

Appendix for paper: A sustainability-based model for robotic disassembly sequence planning in remanufacturing using the Bees Algorithm





Natalia Hartono* F. Javier Ramírez ** D.T. Pham ***

*Department of Mechanical Engineering, College of Engineering and Physical Sciences, University of Birmingham, B15 2TT UK and Department of Industrial Engineering, University of Pelita Harapan, Indonesia (e-mail: nxh886@student.bham.ac.uk)

** School of Industrial Engineering, Department of Business Administration, Universidad de Castilla-La Mancha, 02071 Albacete, Spain (e-mail: franciscoj.ramirez@uclm.es)

*** Department of Mechanical Engineering, College of Engineering and Physical Sciences, University of Birmingham, B15 2TT UK (e-mail: d.t.pham@bham.ac.uk)

Appendix A. VOSViewer Results

VOSViewer Interactive Online Link	
Co-authorship based on author: 	Co-authorship based on country: 
Co-occurrences based on keywords: 	Citation based on document: 

Appendix B. INPUT DATA AND RESULTS

Table B.1. Gear Pump A. Information and Disassembly Properties.

Part no.	Name	Material	Volume (mm ³)	Weight (g.)	Disassembly Point			Disassembly tool	$t_b(x_i)$ (s)
					X	Y	Z		
1	Bolt A	Steel	1,006.5	7.9	49.4	-12.6	106	Spanner-I	3
2	Bolt B	Steel	1,006.5	7.9	74.4	-12.6	81	Spanner-I	3
3	Bolt C	Steel	1,006.5	7.9	74.4	-12.6	45	Spanner-I	3
4	Bolt D	Steel	1,006.5	7.9	49.4	-12.6	20.5	Spanner-I	3
5	Bolt E	Steel	1,006.5	7.9	24.4	-12.6	45	Spanner-I	3
6	Bolt F	Steel	1,006.5	7.9	24.4	-12.6	81	Spanner-I	3
7	Cover	Steel	68,552.5	538.1	49.4	-20.6	63	Gripper-II	4
8	Gasket	Rubber	4,450.4	4.2	49.4	1.4	106	Griper-I	3
9	Gear A	Steel	15,215.5	119.4	49.4	3.4	81	Griper-I	6
10	Gear B	Steel	15,215.5	119.4	49.4	3.4	45	Griper-I	6
11	Driven Shaft A	Steel	5,207.0	40.9	49.4	-7.6	81	Griper-I	4
12	Base	Steel	195,539.3	1,535.0	49.4	49.4	81	Gripper-II	8
13	Driven Shaft B	Steel	18,267.2	143.4	49.4	152	45	Griper-I	4
14	Packing Gland	Steel	2,709.0	21.3	49.4	91.4	45	Griper-I	2
15	Gland Nut	Steel	12,046.9	94.6	49.4	96.4	45	Spanner-II	3

Table B.2. Gear Pump B. Information and Disassembly Properties.

Part no.	Name	Material	Volume (mm ³)	Weight (g.)	Disassembly Point			Disassembly tool	$t_b(x_i)$ (s)
					X	Y	Z		
1	Bolt A	Steel	1,243.1	9.8	59.1	114	-48.4	Spanner-I	4
2	Bolt B	Steel	1,243.1	9.8	90.3	89	-48.4	Spanner-I	4
3	Bolt C	Steel	1,243.1	9.8	90.3	33	-48.4	Spanner-I	4
4	Bolt D	Steel	1,243.1	9.8	59.1	8	-48.4	Spanner-I	4
5	Bolt E	Steel	1,243.1	9.8	27.9	33	-48.4	Spanner-I	4
6	Bolt F	Steel	1,243.1	9.8	27.9	89	-48.4	Spanner-I	4
7	Cover	Steel	95,973.5	753.4	59.1	82	-64.6	Gripper-II	5
8	Gasket	Rubber	5,496.3	5.2	59.1	114	-31.4	Griper-I	4
9	Gear A	Steel	21,301.7	167.2	59.1	82	-30.9	Griper-I	6
10	Gear B	Steel	21,301.7	167.2	59.1	40	-30.9	Griper-I	6
11	Shaft A	Steel	6,430.7	50.5	59.1	40	-48.9	Griper-I	4
12	Base	Steel	273,755.0	2,149.0	59.1	114	7.1	Spanner-I	4
13	Shaft B	Steel	22,560.0	177.1	59.1	82	136	Spanner-I	8
14	Gland A	PTFE	3,243.6	7.1	59.1	94.8	34.1	Spanner-I	3
15	Gland B	PTFE	3,243.6	7.1	59.1	94.8	41.1	Spanner-I	3
16	Gland C	PTFE	3,243.6	7.1	59.1	94.8	48.1	Spanner-I	3
17	Gland D	PTFE	3,243.6	7.1	59.1	94.8	55.1	Spanner-I	3
18	Gland E	Steel	14,456.3	113.5	59.1	82	79.1	Gripper-II	3
19	Bolt stud A	Steel	998.1	7.8	35.1	82	89.1	Griper-I	3
20	Bolt stud B	Steel	998.1	7.8	83.1	82	89.1	Griper-I	3
21	Nut A	Steel	289.5	2.3	35.1	82	84.1	Griper-I	4

Part no.	Name	Material	Volume (mm ³)	Weight (g.)	Disassembly Point			Disassembly tool	t _b (x _i) (s)
					X	Y	Z		
22	Nut B	Steel	289.5	2.3	83.1	82	84.1	Griper-I	4
23	Nut C	Steel	289.5	2.3	35.1	82	87.1	Gripper-II	4
24	Nut D	Steel	289.5	2.3	83.1	82	87.1	Griper-I	4

Table B.3. Gear Pump A (REC strategy)

Goal	Disassembly	
1	Sequence	15-1-2-3-4-5-6-7-10-11-9-14-13-8-12
	Direction	1-2-2-2-2-2-2-2-2-2-1-1-2-2
	Mode	3-3-3-3-3-3-3-3-3-3-3-3-4-3
	Tool	2-1-1-1-1-1-1-4-3-3-3-3-3-4
	MFV	-11.11
2	Sequence	2-1-6-5-4-3-7-10-11-9-8-15-12-13-14
	Direction	2-2-2-2-2-2-2-2-2-2-1-2-2-2
	Mode	3-3-3-3-3-3-3-3-3-3-4-3-3-3
	Tool	1-1-1-1-1-1-4-3-3-3-2-4-3-3
	MFV	-0.15
3	Sequence	3-6-4-5-1-2-15-14-13-12-11-10-7-9-8
	Direction	2-2-2-2-2-2-1-1-1-1-1-1-2-2-1
	Mode	3-3-3-3-3-3-3-3-3-3-3-3-3-4
	Tool	1-1-1-1-1-1-2-3-3-4-3-3-4-3-3
	MFV	-0.04
Disassembly Direction: 1 = Y+ direction, 2 = Y- direction		
Disassembly Mode: 1=reuse, 2=remanufacturing, 3=recycling, 4=disposal		
Disassembly Tool: 1=Spanner-I, 2 = Spanner-II, 3 = Gripper-I, 4 = Gripper-II		
MFV = Max Fitness Value		

Table B.4. Gear Pump A (REU strategy)

Goal	Disassembly	
1	Sequence	15-1-2-3-4-5-6-7-10-11-9-14-13-8-12
	Direction	1-2-2-2-2-2-2-2-2-2-2-1-2-2-1
	Mode	1-3-3-3-3-3-3-1-1-1-1-1-1-4-1
	Tool	2-1-1-1-1-1-1-4-3-3-3-3-3-4
	MFV	64.62
2	Sequence	2-1-6-5-4-3-7-11-9-10-8-15-12-13-14
	Direction	2-2-2-2-2-2-2-2-2-2-1-2-2-1
	Mode	3-3-3-3-3-3-1-1-1-1-4-1-1-1-1
	Tool	1-1-1-1-1-1-4-3-3-3-3-2-4-3-3
	MFV	0.77
3	Sequence	6-2-1-5-3-4-15-7-9-11-14-10-12-13-8
	Direction	2-2-2-2-2-2-1-2-2-2-1-2-1-2-2
	Mode	3-3-3-3-3-3-1-1-1-1-1-1-1-1-4
	Tool	1-1-1-1-1-1-2-4-3-3-3-3-4-3-3
	MFV	0.59
Disassembly Direction: 1 = Y+ direction, 2 = Y- direction		
Disassembly Mode: 1=reuse, 2=remanufacturing, 3=recycling, 4=disposal		
Disassembly Tool: 1=Spanner-I, 2 = Spanner-II, 3 = Gripper-I, 4 = Gripper-II		
MFV = Max Fitness Value		

Table B.5. Gear Pump B (REC strategy)

Goal	Disassembly	
1	Sequence	3-4-5-6-1-2-24-23-21-22-20-19-18-17-16-7-15-9-10-11-14-13-8-12
	Direction	2-2-2-2-2-2-1-1-1-1-1-1-1-1-2-1-2-2-1-1-2-2-1
	Mode	3-3-3-3-3-3-3-3-3-3-3-3-4-4-3-4-3-3-4-3-4-3
	Tool	1-1-1-1-1-1-3-3-3-3-2-2-4-4-4-5-4-4-4-4-4-4-5
	MFV	-14.94
2	Sequence	24-23-21-22-20-19-18-17-16-1-6-5-4-3-2-7-15-9-10-11-14-13-8-12
	Direction	1-1-1-1-1-1-1-1-2-2-2-2-2-2-2-1-2-2-2-1-1-2-2
	Mode	3-3-3-3-3-3-4-4-3-3-3-3-3-3-3-4-3-3-3-4-3-4-3
	Tool	3-3-3-3-2-2-4-4-4-1-1-1-1-1-1-5-4-4-4-4-4-4-5
	MFV	-1.30
3	Sequence	6-1-5-4-2-3-23-21-7-8-9-10-11-19-24-22-20-18-13-17-12-16-14-15
	Direction	2-2-2-2-2-2-1-1-2-2-2-2-2-1-1-1-1-1-1-2-1-2-2
	Mode	3-3-3-3-3-3-3-3-4-3-3-3-3-3-3-3-3-3-4-3-4-4-4
	Tool	1-1-1-1-1-1-3-3-5-4-4-4-4-2-3-3-2-4-4-4-5-4-4-4
	MFV	-0.51
Disassembly Direction: 1 = Y+ direction, 2 = Y- direction		
Disassembly Mode: 1=reuse, 2=remanufacturing, 3=recycling, 4=disposal		
Disassembly Tool: 1=Spanner-I, 2 = Spanner-II, 3 = Gripper-I, 4 = Gripper-II		
MFV = Max Fitness Value		

Table B.6. Gear Pump B (REU strategy)

Goal	Disassembly	
1	Sequence	3-4-5-6-1-2-24-23-21-22-20-19-18-17-16-7-15-9-10-11-14-13-8-12
	Direction	2-2-2-2-2-2-1-1-1-1-1-1-1-1-2-1-2-2-1-1-2-2-1
	Mode	3-3-3-3-3-3-3-3-3-1-1-4-4-1-4-1-1-1-4-1-4-1
	Tool	1-1-1-1-1-1-3-3-3-3-2-2-4-4-4-5-4-4-4-4-4-4-5
	MFV	75.85
2	Sequence	3-4-5-6-1-2-24-23-21-22-20-19-18-17-7-16-15-9-10-11-14-13-8-12
	Direction	2-2-2-2-2-2-1-1-1-1-1-1-1-2-1-1-2-2-2-1-1-2-1
	Mode	3-3-3-3-3-3-3-3-3-1-1-4-1-4-4-1-1-1-4-1-4-1
	Tool	1-1-1-1-1-1-3-3-3-3-2-2-4-4-5-4-4-4-4-4-4-4-5
	MFV	6.76
3	Sequence	5-3-4-2-1-23-6-7-21-8-9-11-10-19-24-22-20-18-13-17-12-14-16-15
	Direction	2-2-2-2-2-1-2-2-1-2-2-2-2-1-1-1-1-1-1-2-2-1-1
	Mode	3-3-3-3-3-3-1-3-4-1-1-1-1-3-3-1-1-1-4-1-4-4-4
	Tool	1-1-1-1-1-3-1-5-3-4-4-4-4-2-3-3-2-4-4-4-5-4-4-4
	MFV	0.75
Disassembly Direction: 1 = Y+ direction, 2 = Y- direction		
Disassembly Mode: 1=reuse, 2=remanufacturing, 3=recycling, 4=disposal		
Disassembly Tool: 1=Spanner-I, 2 = Spanner-II, 3 = Gripper-I, 4 = Gripper-II		
MFV = Max Fitness Value		

Table B.7. Gear Pump B (REM strategy)

Goal	Disassembly	
1	Sequence	3-4-5-6-1-2-24-23-21-22-20-19-18-17-16-7-15-9-10-11-14-13-8-12
	Direction	2-2-2-2-2-2-1-1-1-1-1-1-1-1-1-2-1-2-2-1-1-2-2-1
	Mode	3-3-3-3-3-3-3-3-3-2-2-2-4-4-2-4-2-2-2-4-2-4-2
	Tool	1-1-1-1-1-1-3-3-3-3-2-2-4-4-4-5-4-4-4-4-4-4-5
	MFV	63.03
2	Sequence	3-4-5-6-1-2-24-23-21-22-20-19-18-17-16-7-15-9-10-11-14-13-8-12
	Direction	2-2-2-2-2-2-1-1-1-1-1-1-1-1-1-2-1-2-2-2-1-1-2-2
	Mode	3-3-3-3-3-3-3-3-3-2-2-2-4-4-2-4-2-2-2-4-2-4-2
	Tool	1-1-1-1-1-1-3-3-3-3-2-2-4-4-4-5-4-4-4-4-4-4-5
	MFV	4.84
3	Sequence	1-4-5-2-6-3-7-23-10-11-24-21-22-9-19-8-20-18-13-12-17-14-16-15
	Direction	2-2-2-2-2-2-2-1-2-2-1-1-1-2-1-2-1-1-1-2-1-2-1-2
	Mode	3-3-3-3-3-3-2-3-2-2-3-3-3-2-2-4-2-2-2-2-4-4-4-4
	Tool	1-1-1-1-1-1-5-3-4-4-3-3-3-4-2-4-2-4-4-5-4-4-4-4
	MFV	0.58
Disassembly Direction: 1 = Y+ direction, 2 = Y- direction		
Disassembly Mode: 1=reuse, 2=remanufacturing, 3=recycling, 4=disposal		
Disassembly Tool: 1=Spanner-I, 2 = Spanner-II, 3 = Gripper-I, 4 = Gripper-II		
MFV = Max Fitness Value		