cost	First-level Vehicles	Second-level Vehicles	Travel Cost	Expected Failure Cost	Total Cost			Gap %	CPU (min)
											Best	Mean	Std		
a	E-n22-k4-s6-17	2	4	417.07	24.23	441.30	2	4	417.07	24.16	441.23	441.23	0.00	0.02	0.29
	E-n22-k4-s8-14	2	4	384.96	31.51	416.47	2	4	384.96	30.38	415.34	415.34	0.00	0.27	0.32
	E-n22-k4-s9-19	2	4	470.60	35.23	505.83	2	4	472.73	22.27	495.00	495.00	0.00	2.19	0.29
	E-n22-k4-s10-14	2	4	371.50	28.37	399.87	2	4	371.50	27.23	398.73	398.73	0.00	0.29	0.32
	E-n22-k4-s11-12	2	4	427.22	28.38	455.60	2	4	427.22	28.34	455.56	455.56	0.00	0.01	0.35
	E-n22-k4-s12-16	2	4	392.78	24.76	417.54	2	4	392.78	24.76	417.54	417.54	0.00	0.00	0.31
	E-n33-k4-s1-9	2	4	730.16	21.85	752.01	2	4	730.16	15.12	745.28	745.28	0.00	0.90	0.94

	E-n33-k4-s2-13	2	4	714.63	33.60	748.23	2	4	714.63	29.99	744.62	744.62	0.00	0.48	1.12
	E-n33-k4-s3-17	2	4	707.48	30.81	738.29	2	4	707.48	26.76	734.24	734.24	0.00	0.55	0.87
	E-n33-k4-s4-5	2	4	778.74	81.80	860.54	2	4	801.14	37.12	838.26	838.26	0.00	2.66	2.44
	E-n33-k4-s7-25	2	4	756.85	16.59	773.44	2	4	756.85	16.57	773.42	773.42	0.00	0.00	0.94
	E-n33-k4-s14-22	2	4	779.05	24.80	803.85	2	4	779.92	20.60	800.52	800.52	0.00	0.42	2.53
b	E-n51-k5-s2-17	2	5	597.49	39.07	636.56	3	5	603.08	26.33	629.41	629.41	0.00	1.35	7.61
	E-n51-k5-s4-46	2	5	530.76	42.37	573.13	2	5	530.76	39.54	570.30	570.30	0.00	0.54	5.34
	E-n51-k5-s6-12	2	5	554.81	29.89	584.70	3	5	556.24	25.62	581.86	581.86	0.00	0.50	8.06
	E-n51-k5-s11-19	2	5	581.64	51.50	633.14	2	5	586.03	42.81	628.84	631.42	1.78	0.70	6.48
	E-n51-k5-s27-47	2	5	538.22	32.17	570.39	3	5	539.02	27.09	566.11	566.39	0.34	0.76	7.30
	E-n51-k5-s32-37	2	5	552.28	35.95	588.23	3	5	555.65	30.95	586.60	586.60	0.00	0.42	7.42
	E-n51-k5-s2-4-17-46	2	5	530.76	42.59	573.35	2	5	541.55	26.84	568.39	568.39	0.00	0.91	7.16
	E-n51-k5-s6-12-32-37	3	5	531.92	16.23	548.15	3	5	531.92	16.13	548.05	548.05	0.00	0.02	3.19
	E-n51-k5-s11-19-27-47	3	5	527.63	16.15	543.78	3	5	527.63	15.12	542.75	542.75	0.00	0.19	3.62
c	E-n51-k5-s2-17	2	5	601.39	67.52	668.91	2	5	607.86	35.25	643.11	643.47	0.72	4.23	8.86
	E-n51-k5-s4-46	2	5	702.33	60.34	762.67	3	5	721.02	30.69	751.71	751.91	0.40	1.52	7.66
	E-n51-k5-s6-12	2	5	567.42	42.26	609.68	2	5	572.27	32.14	604.41	604.68	0.54	1.14	7.42
	E-n51-k5-s11-19	2	5	617.42	54.11	671.53	3	5	629.33	27.23	656.56	656.56	0.00	2.46	7.89
	E-n51-k5-s27-47	2	5	530.76	42.37	573.13	2	5	530.76	39.54	570.30	570.30	0.00	0.55	3.85
	E-n51-k5-s32-37	2	5	752.59	100.04	852.63	2	5	766.02	70.32	836.34	837.93	1.16	2.21	5.57
	E-n51-k5-s2-4-17-46	2	5	601.39	65.21	666.60	2	5	604.86	33.38	638.24	638.24	0.00	4.70	8.64
	E-n51-k5-s6-12-32-37	2	5	567.42	41.87	609.29	2	5	572.27	32.14	604.41	604.41	0.00	0.85	11.70
	E-n51-k5-s11-19-27-47	2	5	530.76	42.37	573.13	3	5	536.67	30.17	566.84	566.84	0.00	1.12	8.02

Table A2 Details of solutions of Set 3 by the GA

Subset	Instance	Best Known Deterministic Solution					GA								
		First-level Vehicles	Second-level Vehicles	Travel Cost	Expected Failure Cost	Total Cost	First-level Vehicles	Second-level Vehicles	Travel Cost	Expected Failure Cost	Total Cost			Gap %	CPU (min)
											Best	Mean	Std		
a	E-n22-k4-s13-14	2	4	526.15	30.39	556.54	2	4	526.15	25.34	551.49	551.49	0.00	0.92	0.34
	E-n22-k4-s13-16	2	4	521.09	43.49	564.58	2	4	529.63	20.24	549.87	549.87	0.00	2.68	0.32
	E-n22-k4-s13-17	2	4	496.38	37.13	533.51	2	4	498.90	23.51	522.41	522.41	0.00	2.12	0.31
	E-n22-k4-s14-19	2	4	498.80	34.17	532.97	2	4	498.80	30.73	529.53	529.53	0.00	0.65	0.35
	E-n22-k4-s17-19	2	4	512.80	57.24	570.04	2	4	519.44	40.85	560.29	560.29	0.00	1.74	0.36
	E-n22-k4-s19-21	2	4	520.42	54.55	574.97	2	4	546.67	26.18	572.85	572.85	0.00	0.37	0.43
	E-n33-k4-s16-22	2	4	672.17	55.44	727.61	2	4	687.87	21.16	709.03	709.03	0.00	2.62	0.83
	E-n33-k4-s16-24	2	4	666.02	52.89	718.91	2	4	683.33	26.00	709.33	709.33	0.00	1.35	0.86
	E-n33-k4-s19-26	2	4	680.36	52.55	732.91	2	4	698.89	9.68	708.57	708.57	0.00	3.44	0.93
	E-n33-k4-s22-26	2	4	680.36	52.55	732.91	2	4	691.75	21.34	713.09	713.09	0.00	2.78	1.02
	E-n33-k4-s24-28	2	4	670.43	41.57	712.00	2	4	687.76	18.05	705.81	705.81	0.00	0.88	0.90
	E-n33-k4-s25-28	2	4	650.58	35.97	686.55	2	4	651.27	32.29	683.56	683.56	0.00	0.44	0.95
b	E-n51-k5-s12-18	2	5	690.59	44.09	734.68	2	5	690.59	44.09	734.68	734.68	0.52	0.00	7.09
	E-n51-k5-s12-41	2	5	683.05	46.58	729.63	2	5	689.43	36.40	725.83	729.20	3.66	0.52	7.47
	E-n51-k5-s12-43	2	5	710.41	67.65	778.06	2	5	712.82	57.48	770.30	771.25	1.89	1.01	4.26
	E-n51-k5-s39-41	2	5	728.54	92.75	821.29	2	5	741.00	38.66	779.66	779.66	0.00	5.34	9.64
	E-n51-k5-s40-41	2	5	723.75	87.62	811.37	2	5	739.41	49.79	789.20	794.32	3.62	2.81	10.36
	E-n51-k5-s40-43	2	5	752.15	74.98	827.13	2	5	752.92	58.08	811.00	811.47	0.57	1.99	7.79
c	E-n51-k5-s13-19	2	5	560.73	27.87	588.60	2	5	560.73	27.87	588.60	588.60	0.00	0.00	7.11
	E-n51-k5-s13-42	2	5	564.45	49.41	613.86	2	5	566.86	39.24	606.10	606.10	0.00	1.28	4.06

E-n51-k5-s13-44	2	5	564.45	49.39	613.84	2	5	566.86	39.24	606.10	606.10	0.00	1.28	4.09
E-n51-k5-s40-42	2	5	746.31	62.81	809.12	2	5	750.68	44.03	794.71	796.08	2.74	1.81	11.07
E-n51-k5-s41-42	2	5	771.56	97.75	869.31	2	5	785.61	63.30	848.91	854.81	3.09	2.40	4.62
E-n51-k5-s41-44	2	5	802.91	91.67	894.58	2	5	813.18	65.08	878.26	878.26	0.00	1.86	7.50

Table A3 Details of solutions of Set 4a by the GA

Instance	Best Known Deterministic Solution					GA								
	First-level Vehicles	Second-level Vehicles	Travel Cost	Expected Failure Cost	Total Cost	First-level Vehicles	Second-level Vehicles	Travel Cost	Expected Failure Cost	Total Cost			Gap %	CPU (min)
										Best	Mean	Std		
Instance50-1	3	6	1569.42	94.50	1663.92	3	6	1575.08	83.06	1658.14	1658.14	0.00	0.35	14.21
Instance50-2	2	5	1438.32	143.58	1581.90	2	5	1505.71	20.26	1525.97	1525.97	0.00	3.67	18.91
Instance50-3	3	6	1570.43	107.26	1677.69	3	6	1582.65	78.62	1661.27	1661.27	0.00	0.99	13.22
Instance50-4	2	5	1424.04	111.33	1535.37	2	5	1474.23	28.23	1502.46	1502.54	0.10	2.19	4.03
Instance50-5	3	6	2193.52	172.64	2366.16	3	6	2245.03	76.87	2321.90	2321.90	0.00	1.91	14.76
Instance50-6	2	5	1279.89	65.57	1345.46	2	5	1279.89	65.57	1345.46	1345.46	0.00	0.00	2.75
Instance50-7	3	6	1458.60	179.06	1637.66	3	6	1492.71	122.01	1614.72	1614.88	0.08	1.42	13.70
Instance50-8	2	5	1363.76	217.52	1581.28	2	5	1407.10	36.46	1443.56	1443.91	0.40	9.54	21.57
Instance50-9	3	6	1450.25	183.74	1633.99	3	6	1503.27	116.13	1619.40	1619.44	0.07	0.90	13.78
Instance50-10	2	5	1407.65	135.44	1543.09	2	5	1435.98	44.12	1480.10	1480.10	0.00	4.26	18.39
Instance50-11	3	6	2047.43	233.83	2281.26	3	6	2071.80	130.30	2202.10	2202.10	0.00	3.59	16.27
Instance50-12	2	5	1209.46	85.77	1295.23	2	6	1258.09	6.15	1264.24	1266.77	2.44	2.45	4.08
Instance50-13	3	6	1481.80	135.72	1617.52	3	6	1491.15	90.92	1582.07	1582.07	0.00	2.24	12.74
Instance50-14	2	5	1393.64	108.23	1501.87	2	5	1442.72	17.62	1460.34	1463.99	3.08	2.84	15.05
Instance50-15	3	6	1489.92	129.15	1619.07	3	6	1499.30	102.27	1601.57	1601.57	0.00	1.09	12.97

Instance50-16	2	5	1389.20	211.86	1601.06	2	5	1416.81	37.68	1454.49	1454.49	0.00	10.08	10.75
Instance50-17	3	6	2088.48	212.71	2301.19	3	6	2114.89	99.02	2213.91	2213.91	0.00	3.94	16.12
Instance50-18	2	5	1227.68	72.62	1300.30	2	5	1240.05	45.27	1285.32	1285.32	0.00	1.17	3.60
Instance50-19	3	6	1564.66	66.57	1631.23	3	6	1571.24	52.84	1624.08	1624.08	0.00	0.44	7.05
Instance50-20	2	5	1272.98	213.08	1486.06	2	5	1297.41	45.01	1342.42	1342.42	0.00	10.70	2.98
Instance50-21	3	6	1577.82	85.55	1663.37	3	6	1591.99	59.64	1651.63	1651.63	0.00	0.71	8.32
Instance50-22	2	5	1281.83	81.89	1363.72	2	5	1288.24	64.55	1352.79	1355.08	2.69	0.81	3.16
Instance50-23	3	6	1807.35	115.99	1923.34	3	6	1837.54	45.09	1882.63	1882.63	0.00	2.16	23.23
Instance50-24	2	5	1282.69	65.54	1348.23	2	5	1282.69	65.54	1348.23	1348.23	0.00	0.00	2.82
Instance50-25	3	6	1522.40	163.43	1685.83	3	6	1548.53	104.58	1653.11	1653.11	0.00	1.98	8.90
Instance50-26	2	5	1167.47	131.67	1299.14	2	6	1241.72	8.58	1250.30	1253.11	2.31	3.91	3.85
Instance50-27	3	6	1481.56	172.04	1653.60	3	6	1506.20	84.75	1590.95	1590.95	0.00	3.94	19.70
Instance50-28	2	5	1210.46	91.03	1301.49	2	6	1258.86	6.42	1265.28	1268.22	1.47	2.86	3.89
Instance50-29	3	6	1722.00	175.84	1897.84	3	6	1753.17	70.35	1823.52	1826.49	3.64	4.08	26.17
Instance50-30	2	5	1211.63	85.59	1297.22	2	6	1260.55	6.14	1266.69	1270.60	2.60	2.41	4.26
Instance50-31	3	6	1490.32	89.43	1579.75	3	6	1496.41	71.64	1568.05	1569.34	1.28	0.75	5.94
Instance50-32	2	5	1199.05	90.20	1289.25	2	5	1223.59	30.11	1253.70	1253.89	0.39	2.84	3.09
Instance50-33	3	6	1508.32	88.37	1596.69	3	6	1511.98	75.81	1587.79	1588.72	1.28	0.56	18.46
Instance50-34	2	5	1233.96	75.96	1309.92	2	5	1264.08	29.70	1293.78	1293.78	0.00	1.25	2.52
Instance50-35	3	6	1718.42	85.69	1804.11	3	6	1729.30	57.11	1786.41	1789.87	1.83	0.99	22.53
Instance50-36	2	5	1228.95	72.27	1301.22	2	5	1240.74	45.24	1285.98	1285.98	0.00	1.19	3.14
Instance50-37	3	6	1528.73	113.80	1642.53	3	6	1545.26	70.14	1615.40	1616.82	1.96	1.68	1.93
Instance50-38	2	5	1169.20	220.45	1389.65	2	5	1183.73	61.50	1245.23	1254.01	4.39	11.60	2.96
Instance50-39	3	6	1520.92	69.95	1590.87	3	6	1527.46	44.51	1571.97	1572.86	0.45	1.20	1.99
Instance50-40	2	6	1199.42	50.65	1250.07	2	5	1214.40	28.11	1242.51	1244.56	2.51	0.61	2.96

Instance50-41	3	6	1667.96	92.32	1760.28	3	6	1704.23	28.33	1732.56	1733.14	0.72	1.60	1.86
Instance50-42	2	5	1194.54	92.90	1287.44	2	5	1245.58	26.36	1271.94	1274.52	1.63	1.22	2.86
Instance50-43	3	6	1439.67	177.09	1616.76	3	6	1475.42	82.80	1558.22	1558.73	0.62	3.76	2.31
Instance50-44	2	5	1045.14	135.38	1180.52	2	5	1058.26	30.65	1088.91	1095.19	7.23	8.41	3.29
Instance50-45	3	6	1450.95	149.51	1600.46	3	6	1487.71	67.08	1554.79	1555.46	1.34	2.94	2.07
Instance50-46	2	6	1088.79	82.66	1171.45	2	6	1098.98	36.57	1135.55	1136.66	1.34	3.16	2.96
Instance50-47	3	6	1587.29	182.79	1770.08	3	6	1628.87	59.42	1688.29	1690.79	2.33	4.84	2.70
Instance50-48	2	5	1082.21	79.31	1161.52	2	5	1085.97	56.09	1142.06	1142.06	0.00	1.70	2.76
Instance50-49	3	6	1434.88	147.37	1582.25	3	6	1470.64	84.22	1554.86	1560.67	5.78	1.76	2.62
Instance50-50	2	5	1083.16	117.94	1201.10	2	5	1123.06	18.54	1141.60	1141.60	0.00	5.21	2.70
Instance50-51	3	6	1398.03	71.74	1469.77	3	6	1402.72	55.44	1458.16	1460.45	2.37	0.80	2.32
Instance50-52	2	5	1125.69	56.86	1182.55	2	5	1146.73	18.89	1165.62	1166.52	1.10	1.45	2.50
Instance50-53	3	6	1567.79	92.84	1660.63	3	6	1574.09	50.62	1624.71	1624.71	0.00	2.21	2.10
Instance50-54	2	5	1127.66	81.83	1209.49	2	5	1156.16	28.38	1184.54	1184.54	0.00	2.11	2.08

Table A4 Details of solutions of Set 4b by the GA

Instance	Best Known Deterministic Solution					GA								
	First-level Vehicles	Second-level Vehicles	Travel Cost	Expected Failure Cost	Total Cost	First-level Vehicles	Second-level Vehicles	Travel Cost	Expected Failure Cost	Total Cost			Gap %	CPU (min)
										Best	Mean	Std		
Instance50-1	3	6	1569.42	94.50	1663.92	3	6	1575.08	83.06	1658.14	1658.76	1.24	0.35	14.95
Instance50-2	2	5	1438.32	143.58	1581.90	2	5	1505.71	20.26	1525.97	1526.35	0.74	3.67	20.64
Instance50-3	3	6	1570.43	107.26	1677.69	3	6	1582.65	78.62	1661.27	1661.27	0.00	0.99	14.18
Instance50-4	2	5	1424.04	111.33	1535.37	2	5	1474.23	28.23	1502.46	1502.54	0.10	2.19	4.92
Instance50-5	3	6	2193.52	172.64	2366.16	3	6	2245.03	76.87	2321.90	2322.02	0.24	1.91	15.71
Instance50-6	2	5	1279.89	65.57	1345.46	2	5	1279.89	65.57	1345.46	1345.46	0.00	0.00	3.05

Instance50-7	3	6	1408.58	265.27	1673.85	3	6	1451.48	151.33	1602.81	1602.82	0.01	4.43	12.20
Instance50-8	2	5	1360.32	131.83	1492.15	2	5	1415.68	20.15	1435.83	1436.59	1.24	3.92	16.09
Instance50-9	3	6	1403.53	260.07	1663.60	3	6	1472.02	124.60	1596.62	1596.62	0.00	4.20	11.25
Instance50-10	2	5	1360.54	91.92	1452.46	2	5	1408.32	12.66	1420.98	1420.98	0.00	2.22	16.98
Instance50-11	3	6	2047.43	233.83	2281.26	3	6	2071.80	130.30	2202.10	2202.10	0.00	3.59	15.97
Instance50-12	2	5	1209.46	85.77	1295.23	2	6	1258.09	6.15	1264.24	1267.79	2.23	2.45	4.35
Instance50-13	3	6	1450.94	207.89	1658.83	3	6	1491.15	90.92	1582.07	1582.07	0.00	4.85	12.88
Instance50-14	2	5	1393.64	108.23	1501.87	2	5	1442.72	17.62	1460.34	1461.34	1.12	2.84	16.93
Instance50-15	3	6	1466.84	206.19	1673.03	3	6	1499.30	102.27	1601.57	1601.57	0.00	4.46	12.86
Instance50-16	2	5	1387.85	133.05	1520.90	2	5	1405.70	26.89	1432.59	1432.59	0.00	6.16	10.24
Instance50-17	3	6	2088.48	212.71	2301.19	3	6	2114.89	99.02	2213.91	2213.91	0.00	3.94	16.39
Instance50-18	2	5	1227.68	72.62	1300.30	2	5	1240.05	45.27	1285.32	1285.32	0.00	1.17	3.58
Instance50-19	3	6	1546.28	149.64	1695.92	3	6	1571.24	52.84	1624.08	1624.08	0.00	4.42	7.13
Instance50-20	2	5	1272.98	213.08	1486.06	2	5	1297.41	45.01	1342.42	1342.42	0.00	10.70	3.12
Instance50-21	3	6	1577.82	85.55	1663.37	3	6	1591.99	59.64	1651.63	1651.63	0.00	0.71	7.67
Instance50-22	2	5	1281.83	81.89	1363.72	2	5	1288.24	64.55	1352.79	1356.20	2.78	0.81	3.07
Instance50-23	3	6	1652.98	105.09	1758.07	3	6	1684.28	48.59	1732.87	1733.66	0.40	1.45	17.49
Instance50-24	2	5	1282.69	65.54	1348.23	2	5	1282.69	65.54	1348.23	1348.23	0.00	0.00	3.23
Instance50-25	3	6	1408.58	265.27	1673.85	3	6	1451.48	151.33	1602.81	1602.81	0.00	4.43	15.39
Instance50-26	2	5	1167.47	131.67	1299.14	2	6	1241.72	8.58	1250.30	1253.95	2.76	3.91	4.87
Instance50-27	3	6	1444.49	199.87	1644.36	3	6	1508.56	49.98	1558.54	1558.98	0.44	5.51	18.43
Instance50-28	2	5	1210.46	91.03	1301.49	2	6	1258.86	6.42	1265.28	1268.21	2.69	2.86	5.11
Instance50-29	3	6	1552.66	225.73	1778.39	3	6	1612.25	63.94	1676.19	1676.44	0.42	6.10	16.93
Instance50-30	2	5	1211.63	85.59	1297.22	2	6	1260.55	6.14	1266.69	1268.94	1.89	2.41	5.36
Instance50-31	3	6	1440.85	175.83	1616.68	3	6	1496.41	71.64	1568.05	1568.60	0.42	3.10	6.47

Instance50-32	2	5	1199.05	90.20	1289.25	2	5	1223.59	30.11	1253.70	1254.23	1.06	2.76	2.62
Instance50-33	3	6	1478.87	138.83	1617.70	3	6	1503.20	71.41	1574.61	1576.99	2.20	2.74	17.45
Instance50-34	2	5	1233.96	75.96	1309.92	2	5	1264.08	29.70	1293.78	1293.78	0.00	1.25	2.86
Instance50-35	3	6	1570.73	105.91	1676.64	3	6	1583.68	62.41	1646.09	1647.82	3.47	1.86	23.38
Instance50-36	2	5	1228.95	72.27	1301.22	2	5	1240.74	45.24	1285.98	1285.98	0.00	1.19	3.71
Instance50-37	3	6	1528.73	113.80	1642.53	3	6	1545.26	70.14	1615.40	1616.11	1.44	1.68	5.35
Instance50-38	2	5	1163.07	53.92	1216.99	2	5	1163.07	53.92	1216.99	1221.88	5.16	0.00	3.47
Instance50-39	3	6	1520.92	69.95	1590.87	3	6	1527.46	44.51	1571.97	1572.86	0.45	1.20	6.93
Instance50-40	2	5	1163.04	103.36	1266.40	2	5	1214.40	28.11	1242.51	1245.33	2.31	1.92	3.12
Instance50-41	3	6	1652.98	105.09	1758.07	3	6	1698.94	31.03	1729.97	1731.81	1.11	1.62	17.91
Instance50-42	2	5	1190.17	95.61	1285.78	2	6	1231.09	17.22	1248.31	1254.16	3.02	3.00	3.84
Instance50-43	3	6	1406.10	223.04	1629.14	3	6	1455.82	92.93	1548.75	1552.46	3.22	5.19	10.44
Instance50-44	2	5	1035.05	144.50	1179.55	2	5	1056.89	30.69	1087.58	1087.58	1.48	8.46	5.49
Instance50-45	3	6	1401.87	215.84	1617.71	3	6	1487.71	67.08	1554.79	1556.97	1.23	4.05	9.33
Instance50-46	2	5	1058.10	145.02	1203.12	2	5	1076.88	50.47	1127.35	1134.29	3.55	6.72	5.28
Instance50-47	3	6	1552.66	225.73	1778.39	3	6	1609.61	55.99	1665.60	1666.27	0.84	6.77	27.04
Instance50-48	2	5	1074.51	78.00	1152.51	2	6	1114.98	9.40	1124.38	1130.91	3.64	2.50	4.72
Instance50-49	3	6	1434.88	147.37	1582.25	3	6	1470.64	84.22	1554.86	1556.34	2.95	1.76	6.89
Instance50-50	2	5	1065.30	88.59	1153.89	2	5	1123.06	18.54	1141.60	1141.60	0.00	1.08	2.82
Instance50-51	3	6	1387.51	186.33	1573.84	3	6	1402.72	55.44	1458.16	1459.18	1.11	7.93	6.89
Instance50-52	2	5	1103.47	134.07	1237.54	2	5	1146.73	18.89	1165.62	1166.07	0.90	6.17	2.73
Instance50-53	3	6	1545.76	107.07	1652.83	3	6	1567.04	54.49	1621.53	1621.73	0.42	1.93	21.12
Instance50-54	2	5	1113.66	81.41	1195.07	2	5	1142.69	27.25	1169.94	1169.98	0.07	2.15	2.43

Table A5 Details of solutions of Set 5 by the GA

Instance	Best Known Deterministic Solution						GA								
	First-level Vehicles	Second-level Vehicles	Travel Cost	Expected Failure Cost	Over Capacity	Total Cost	First-level Vehicles	Second-level Vehicles	Travel Cost	Expected Failure Cost	Total Cost			Gap %	CPU (min)
											Best	Mean	Std		
100-5-1	3	24	1564.46	481.36	0.00	2045.82	3	26	1709.88	192.04	1901.92	1916.65	12.38	7.57	180.00
100-5-1b	3	12	1108.77	289.61	0.00	1398.38	3	12	1205.22	105.55	1310.77	1333.36	12.32	6.68	180.00
100-5-2	3	23	1016.32	170.69	0.73	1187.01	3	25	1049.75	100.29	1150.04	1153.19	2.22	3.21	180.00
100-5-2b	3	12	782.25	169.07	7.78	951.32	3	12	822.90	63.51	886.41	892.84	4.34	7.32	180.00
100-5-3	3	26	1045.29	183.41	5.00	1228.70	3	25	1072.32	127.88	1200.20	1210.95	6.04	2.37	180.00
100-5-3b	3	12	828.54	99.91	0.05	928.45	3	13	867.58	60.19	927.77	933.33	3.59	0.07	180.00
100-10-1	3	27	1124.93	248.00	0.00	1372.93	4	27	1234.02	65.20	1299.22	1309.61	7.34	5.67	57.44
100-10-1b	3	13	916.25	160.38	8.63	1076.63	4	13	1001.84	13.17	1015.01	1017.38	1.79	6.07	71.52
100-10-2	3	25	1002.15	225.18	7.82	1227.33	4	25	1093.96	82.65	1176.61	1187.64	6.02	4.31	77.01
100-10-2b	3	12	779.38	158.72	9.04	938.10	3	11	804.66	64.57	869.23	875.03	5.42	7.92	180.00
100-10-3	3	27	1048.53	249.75	0.00	1298.28	4	27	1173.48	42.36	1215.84	1220.68	4.12	6.78	51.91
100-10-3b	3	13	857.93	208.55	0.00	1066.48	4	13	944.56	22.99	967.55	973.79	4.18	10.22	58.01
200-10-1	3	49	1556.95	307.88	0.00	1864.83	4	51	1694.63	125.97	1820.60	1830.49	9.87	2.43	179.40
200-10-1b	3	25	1198.10	185.74	0.00	1383.84	4	25	1304.42	29.09	1333.51	1342.42	6.66	3.77	180.00
200-10-2	3	48	1365.74	311.36	0.00	1677.10	4	50	1484.36	113.86	1598.22	1599.84	1.24	4.94	162.05
200-10-2b	3	24	1002.85	178.86	12.01	1181.71	4	23	1101.85	32.43	1134.28	1144.98	10.47	4.18	180.00
200-10-3	3	47	1800.09	448.67	0.00	2248.76	4	49	1975.85	180.89	2156.74	2174.09	10.57	4.27	180.00
200-10-3b	3	22	1204.71	211.21	0.00	1415.92	4	23	1351.94	49.29	1401.23	1431.69	22.33	1.05	180.00

Table A6 Details of solutions of Set 6 by the GA

Instance	Best Known Deterministic Solution					GA								
	First-level Vehicles	Second-level Vehicles	Travel Cost	Expected Failure Cost	Total Cost	First-level Vehicles	Second-level Vehicles	Travel Cost	Expected Failure Cost	Total Cost			Gap %	CPU (min)
										Best	Mean	Std		
A-n51-4	2	6	652.00	45.47	697.47	2	6	670.61	3.41	674.02	675.76	2.47	3.48	2.16
A-n51-5	2	7	663.41	44.15	707.56	2	7	675.02	3.13	678.15	681.59	4.21	4.34	3.14
A-n51-6	2	8	662.51	33.24	695.75	2	9	682.02	2.91	684.93	684.93	0.00	1.58	3.57
B-n51-4	2	7	563.98	29.31	593.29	2	6	577.42	5.39	582.81	582.81	0.00	1.80	1.76
B-n51-5	2	6	549.23	34.33	583.56	2	6	567.62	3.02	570.64	573.18	2.33	2.26	2.12
B-n51-6	2	6	556.32	16.97	573.29	2	6	556.32	16.97	573.29	578.83	3.07	0.00	2.64
C-n51-4	2	6	689.18	40.75	729.93	2	6	689.18	40.75	729.93	734.44	2.68	0.00	2.09
C-n51-5	2	6	723.12	31.88	755.00	2	6	724.07	26.59	750.66	755.98	5.05	0.58	2.47
C-n51-6	2	6	697.00	47.59	744.59	2	6	706.68	26.21	732.89	736.84	3.47	1.60	2.98
A-n76-4	3	12	985.95	79.04	1064.99	3	12	1014.26	27.44	1041.70	1044.63	2.27	2.24	7.31
A-n76-5	3	13	979.48	79.57	1059.05	3	12	1006.55	16.47	1023.02	1025.41	1.32	3.52	7.39
A-n76-6	3	13	970.20	94.67	1064.87	3	12	995.35	18.11	1013.46	1016.09	2.86	5.07	11.73
B-n76-4	3	12	792.73	53.16	845.89	3	11	800.60	21.55	822.15	822.15	0.00	2.89	7.23
B-n76-5	3	13	784.44	50.61	835.05	3	11	790.72	16.44	807.16	807.16	1.43	3.46	8.46
B-n76-6	3	13	774.17	60.90	835.07	3	12	793.43	18.35	811.78	811.78	0.00	2.87	10.35
C-n76-4	3	12	1054.89	148.63	1203.52	3	11	1083.99	30.21	1114.20	1114.36	0.32	8.02	11.51
C-n76-5	3	12	1115.32	163.80	1279.12	3	12	1154.40	49.47	1203.87	1203.93	0.07	6.25	8.43
C-n76-6	3	15	1060.52	149.29	1209.81	3	11	1108.92	26.26	1135.18	1135.24	0.13	6.57	10.37
A-n101-4	4	16	1194.17	104.32	1298.49	4	15	1218.40	36.63	1255.03	1257.04	2.04	3.46	180.00
A-n101-5	4	16	1211.68	136.55	1348.23	4	15	1253.91	41.86	1295.77	1297.98	1.76	4.05	151.05

A-n101-6	4	16	1156.62	135.36	1291.98	4	15	1198.59	34.81	1233.40	1237.85	2.90	4.75	51.75
B-n101-4	4	16	939.83	78.32	1018.15	4	15	975.06	28.33	1003.39	1004.03	0.52	1.47	148.15
B-n101-5	4	15	969.13	104.35	1073.48	4	15	995.72	45.81	1041.53	1044.30	1.56	3.07	180.00
B-n101-6	4	16	960.76	84.45	1045.21	4	15	986.85	26.30	1013.15	1015.53	1.47	3.16	34.38
C-n101-4	4	15	1302.16	152.81	1454.97	4	15	1359.68	35.29	1394.97	1396.69	0.93	4.30	180.00
C-n101-5	4	15	1305.82	183.06	1488.88	4	15	1364.85	46.35	1411.20	1427.15	9.10	5.50	180.00
C-n101-6	4	16	1284.48	242.65	1527.13	4	16	1406.99	29.20	1436.19	1438.14	2.05	6.33	171.49