

Online Appendix for: Improving last-mile parcel delivery through shared portering: A case study in London

Carlos Lamas-Fernandez^a, Antonio Martinez-Sykora^a, Fraser McLeod^b, Tolga Bektaş^c, Tom Cherrett^b and Julian Allen^d

^aCentre for Operational Research, Management Science and Information Systems, Southampton Business School, University of Southampton, Southampton, Highfield, SO17 1BJ, United Kingdom;

^bFaculty of Engineering and Physical Sciences, University of Southampton, Southampton, Highfield SO17 1BJ, United Kingdom;

^cUniversity of Liverpool Management School, University of Liverpool, Chatham Street, Liverpool, L69 7ZH, United Kingdom;

^dFaculty of Architecture and the Built Environment, University of Westminster, London, NW1 5LS, United Kingdom

ARTICLE HISTORY

Compiled March 11, 2023

Contents

A Pseudo-code for the constructive algorithm	2
B Fine-tuning of the algorithm parameters	3
C Extended results	4
C.1 Extended results for bag analysis	4
C.2 Extended results for the game theoretical analysis	8

Appendix A. Pseudo-code for the constructive algorithm

Algorithm 1 Constructive algorithm

```

1: for  $s = 1, \dots, |V_d|$  do
2:    $V_h^s = \{v \in V_h : v \text{ belongs to carrier } s\}$ 
3:   Solve the TSP defined on set  $Q_c = \{\{d_s\} \cup V_h^s\}$ 
4: end for
5:  $i = 1, P = \emptyset, U = V_c$ 
6: while  $U \neq \emptyset$  do
7:   Select randomly  $\bar{u} \in U$ 
8:   Set  $P_i = \{\bar{u}\}$ 
9:    $U = U \setminus \{\bar{u}\}$ 
10:   $U' = \{u \mid u \in U, \sum_{p \in P_i} w_p + w_u \leq W, \sum_{p \in P_i} l_p + l_u \leq L\}$ 
11:  while  $U' \neq \emptyset$  do
12:     $u^*, j^* = \arg \min_{u \in U', j=1, \dots, |P_i|} \mathcal{D}_w(\{P_i(1), \dots, P_i(j-1), u^*, P_i(j), \dots, P_i(|P_i|)\})$ 
13:    Let  $P^* = \{P_i(1), \dots, P_i(j-1), u^*, P_i(j), \dots, P_i(|P_i|)\}$ 
14:    if  $\nexists m_1, m_2 \in V_m$  such that  $\mathcal{D}_w(\{m_1\} \cup P^* \cup \{m_2\}) < d_{max}$  then
15:      break
16:    else
17:       $P_i = P^*$ 
18:       $U = U \setminus \{u^*\}$ 
19:       $U' = \{u \mid u \in U, \sum_{p \in P_i} w_p + w_u \leq W, \sum_{p \in P_i} l_p + l_u \leq L\}$ 
20:    end if
21:  end while
22:   $P = P \cup \{P_i\}$ 
23:   $i = i + 1$ 
24: end while
25: for  $P_i \in P$  do
26:   Let  $m = \arg \min_{m \in V_m} \mathcal{D}_w(P_i \cup \{m\})$ 
27:    $P_i = P_i \cup \{m\}$ 
28: end for
29: for  $P_i \in P$  do
30:   for  $j$  drivers required for items in  $P$  do
31:     $M^* = \{m \in V_m : \mathcal{D}_w(\{m\} \cup P_i) < d_{max}\}$ 
32:     $m^* = \arg \min_{m \in M^*} \mathcal{D}_w(\{m\} \cup P_i) + D_j(m)$ 
33:     $D_j(m) = \min_{h=1, \dots, |Q_j|} \mathcal{D}_d(\{Q_j(0), \dots, Q_j(h-1), \{m\}, Q_j(h), \dots, Q_j(|Q_j|)\})$ 
34:     $P_i = \{m^*\} \cup P_i$ 
35:   end for
36: end for

```

Appendix B. Fine-tuning of the algorithm parameters

The Tabu Search uses two parameters, namely the size t_n of the tabu list and the number n_{2opt} of moves between runs of the 2OPT heuristic. In order to analyse the performance of the algorithm with respect to parameter choice, we have performed preliminary tests using $t_n = a_1 + \lfloor a_2|V| \rfloor$, where $a_1 \in \{5, 6, \dots, 50\}$ and $a_2 \in [0, 0.25]$, and $n_{2opt} \in \{1, 2, \dots, 500\}$ as possible settings. The fine-tuning has been performed with the software package `irace` (López-Ibáñez et al., 2016) using a total of 1000 runs.

To test the performance of the algorithm for several carriers, we have used our data from two the carriers C1 and C2 and constructed four instances where the parcel data from a given day of a carrier (e.g., Monday for C1) is treated as the daily data of a new carrier. For example, the input data for carrier C1 on Monday is shown as (C1, Mon). The instances are labelled I1, I2, I3 and I4, which assume one, two, three and four carriers, respectively, as shown in Table B1. In these instances, we set the bag capacity equal to 20kg (in weight) and 200L (in volume), the maximum distance that a porter could walk as 10km, and the maximum weight and volume of a portable item to 5kg (in weight) and 50L (in volume).

Table B1. Data used to construct tuning instances with a different number of carriers. The resulting instances I1 - I4 are used only for parameter tuning.

Instance	Carrier 1	Carrier 2	Carrier 3	Carrier 4
I1	C1, Mon	-	-	-
I2	C2, Mon	C1, Tue	-	-
I3	C2, Tue,	C1, Wed	C2, Wed	-
I4	C1, Thu	C2, Thu	C1, Fri	C2, Fri

The fine-tuning experiment suggested that the settings $t_n = 22$ (with $a_1 = 22$ and $a_2 = 0$) and $n_{2opt} = 18$ provided the best results in terms of the total cost, which are used in the computational experiments.

Appendix C. Extended results

C.1. Extended results for bag analysis

In this section we show the full results for the bag/distance variation analysis (Table 3 in the article). They are presented in four tables that report with GBP costs (average over 10 runs of the algorithm) for each day of the week, for the SPR model (collaboration, Table C1 the SI model (no collaboration, Table C2) and the individual results of C1 and C2 (Tables C3 and C4). Note that here $SI = C1 + C2$.

Table C1. Bag analysis for the SPR model.

SPR

Configuration	Monday	Tuesday	Wednesday	Thursday	Friday	Weekly Avg
(A, A, 8)	247.54	225.41	252.92	244.03	251.95	244.37
(A, C, 8)	235.25	212.25	230.92	223.87	239.79	228.42
(B, A, 8)	251.76	248.30	270.22	252.82	255.67	255.75
(B, C, 8)	236.50	220.02	246.95	238.60	246.30	237.67
(C, A, 8)	250.05	251.11	262.61	251.09	259.33	254.84
(C, C, 8)	236.56	224.54	240.14	241.30	244.89	237.48
(A, A, 10)	226.32	202.61	231.42	226.29	233.57	224.04
(A, C, 10)	215.66	196.17	215.20	207.55	222.92	211.50
(B, A, 10)	230.96	226.06	241.57	232.60	237.99	233.84
(B, C, 10)	217.68	203.41	222.28	222.44	224.74	218.11
(C, A, 10)	228.15	229.42	236.87	229.09	233.56	231.42
(C, C, 10)	214.58	216.45	218.83	219.52	221.60	218.20
(A, A, 12)	206.35	202.39	209.72	207.36	214.85	208.13
(A, C, 12)	199.07	188.91	203.49	201.78	205.50	199.75
(B, A, 12)	212.73	207.66	234.16	217.52	212.17	216.85
(B, C, 12)	199.39	199.18	204.93	201.89	206.06	202.29
(C, A, 12)	224.36	211.02	228.07	218.70	220.51	220.53
(C, C, 12)	199.29	200.28	201.55	199.51	204.52	201.03
(A, A, 14)	206.10	181.95	209.75	206.01	213.87	203.54
(A, C, 14)	192.11	176.01	197.67	184.70	197.73	189.64
(B, A, 14)	207.19	204.09	212.29	208.71	211.38	208.73
(B, C, 14)	193.05	182.23	201.42	199.22	205.98	196.38
(C, A, 14)	204.60	203.69	210.34	208.27	207.78	206.93
(C, C, 14)	197.17	186.92	198.89	199.69	198.99	196.33

Table C2. Bag analysis for the SI model.

SI

Configuration	Monday	Tuesday	Wednesday	Thursday	Friday	Weekly Avg
(A, A, 8)	267.86	254.62	281.60	268.57	281.92	270.92
(A, C, 8)	256.23	252.78	265.39	253.07	270.54	259.60
(B, A, 8)	278.81	274.86	288.69	277.48	288.18	281.60
(B, C, 8)	263.02	253.03	272.69	268.01	279.08	267.16
(C, A, 8)	274.41	282.10	289.79	276.77	284.15	281.44
(C, C, 8)	264.27	257.89	271.12	266.27	274.63	266.84
(A, A, 10)	255.81	235.75	261.91	258.12	262.50	254.82
(A, C, 10)	250.00	229.89	254.58	240.20	258.21	246.58
(B, A, 10)	255.61	259.49	269.47	258.67	264.15	261.48
(B, C, 10)	248.09	242.58	250.74	250.62	256.96	249.80
(C, A, 10)	256.40	260.99	268.07	257.69	268.08	262.25
(C, C, 10)	243.05	250.95	249.27	248.98	251.90	248.83
(A, A, 12)	219.33	221.34	232.93	216.84	232.84	224.66
(A, C, 12)	211.53	209.60	218.18	212.05	223.40	214.95
(B, A, 12)	236.41	235.76	258.30	237.69	241.32	241.90
(B, C, 12)	211.54	231.74	224.30	209.63	232.43	221.93
(C, A, 12)	230.10	245.03	256.85	257.41	237.12	245.30
(C, C, 12)	212.85	232.75	232.78	207.34	229.39	223.02
(A, A, 14)	213.47	213.11	217.80	216.95	219.78	216.22
(A, C, 14)	208.95	209.39	213.76	212.27	216.32	212.14
(B, A, 14)	213.62	216.34	225.68	216.77	222.58	219.00
(B, C, 14)	206.84	210.78	210.32	209.88	215.63	210.69
(C, A, 14)	212.50	229.53	223.94	214.93	218.49	219.88
(C, C, 14)	202.37	210.05	208.02	207.72	210.05	207.64

Table C3. Bag analysis for C1.

C1

Configuration	Monday	Tuesday	Wednesday	Thursday	Friday	Weekly Avg
(A, A, 8)	176.47	157.53	186.90	167.82	183.80	174.50
(A, C, 8)	166.30	154.33	171.28	154.11	172.85	163.77
(B, A, 8)	187.42	172.67	194.26	176.74	190.60	184.34
(B, C, 8)	173.09	154.81	179.29	168.43	182.29	171.58
(C, A, 8)	183.02	174.53	194.27	176.74	186.58	183.03
(C, C, 8)	174.34	158.34	179.28	168.43	177.84	171.65
(A, A, 10)	164.55	138.70	167.15	157.73	164.01	158.43
(A, C, 10)	159.92	133.65	160.66	140.82	160.91	151.19
(B, A, 10)	164.30	159.68	174.53	157.66	166.19	164.47
(B, C, 10)	158.01	144.08	157.49	151.22	160.43	154.25
(C, A, 10)	165.09	159.54	174.57	157.67	170.13	165.40
(C, C, 10)	152.97	151.51	157.49	151.22	155.37	153.71
(A, A, 12)	148.20	136.45	158.03	136.34	155.46	146.90
(A, C, 12)	141.21	133.63	143.88	132.55	146.06	139.46
(B, A, 12)	165.28	135.70	163.37	157.06	164.77	157.23
(B, C, 12)	141.22	133.28	146.70	129.85	156.42	141.50
(C, A, 12)	158.97	143.58	163.37	157.04	160.57	156.71
(C, C, 12)	142.53	133.96	146.70	129.85	153.38	141.28
(A, A, 14)	142.35	136.36	142.89	136.33	142.68	140.12
(A, C, 14)	138.74	132.93	139.05	132.50	139.03	136.45
(B, A, 14)	142.49	137.21	151.36	135.62	146.26	142.59
(B, C, 14)	136.63	133.30	136.31	130.05	139.65	135.19
(C, A, 14)	141.38	136.50	151.36	135.65	142.16	141.41
(C, C, 14)	132.16	131.79	136.31	130.05	134.08	132.88

Table C4. Bag analysis for C2.**C2**

Configuration	Monday	Tuesday	Wednesday	Thursday	Friday	Weekly Avg
(A, A, 8)	91.39	97.10	94.70	100.76	98.12	96.41
(A, C, 8)	89.93	98.45	94.11	98.97	97.68	95.83
(B, A, 8)	91.39	102.19	94.43	100.74	97.58	97.26
(B, C, 8)	89.93	98.22	93.40	99.58	96.79	95.58
(C, A, 8)	91.39	107.57	95.52	100.03	97.58	98.42
(C, C, 8)	89.93	99.55	91.84	97.84	96.79	95.19
(A, A, 10)	91.26	97.05	94.76	100.39	98.49	96.39
(A, C, 10)	90.08	96.24	93.93	99.38	97.30	95.38
(B, A, 10)	91.31	99.81	94.94	101.01	97.95	97.00
(B, C, 10)	90.08	98.49	93.25	99.40	96.53	95.55
(C, A, 10)	91.31	101.45	93.50	100.02	97.95	96.85
(C, C, 10)	90.08	99.44	91.77	97.77	96.53	95.12
(A, A, 12)	71.13	84.89	74.90	80.50	77.38	77.76
(A, C, 12)	70.32	75.96	74.30	79.50	77.34	75.49
(B, A, 12)	71.13	100.07	94.93	80.63	76.55	84.66
(B, C, 12)	70.32	98.46	77.60	79.78	76.01	80.43
(C, A, 12)	71.13	101.45	93.48	100.37	76.55	88.60
(C, C, 12)	70.32	98.79	86.07	77.48	76.01	81.74
(A, A, 14)	71.12	76.75	74.91	80.62	77.10	76.10
(A, C, 14)	70.21	76.46	74.71	79.76	77.29	75.69
(B, A, 14)	71.12	79.13	74.31	81.15	76.32	76.41
(B, C, 14)	70.21	77.48	74.00	79.83	75.97	75.50
(C, A, 14)	71.12	93.03	72.57	79.28	76.32	78.47
(C, C, 14)	70.21	78.25	71.70	77.66	75.97	74.76

C.2. Extended results for the game theoretical analysis

The following two tables (Table C5 and Table C6) detail the full results for the game theoretical analysis (Table 5 in the article). The values reported are GBP costs, the best out of 5 algorithm runs. In Table C7 a possible cost allocation belonging to the core for the instances where the Shapley value does not fulfil this criteria, is shown. Values reported are GBP.

Table C5. Extended game theoretical analysis, part 1.

Instance	Results per coalition type																	
	Grand	Single coalitions			Coalitions of two			Shapley Value			In core?	Shapley saving			Nucleolus			
	(C1, C2, C3)	C1,C2,C3	C1	C2	C3	C1,C2	C1,C3	C2,C3	C1	C2	C3	Y/N	C1	C2	C3	C1	C2	C3
(L1, L2, L3)	371.87	162.23	135.36	163.93	266.44	272.96	266.32	129.28	112.53	130.07	Yes	20%	17%	21%	131.08	109.83	130.96	
(L1, L2, L4)	367.91	162.23	135.36	153.51	266.44	262.51	255.44	131.58	114.61	121.72	Yes	19%	15%	21%	131.08	116.75	120.08	
(L1, L2, L5)	367.19	162.23	135.36	161.00	266.44	267.68	262.76	128.52	112.62	126.06	Yes	21%	17%	22%	131.08	108.72	127.39	
(L1, L2, S1)	327.69	162.23	135.36	89.79	266.44	223.49	199.31	141.00	115.48	71.21	Yes	13%	15%	21%	139.67	115.49	72.53	
(L1, L2, S2)	324.89	162.23	135.36	96.28	266.44	225.14	197.80	139.76	112.66	72.47	Yes	14%	17%	25%	140.29	112.96	71.65	
(L1, L2, S3)	321.61	162.23	135.36	94.08	266.44	225.27	198.61	138.79	112.03	70.79	Yes	14%	17%	25%	138.70	112.04	70.87	
(L1, L2, S4)	311.61	162.23	135.36	98.75	266.44	233.59	204.92	133.96	106.19	71.46	Yes	17%	22%	28%	134.16	105.49	71.96	
(L1, L2, S5)	330.66	162.23	135.36	97.80	266.44	228.90	203.93	140.02	114.10	76.54	Yes	14%	16%	22%	139.38	114.41	76.87	
(L1, L3, L4)	393.91	162.23	163.93	153.51	272.96	262.51	266.16	133.00	135.67	125.24	Yes	18%	17%	18%	132.35	136.00	125.55	
(L1, L3, L5)	393.99	162.23	163.93	161.00	272.96	267.68	271.76	130.77	133.66	129.56	Yes	19%	18%	20%	130.37	134.45	129.17	
(L1, L3, S1)	332.65	162.23	163.93	89.79	272.96	223.49	224.56	130.56	131.95	70.14	Yes	20%	20%	22%	128.42	129.50	74.74	
(L1, L3, S2)	337.74	162.23	163.93	96.28	272.96	225.14	224.35	131.52	131.98	74.24	Yes	19%	19%	23%	129.04	128.26	80.44	
(L1, L3, S3)	333.79	162.23	163.93	94.08	272.96	225.27	226.84	129.76	131.40	72.63	Yes	20%	20%	23%	127.39	128.95	77.46	
(L1, L3, S4)	342.55	162.23	163.93	98.75	272.96	233.59	235.68	130.35	132.24	79.96	Yes	20%	19%	19%	128.15	130.23	84.17	
(L1, L3, S5)	341.44	162.23	163.93	97.80	272.96	228.90	234.65	129.69	133.42	78.32	Yes	20%	19%	20%	126.27	132.03	83.14	
(L1, L4, L5)	364.02	162.23	153.51	161.00	262.51	267.68	262.61	123.83	116.93	123.26	Yes	24%	24%	23%	122.99	117.93	123.09	
(L1, L4, S1)	329.72	162.23	153.51	89.79	262.51	223.49	219.29	131.34	124.88	73.50	Yes	19%	19%	18%	127.71	123.51	78.50	
(L1, L4, S2)	327.06	162.23	153.51	96.28	262.51	225.14	222.66	128.52	122.92	75.62	Yes	21%	20%	21%	124.56	122.09	80.42	
(L1, L4, S3)	325.37	162.23	153.51	94.08	262.51	225.27	200.67	135.68	119.02	70.68	Yes	16%	22%	25%	137.27	112.67	75.43	
(L1, L4, S4)	333.01	162.23	153.51	98.75	262.51	233.59	208.16	136.34	119.26	77.42	Yes	16%	22%	22%	137.60	112.17	83.25	
(L1, L4, S5)	331.42	162.23	153.51	97.80	262.51	228.90	225.12	129.49	123.29	78.63	Yes	20%	20%	20%	125.87	122.19	83.35	
(L1, L5, S1)	331.22	162.23	161.00	89.79	267.68	223.49	222.13	130.50	129.21	71.51	Yes	20%	20%	20%	127.95	126.60	76.66	
(L1, L5, S2)	328.43	162.23	161.00	96.28	267.68	225.14	228.89	126.51	127.78	74.14	Yes	22%	21%	23%	123.08	126.83	78.52	
(L1, L5, S3)	331.29	162.23	161.00	94.08	267.68	225.27	228.50	127.99	128.99	74.32	Yes	21%	20%	21%	124.61	127.83	78.85	
(L1, L5, S4)	337.92	162.23	161.00	98.75	267.68	233.59	238.13	127.59	129.25	81.08	Yes	21%	20%	18%	124.44	128.98	84.49	
(L1, L5, S5)	339.36	162.23	161.00	97.80	267.68	228.90	229.76	130.24	130.06	79.06	Yes	20%	19%	19%	126.88	127.74	84.74	
(L1, S1, S2)	269.31	162.23	89.79	96.28	223.49	225.14	135.04	142.59	61.33	65.40	Yes	12%	32%	32%	145.15	61.26	62.90	
(L1, S1, S3)	266.17	162.23	89.79	94.08	223.49	225.27	136.14	141.57	60.78	63.82	Yes	13%	32%	32%	141.88	61.26	63.04	
(L1, S1, S4)	298.10	162.23	89.79	98.75	223.49	233.59	163.69	143.64	72.46	82.00	Yes	11%	19%	17%	142.60	72.70	82.80	
(L1, S1, S5)	271.40	162.23	89.79	97.80	223.49	228.90	140.07	141.98	61.35	68.06	Yes	12%	32%	30%	143.47	61.26	66.67	
(L1, S2, S3)	267.84	162.23	96.28	94.08	225.14	225.27	141.94	139.39	64.75	63.71	Yes	14%	33%	32%	141.90	62.90	63.04	
(L1, S2, S4)	275.70	162.23	96.28	98.75	225.14	233.59	148.96	140.27	64.98	70.44	Yes	14%	33%	29%	141.43	62.90	71.36	
(L1, S2, S5)	272.04	162.23	96.28	97.80	225.14	228.90	162.04	134.07	67.67	70.30	Yes	17%	30%	28%	134.00	61.71	70.91	
(L1, S3, S4)	281.30	162.23	94.08	98.75	225.27	233.59	145.53	143.67	65.57	72.06	Yes	11%	30%	27%	146.91	63.04	71.36	
(L1, S3, S5)	268.69	162.23	94.08	97.80	225.27	228.90	141.36	140.24	62.39	66.07	Yes	14%	34%	32%	138.99	63.04	66.67	
(L1, S4, S5)	279.31	162.23	98.75	97.80	233.59	228.90	147.59	142.30	69.91	67.09	Yes	12%	29%	31%	141.28	71.36	66.67	
(L2, L3, L4)	388.74	135.36	163.93	153.51	266.32	255.44	266.16	120.03	139.68	129.03	No	11%	15%	16%	126.06	136.78	125.90	
(L2, L3, L5)	399.53	135.36	163.93	161.00	266.32	262.76	271.76	121.74	140.52	137.28	No	10%	14%	15%	128.37	137.36	133.80	
(L2, L3, S1)	331.66	135.36	163.93	89.79	266.32	199.31	224.56	116.14	143.05	72.47	Yes	14%	13%	19%	116.05	141.31	74.30	
(L2, L3, S2)	327.33	135.36	163.93	96.28	266.32	197.80	224.35	113.43	140.99	72.91	Yes	16%	14%	24%	114.25	140.80	72.28	
(L2, L3, S3)	335.14	135.36	163.93	94.08	266.32	198.61	226.84	115.71	144.11	75.33	Yes	15%	12%	20%	115.47	143.69	75.98	
(L2, L3, S4)	339.35	135.36	163.93	98.75	266.32	204.92	235.68	114.44	144.10	80.81	Yes	15%	12%	18%	113.08	143.83	82.44	
(L2, L3, S5)	335.18	135.36	163.93	97.80	266.32	203.93	234.65	113.38	143.03	78.77	Yes	16%	13%	19%	112.04	142.76	80.37	
(L2, L4, L5)	359.67	135.36	153.51	161.00	255.44	262.76	262.61	111.42	120.42	127.83	Yes	18%	22%	21%	112.19	120.08	127.39	
(L2, L4, S1)	319.68	135.36	153.51	89.79	255.44	199.31	219.29	113.83	132.89	72.97	Yes	16%	13%	19%	111.95	131.94	75.80	
(L2, L4, S2)	325.02	135.36	153.51	96.28	255.44	197.80	222.66	113.15	134.65	77.22	Yes	16%	12%	20%	110.98	135.84	78.20	
(L2, L4, S3)	303.30	135.36	153.51	94.08	255.44	198.61	200.67	113.74	123.84	65.71	Yes	16%	19%	30%	118.67	120.73	63.90	
(L2, L4, S4)	308.65	135.36	153.51	98.75	255.44	204.92	208.16	113.30	123.99	71.36	Yes	16%	19%	28%	117.57	120.80	70.28	
(L2, L4, S5)	304.55	135.36	153.51	97.80	255.44	203.93	225.12	106.24	125.96	72.35	Yes	22%	18%	26%	104.91	126.19	73.45	
(L2, L5, S1)	329.91	135.36	161.00	89.79	262.76	199.31	222.13	116.26	140.49	73.16	Yes	14%	13%	19%	115.90	138.73	75.28	
(L2, L5, S2)	329.15	135.36	161.00	96.28	262.76	197.80	228.89	112.42	140.78	75.94	Yes	17%	13%	21%	110.65	141.73	76.78	
(L2, L5, S3)	326.11	135.36	161.00	94.08	262.76	198.61	228.50	112.04	139.80	74.27	Yes	17%	13%	21%	110.16	140.04	75.90	
(L2, L5, S4)	336.90	135.36	161.00	98.75	262.76	204.92	238.13	112.70	142.12	82.08	Yes	17%	12%	17%	109.44	142.65	84.81	
(L2, L5, S5)	334.77	135.36	161.00	97.80	262.76	203.93	229.76	114.77	140.51	79.49	Yes	15%	13%	19%	113.98	139.81	80.98	
(L2, S1, S2)	263.54	135.36	89.79	96.28	199.31	197.80	135.04	123.13	68.96	71.45	No	9%	23%	26%	130.19	67.43	65.93	
(L2, S1, S3)	259.63	135.36	89.79	94.08	199.31	198.61	136.14	121.96	67.94	69.73	No	10%	24%	26%	128.42	65.95	65.26	
(L2, S1, S4)	272.20	135.36	89.79	98.75	199.31	204.92	163.69	117.24	73.84	81.13	Yes	13%	18%	18%	116.35	75.12	80.74	
(L2, S1, S5)	267.43	135.36	89.79	97.80	199.31	203.93	140.07	123.52	68.80	75.12	No	9%	23%	23%	130.17	66.32	70.94	
(L2, S2, S3)	261.36	135.36	96.28	94.08	197.80	198.61	141.94	119.27	71.39	70.70	No	12%	26%	25%	124.63	67.96	68.76	
(L2, S2, S4)	268.53	135.36	96.28	98.75	197.80	204.92	148.96	119.59	72.07	76.87	Yes	12%	25%	22%	124.45	68.48	75.60	
(L2, S2, S5)	265.06	135.36	96.28	97.80	197.80	203.93	162.04	114.07	73.58	77.41	Yes	16%	24%	21%	114.24	72.35	78.47	
(L2, S3, S4)	270.00	135.36	94.08	98.75	198.61	204.92	145.53	121.73	71.39	76.88	No	10%	24%	22%	127.49	68.10	74.41	
(L2, S3, S5)	266.89	135.36	94.08	97.80	198.61	203.93	141.36	122.08	70.15	74.67	No	10%	25%	24%	128.90	66.33	71.65	
(L2, S4, S5)	274.56	135.36	98.75	97.80	204.92	203.93	147.59	122.83	76.35	75.38	No	9%	23%	23%	129.41	73.07	72.08	

Table C6. Extended game theoretical analysis, part 2.

Results per coalition type																			
Instance	Grand	Single coalitions			Coalitions of two			Shapley Value			In core?	Shapley saving			Nucleolus				
(C1, C2, C3)	C1,C2,C3	C1	C2	C3	C1,C2	C1,C3	C2,C3	C1	C2	C3	Y/N	C1	C2	C3	C1	C2	C3		
(L3, L4, L5)	390.07	163.93	153.51	161.00	266.16	271.76	262.61	134.36	124.58	131.13	Yes	18%	19%	19%	134.25	125.11	130.71		
(L3, L4, S1)	330.09	163.93	153.51	89.79	266.16	224.56	219.29	132.81	124.97	72.31	Yes	19%	19%	19%	129.26	123.98	76.86		
(L3, L4, S2)	328.85	163.93	153.51	96.28	266.16	224.35	222.66	130.16	124.11	74.59	Yes	21%	19%	23%	125.53	123.84	79.49		
(L3, L4, S3)	328.61	163.93	153.51	94.08	266.16	226.84	200.67	138.19	119.90	70.52	Yes	16%	22%	25%	140.09	113.92	74.60		
(L3, L4, S4)	337.30	163.93	153.51	98.75	266.16	235.68	208.16	139.29	120.32	77.70	Yes	15%	22%	21%	140.94	113.42	82.94		
(L3, L4, S5)	330.30	163.93	153.51	97.80	266.16	234.65	225.22	131.25	121.33	77.72	Yes	20%	21%	21%	129.38	119.94	80.97		
(L3, L5, S1)	335.48	163.93	161.00	89.79	271.76	224.56	222.13	133.35	130.67	71.47	Yes	19%	19%	20%	130.58	128.14	76.76		
(L3, L5, S2)	335.92	163.93	161.00	96.28	271.76	224.35	228.89	130.12	130.93	74.86	Yes	21%	19%	22%	125.58	130.11	80.22		
(L3, L5, S3)	333.19	163.93	161.00	94.08	271.76	226.84	228.50	130.13	129.49	73.57	Yes	21%	20%	22%	126.89	128.54	77.76		
(L3, L5, S4)	337.35	163.93	161.00	98.75	271.76	235.68	238.13	129.00	128.76	79.59	Yes	21%	20%	19%	126.36	128.82	82.17		
(L3, L5, S5)	338.26	163.93	161.00	97.80	271.76	234.65	229.76	132.08	128.17	78.02	Yes	19%	20%	20%	130.50	125.61	82.16		
(L3, S1, S2)	274.26	163.93	89.79	96.28	224.56	224.35	135.04	144.86	63.14	66.27	Yes	12%	30%	31%	151.03	61.72	61.51		
(L3, S1, S3)	265.56	163.93	89.79	94.08	224.56	226.84	136.14	142.37	59.95	63.23	Yes	13%	33%	33%	142.02	60.64	62.91		
(L3, S1, S4)	296.26	163.93	89.79	98.75	224.56	235.68	163.69	144.12	71.05	81.09	Yes	12%	21%	18%	143.04	71.06	82.17		
(L3, S1, S5)	272.79	163.93	89.79	97.80	224.56	234.65	140.07	144.16	59.80	68.84	Yes	12%	33%	30%	141.43	60.64	70.73		
(L3, S2, S3)	270.35	163.93	96.28	94.08	224.35	226.84	141.94	140.92	64.65	64.79	Yes	14%	33%	31%	145.88	60.99	63.47		
(L3, S2, S4)	276.81	163.93	96.28	98.75	224.35	235.68	148.96	141.42	64.24	71.14	Yes	14%	33%	28%	145.89	59.79	71.12		
(L3, S2, S5)	275.63	163.93	96.28	97.80	224.35	234.65	162.04	136.66	66.53	72.44	Yes	17%	31%	26%	136.85	64.24	74.54		
(L3, S3, S4)	274.84	163.93	94.08	98.75	226.84	235.68	145.53	142.69	62.70	69.45	Yes	13%	33%	30%	146.62	59.69	68.53		
(L3, S3, S5)	274.96	163.93	94.08	97.80	226.84	234.65	141.36	144.11	62.54	68.31	Yes	12%	34%	30%	141.33	62.91	70.73		
(L3, S4, S5)	280.05	163.93	98.75	97.80	235.68	234.65	147.59	144.43	68.31	67.32	Yes	12%	31%	31%	137.58	71.75	70.73		
(L4, L5, S1)	330.00	153.51	161.00	89.79	262.61	219.29	222.13	125.64	130.81	73.55	Yes	18%	19%	18%	124.28	127.13	78.59		
(L4, L5, S2)	327.86	153.51	161.00	96.28	262.61	222.66	228.89	122.16	129.02	76.69	Yes	20%	20%	20%	120.44	126.66	80.77		
(L4, L5, S3)	322.08	153.51	161.00	94.08	262.61	200.67	228.50	117.06	134.73	70.29	Yes	24%	16%	25%	109.46	137.28	75.34		
(L4, L5, S4)	333.91	153.51	161.00	98.75	262.61	208.16	238.13	118.26	137.00	78.65	Yes	23%	15%	20%	109.47	139.44	84.99		
(L4, L5, S5)	331.02	153.51	161.00	97.80	262.61	225.22	229.76	123.09	129.11	78.81	Yes	20%	20%	19%	121.69	126.23	83.10		
(L4, S1, S2)	260.58	153.51	89.79	96.28	219.29	222.66	135.04	135.66	59.99	64.92	Yes	12%	33%	33%	127.57	63.85	69.15		
(L4, S1, S3)	258.55	153.51	89.79	94.08	219.29	200.67	136.14	131.32	67.20	60.03	Yes	14%	25%	36%	135.41	70.88	52.26		
(L4, S1, S4)	269.03	153.51	89.79	98.75	219.29	208.16	163.69	126.10	72.01	70.92	Yes	18%	20%	28%	129.42	65.70	73.90		
(L4, S1, S5)	264.24	153.51	89.79	97.80	219.29	225.22	140.07	135.38	60.95	67.91	Yes	12%	32%	31%	128.12	64.40	71.71		
(L4, S2, S3)	265.09	153.51	96.28	94.08	222.66	200.67	141.94	131.05	73.07	60.97	Yes	15%	24%	35%	134.85	76.12	54.12		
(L4, S2, S4)	272.58	153.51	96.28	98.75	222.66	208.16	148.96	131.68	73.46	67.44	Yes	14%	24%	32%	135.17	75.96	61.46		
(L4, S2, S5)	270.05	153.51	96.28	97.80	222.66	225.22	162.04	129.47	69.27	71.30	Yes	16%	28%	27%	129.19	69.15	71.71		
(L4, S3, S4)	267.36	153.51	94.08	98.75	200.67	208.16	145.53	127.78	66.75	72.83	Yes	17%	29%	26%	128.37	65.75	73.24		
(L4, S3, S5)	263.28	153.51	94.08	97.80	200.67	225.22	141.36	130.81	59.17	73.30	Yes	15%	37%	25%	135.48	51.63	76.18		
(L4, S4, S5)	272.72	153.51	98.75	97.80	208.16	225.22	147.59	132.35	66.16	74.21	Yes	14%	33%	24%	136.97	59.35	76.41		
(L5, S1, S2)	290.67	161.00	89.79	96.28	222.13	228.89	135.04	149.70	67.17	73.80	No	7%	25%	23%	157.20	63.36	70.11		
(L5, S1, S3)	267.11	161.00	89.79	94.08	222.13	228.50	136.14	141.79	60.00	65.33	Yes	12%	33%	31%	138.49	61.13	67.49		
(L5, S1, S4)	292.00	161.00	89.79	98.75	222.13	238.13	163.69	141.73	68.90	81.38	Yes	12%	23%	18%	141.63	67.19	83.19		
(L5, S1, S5)	270.10	161.00	89.79	97.80	222.13	229.76	140.07	141.06	60.61	68.43	Yes	12%	32%	30%	140.21	61.13	68.76		
(L5, S2, S3)	273.54	161.00	96.28	94.08	228.89	228.50	141.94	142.04	66.40	65.10	Yes	12%	31%	31%	138.17	67.88	67.49		
(L5, S2, S4)	271.86	161.00	96.28	98.75	228.89	238.13	148.96	139.97	63.02	68.87	Yes	13%	35%	30%	141.95	60.33	69.57		
(L5, S2, S5)	275.43	161.00	96.28	97.80	228.89	229.76	162.04	135.56	69.34	70.53	Yes	16%	28%	28%	136.67	68.95	69.82		
(L5, S3, S4)	291.17	161.00	94.08	98.75	228.50	238.13	145.53	147.85	68.08	75.24	Yes	8%	28%	24%	146.55	67.49	77.13		
(L5, S3, S5)	273.29	161.00	94.08	97.80	228.50	229.76	141.36	142.04	64.38	66.87	Yes	12%	32%	32%	137.04	67.49	68.76		
(L5, S4, S5)	278.60	161.00	98.75	97.80	238.13	229.76	147.59	142.56	70.35	65.69	Yes	11%	29%	33%	136.05	73.79	68.76		
(S1, S2, S3)	199.23	89.79	96.28	94.08	135.04	136.14	141.94	62.50	68.65	68.09	Yes	30%	29%	28%	62.18	67.98	69.08		
(S1, S2, S4)	211.13	89.79	96.28	98.75	135.04	163.69	148.96	67.94	63.82	79.37	Yes	24%	34%	20%	70.65	55.92	84.56		
(S1, S2, S5)	208.43	89.79	96.28	97.80	135.04	140.07	162.04	58.90	73.13	76.40	Yes	34%	24%	22%	53.16	75.12	80.15		
(S1, S3, S4)	204.66	89.79	94.08	98.75	136.14	163.69	145.53	67.47	60.54	76.65	Yes	25%	36%	22%	71.14	52.98	80.54		
(S1, S3, S5)	202.35	89.79	94.08	97.80	136.14	140.07	141.36	64.32	67.11	70.93	Yes	28%	29%	27%	65.28	66.57	70.51		
(S1, S4, S5)	210.20	89.79	98.75	97.80	163.69	140.07	147.59	68.67	76.91	64.62	Yes	24%	22%	34%	72.92	80.44	56.83		
(S2, S3, S4)	210.15	96.28	94.08	98.75	141.94	148.96	145.53	69.98	67.16	73.01	Yes	27%	29%	26%	69.99	66.57	73.59		
(S2, S3, S5)	205.96	96.28	94.08	97.80	141.94	162.04	141.36	72.31	60.87	72.78	Yes	25%	35%	26%	75.74	55.06	75.16		
(S2, S4, S5)	212.79	96.28	98.75	97.80	148.96	162.04	147.59	72.90	66.91	72.98	Yes	24%	32%	25%	76.20	61.75	74.84		
(S3, S4, S5)	212.89	94.08	98.75	97.80	145.53	141.36	147.59	68.18	73.64	71.07	Yes	28%	25%	27%	68.20	74.43	70.26		

Table C7. Possible cost allocations belonging to the core for the instances where the Shapley value is not in the core.

Instance	C1	C2	C3
(L2, L3, L4)	122.58	133.30	132.85
(L2, L3, L5)	127.78	136.78	134.98
(L2, S1, S2)	128.50	65.74	69.30
(L2, S1, S3)	123.49	61.02	75.12
(L2, S1, S5)	127.36	63.50	76.57
(L2, S2, S3)	119.41	62.74	79.20
(L2, S3, S4)	124.46	65.07	80.46
(L2, S3, S5)	125.53	62.96	78.41
(L2, S4, S5)	126.96	70.62	76.97
(L5, S1, S2)	155.63	61.78	73.26

References

- López-Ibáñez, M., Dubois-Lacoste, J., Pérez Cáceres, L., Birattari, M., and Stützle, T. (2016). The irace package: Iterated racing for automatic algorithm configuration. *Operations Research Perspectives*, 3:43–58.