Order batching and robot routing in AGV-assisted mixed-shelves warehouses

Solutions for the Leaderboard Assignment

Laurin Luttmann and Jan-Niklas Anders

Major: Management & Data Science

Supervisor: Prof. Dr. Lin Xie

LEUPHANA
UNIVERSITÄT LÜNEBURG

1. Experimental Setup

For this task we used the Iterated Local Search (ILS) algorithm to solve the given problem under the assumption of a dedicated policy and the Variable Neighborhood Search (VNS) algorithm to solve it under the assumption of a mixed policy. For every dataset we let the algorithms run with different maximal CPU times of execution as stopping criteria. The runtimes after which the algorithms were terminated are $\{5, 10, 20, 40, 80, 140, 200\}$. For each dataset, we determined the minimum runtime after which the best solution in terms of fitness was found.

The results will be presented in the next sections, first for the dedicated case and then for a mixed shelf policy. Furthermore, the optimal tour for each cobot and for each dataset are given. The code for the algorithms as well as the analysis of the obtained solution can be found in the following Github repository: Link

2. Solutions with Dedicated Policy

2.1. Runtimes and Fitness Values for the different Instances

Dedicated policy				
Dataset	#shelves	#orders	ILS	CPU (sec.)
orders_10_mean_1x6_sku_24	24	10	64.4	10
orders_10_mean_5_sku_24_a	24	10	228.0	5
orders_10_mean_5_sku_24_b	24	10	188.9	20
orders_10_mean_5_sku_24	24	10	243.6	5
orders_20_mean_5_sku_24_a	24	20	315.9	5
orders_20_mean_5_sku_24_b	24	20	333.3	40
orders_20_mean_5_sku_24	24	20	362.2	40
orders_10_mean_5_sku_360_a	360	10	869.8	5
orders_10_mean_5_sku_360_b	360	10	815.2	40
orders_10_mean_5_sku_360	360	10	746.2	140
orders_20_mean_5_sku_360_a	360	20	1285.1	140
orders_20_mean_5_sku_360_b	360	20	1427.3	80
orders_20_mean_5_sku_360	360	20	1450.8	140

Table 1: Results for the dedicated policy

2.2. Determined Tours for Cobots of the Instances

orders_10_mean_1x6_sku_24	
Batch	Route
1	OutD0 → 7 → 2 → 10 → 11 → 16 → 15 → OutD0
0	OutD0 → 1 → 7 → 2 → 9 → OutD0

orders_10_mean_5_sku_24_a	
ID	Route
0	OutD0 → 7 → 9 → 11 → 16 → 15 → OutD0
4	OutD0 → 7 → 2 → 10 → 16 → 15 → OutD0
1	OutD1 → 1 → 7 → 4 → 10 → 11 → 16 → OutD1
2	OutD1 → 9 → 2 → 4 → 10 → 11 → 16 → 15 → OutD1
5	OutD1 → 10 → 4 → 9 → 2 → OutD1
6	OutD1 → 2 → 7 → 9 → 4 → 10 → 11 → 16 → OutD1

orders_10_mean_5_sku_24_b	
ID	Route
4	OutD0 → 7 → 1 → 9 → 10 → 4 → 11 → 16 → OutD0
3	OutD0 → 1 → 7 → 9 → 10 → 11 → 15 → OutD0
6	OutD0 → 7 → 1 → 10 → 4 → OutD0
5	OutD0 → 7 → 4 → 11 → 16 → 15 → OutD0
8	OutD1 → 15 → 1 → 2 → 9 → 4 → 10 → 11 → OutD1

orders_10_mean_5_sku_24	
ID	Route
1	OutD0 → 15 → 11 → 10 → 2 → 7 → OutD0
2	OutD0 → 1 → 7 → 9 → 10 → 4 → 16 → OutD0
4	OutD0 → 1 → 7 → 2 → 11 → 16 → 15 → OutD0
0	OutD1 → 15 → 1 → 2 → 9 → OutD1
3	OutD1 → 16 → 15 → 1 → 9 → 4 → 11 → OutD1
5	OutD1 → 9 → 2 → 4 → 11 → 16 → OutD1

orders_20_mean_5_sku_24_a	
ID	**Route**
1	OutD0 → 1 → 7 → 2 → 4 → 11 → 16 → 15 → OutD0
3	OutD0 → 15 → 16 → 11 → 4 → 10 → 9 → 2 → 7 → OutD0
5	OutD0 → 15 → 16 → 4 → 10 → 9 → 1 → OutD0
6	OutD0 → 1 → 2 → 9 → 4 → 11 → 16 → 15 → OutD0
7	OutD0 → 1 → 2 → 9 → 11 → 16 → 15 → OutD0
8	OutD0 → 7 → 2 → 10 → 4 → 11 → 16 → 15 → OutD0
0	OutD1 → 1 → 7 → 2 → 10 → 11 → OutD1
4	OutD1 → 2 → 1 → 9 → 4 → 10 → 11 → OutD1
2	OutD1 → 4 → OutD1

orders_20_mean_5_sku_24_b	
ID	**Route**
2	OutD0 → 7 → 1 → 2 → 9 → 10 → 11 → 16 → 15 → OutD0
8	OutD0 → 1 → 7 → 2 → 10 → 4 → 16 → OutD0
1	OutD1 → 2 → 9 → 4 → 10 → 11 → 16 → 15 → OutD1
6	OutD1 → 11 → 10 → 2 → 7 → 1 → 15 → 16 → OutD1
7	OutD1 → 16 → 15 → 1 → 2 → 9 → 10 → 11 → OutD1
5	OutD1 → 10 → 9 → 2 → 7 → 1 → 15 → 16 → OutD1
4	OutD1 → 7 → 4 → 16 → OutD1
3	OutD1 → 2 → 7 → 10 → 11 → OutD1
0	OutD1 → 4 → 10 → 9 → OutD1

orders_20_mean_5_sku_24	
ID	**Route**
6	OutD0 → 10 → 4 → 2 → 7 → OutD0
8	OutD0 → 15 → 16 → 11 → 10 → 9 → 2 → 7 → OutD0
3	OutD0 → 15 → 16 → 11 → 4 → 10 → 2 → 1 → OutD0
4	OutD1 → 16 → 15 → 1 → 2 → 9 → 4 → 11 → OutD1
2	OutD1 → 1 → 9 → 4 → 10 → 11 → OutD1
9	OutD1 → 11 → 10 → 7 → 1 → 15 → 16 → OutD1
11	OutD1 → 2 → 7 → 9 → 10 → OutD1
5	OutD1 → 7 → 1 → 2 → 10 → 11 → 16 → OutD1
10	OutD1 → 15 → 1 → 7 → 2 → 9 → 4 → OutD1
7	OutD1 → 11 → 10 → 4 → 9 → 1 → 15 → OutD1

orders_10_mean_5_sku_360_a	
ID	Route
0	OutD0 → 150 → 128 → 129 → 74 → 79 → 23 → 36 → 349 → 215 → OutD0
1	OutD0 → 150 → 128 → 14 → 47 → 266 → 215 → OutD0
3	OutD0 → 150 → 128 → 67 → 47 → 14 → 35 → 215 → OutD0
4	OutD0 → 150 → 128 → 74 → 14 → 28 → 144 → 172 → 349 → 215 → OutD0
5	OutD0 → 36 → 14 → 47 → 51 → 28 → 172 → 150 → OutD0
2	OutD1 → 28 → 79 → 150 → 217 → 349 → OutD1

orders_10_mean_5_sku_360_b	
ID	Route
1	OutD0 → 150 → 129 → 144 → 79 → 36 → 349 → 217 → OutD0
3	OutD0 → 150 → 128 → 129 → 74 → 67 → 14 → 47 → 51 → 23 → 144 → 349 → 217 → OutD0
5	OutD0 → 35 → 36 → 47 → 74 → 128 → 172 → 217 → OutD0
4	OutD1 → 23 → 51 → 47 → 79 → 67 → 74 → 349 → 172 → OutD1
2	OutD1 → 266 → 349 → 67 → 150 → 35 → 144 → OutD1

orders_10_mean_5_sku_360	
ID	Route
13	OutD0 → 35 → 36 → 14 → 79 → 129 → 128 → 217 → 215 → OutD0
12	OutD0 → 67 → 74 → 172 → 79 → 47 → 35 → 217 → OutD0
11	OutD0 → 215 → 266 → 349 → 67 → 74 → 14 → 35 → 150 → OutD0
9	OutD1 → 349 → 51 → 47 → 14 → 36 → 35 → 150 → 129 → 172 → 144 → OutD1
10	OutD1 → 266 → 349 → 79 → 67 → 14 → 51 → OutD1

orders_20_mean_5_sku_360_a	
ID	Route
0	OutD0 → 67 → 47 → 51 → 36 → 150 → 128 → 129 → 172 → 217 → 215 → OutD0
4	OutD0 → 150 → 128 → 74 → 79 → 14 → 35 → 215 → 217 → OutD0
1	OutD0 → 35 → 14 → 51 → 23 → 28 → 266 → 217 → OutD0
5	OutD1 → 28 → 51 → 47 → 36 → 35 → 150 → 128 → 172 → 144 → 266 → OutD1
3	OutD1 → 266 → 215 → 150 → 67 → 74 → 79 → 14 → 35 → 23 → OutD1
8	OutD1 → 266 → 349 → 215 → 150 → 128 → 129 → 74 → 67 → 51 → OutD1
7	OutD1 → 172 → 129 → 150 → 215 → 35 → 36 → 14 → 47 → 23 → OutD1
6	OutD1 → 349 → 150 → 35 → 36 → 14 → 47 → 23 → OutD1
2	OutD1 → 23 → 51 → 47 → 67 → 150 → 128 → 172 → OutD1

orders_20_mean_5_sku_360_b	
ID	Route
9	OutD0 → 150 → 128 → 74 → 47 → 266 → 217 → 215 → OutD0
2	OutD0 → 215 → 144 → 172 → 128 → 74 → 67 → 79 → 14 → 36 → OutD0
7	OutD0 → 217 → 144 → 129 → OutD0
4	OutD0 → 150 → 35 → 79 → 47 → 28 → 144 → 215 → OutD0
0	OutD1 → 28 → 144 → 172 → 129 → 217 → 349 → 266 → OutD1
8	OutD1 → 144 → 129 → 14 → 47 → 217 → 349 → OutD1
5	OutD1 → 79 → 67 → 47 → 129 → 217 → 349 → 266 → OutD1
6	OutD1 → 349 → 128 → 79 → 14 → 36 → 47 → 51 → 23 → 28 → 144 → OutD1
1	OutD1 → 79 → 74 → 47 → 14 → 35 → 150 → 128 → 129 → 172 → OutD1
3	OutD1 → 28 → 23 → 51 → 47 → 35 → 36 → 14 → 67 → 74 → 172 → OutD1

orders_20_mean_5_sku_360	
ID	Route
0	OutD0 → 67 → 74 → 144 → 217 → 215 → OutD0
3	OutD0 → 129 → 133 → 74 → 47 → 51 → 172 → 349 → 215 → OutD0
9	OutD0 → 215 → 349 → 172 → 144 → 23 → 47 → 74 → 128 → 150 → OutD0
8	OutD0 → 215 → 217 → 266 → 28 → 144 → 74 → 129 → OutD0
2	OutD1 → 28 → 23 → 51 → 47 → 14 → 36 → 35 → 74 → 67 → 79 → OutD1
4	OutD1 → 349 → 215 → 23 → 51 → 47 → 79 → 172 → 144 → OutD1
6	OutD1 → 172 → 129 → 128 → 74 → 67 → 14 → 36 → 51 → 266 → OutD1
7	OutD1 → 23 → 47 → 79 → 349 → 133 → 172 → 144 → OutD1
1	OutD1 → 51 → 14 → 67 → 150 → 215 → 349 → 266 → OutD1
5	OutD1 → 172 → 144 → 28 → 47 → 349 → 266 → OutD1

3. Solutions with Mixed Policy

3.1. Runtimes and Fitness Values for the different Instances

Mixed policy				
Dataset	#shelves	#orders	VNS	CPU (sec.)
orders_10_mean_1x6_sku_24	24	10	48.6	5
orders_10_mean_5_sku_24_a	24	10	141.4	5
orders_10_mean_5_sku_24_b	24	10	130.1	80
orders_10_mean_5_sku_24	24	10	133.6	80
orders_20_mean_5_sku_24_a	24	20	215.5	80
orders_20_mean_5_sku_24_b	24	20	216.3	80
orders_20_mean_5_sku_24	24	20	249.6	140
orders_10_mean_5_sku_360_a	360	10	468.3	80
orders_10_mean_5_sku_360_b	360	10	362.5	80
orders_10_mean_5_sku_360	360	10	373.3	80
orders_20_mean_5_sku_360_a	360	20	658.3	200
orders_20_mean_5_sku_360_b	360	20	696.3	140
orders_20_mean_5_sku_360	360	20	703.8	80

Table 2: Results for the mixed policy

3.2. Determine Tours for Cobots

orders_10_mean_1x6_sku_24 (Mixed)	
ID	Route
0	OutD0 → 6 → 1 → OutD0
1	OutD1 → 23 → 17 → 14 → 16 → 22 → OutD1

orders_10_mean_5_sku_24_a (Mixed)	
ID	Route
3	OutD0 → 6 → 7 → 1 → OutD0
4	OutD0 → 18 → 12 → OutD0
0	OutD1 → 23 → 17 → 22 → 14 → 15 → OutD1
5	OutD1 → 23 → 22 → 16 → OutD1
2	OutD1 → 23 → 16 → 21 → 14 → 17 → OutD1
1	OutD1 → 17 → 16 → 22 → 14 → 21 → 15 → OutD1

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orders_10_mean_5_sku_24_b (Mixed)	
ID	Route
1	OutD0 → 0 → 1 → 6 → 12 → OutD0
2	OutD0 → 21 → 14 → 18 → 12 → OutD0
3	OutD0 → 6 → 7 → 1 → 0 → OutD0
4	OutD1 → 23 → 17 → 14 → 21 → OutD1
0	OutD1 → 23 → 17 → 15 → 22 → OutD1

orders_10_mean_5_sku_24 (Mixed)	
ID	Route
0	OutD0 → 13 → 14 → 21 → 12 → OutD0
1	OutD0 → 0 → 3 → 1 → OutD0
5	OutD0 → 6 → 0 → 1 → OutD0
4	OutD0 → 0 → 7 → 1 → OutD0
2	OutD0 → 6 → 3 → 7 → 1 → OutD0
3	OutD1 → 17 → 23 → OutD1

orders_20_mean_5_sku_24_a (Mixed)	
ID	Route
1	OutD0 → 0 → 7 → 3 → 1 → OutD0
6	OutD0 → 7 → 2 → 8 → 3 → 1 → 6 → OutD0
4	OutD0 → 0 → 7 → 6 → OutD0
0	OutD1 → 17 → 16 → 21 → 14 → 22 → OutD1
2	OutD1 → 23 → 21 → 14 → 16 → OutD1
3	OutD1 → 17 → 22 → 16 → 21 → 15 → OutD1
5	OutD1 → 23 → 17 → 16 → 14 → 15 → OutD1
7	OutD1 → 23 → 17 → 16 → 22 → OutD1
8	OutD1 → 3 → 9 → 8 → 2 → OutD1

| **orders_20_mean_5_sku_24_b** (Mixed) |
ID	Route
3	OutD0 → 12 → 21 → 14 → 18 → OutD0
4	OutD0 → 0 → 6 → OutD0
6	OutD0 → 7 → 3 → 1 → 6 → OutD0
0	OutD0 → 6 → 1 → 3 → 7 → 0 → OutD0
2	OutD1 → 23 → 16 → 22 → OutD1
5	OutD1 → 17 → 21 → 15 → 22 → 16 → OutD1
8	OutD1 → 17 → 21 → 14 → 16 → 22 → OutD1
7	OutD1 → 23 → 14 → 16 → OutD1
1	OutD1 → 23 → 16 → 21 → 14 → 17 → OutD1

| **orders_20_mean_5_sku_24** (Mixed) |
ID	Route
3	OutD0 → 0 → 7 → 3 → 1 → OutD0
4	OutD0 → 0 → 3 → 7 → 1 → 6 → OutD0
5	OutD0 → 12 → 18 → 23 → OutD0
6	OutD0 → 7 → 1 → 6 → OutD0
9	OutD0 → 21 → 14 → 13 → 12 → OutD0
1	OutD0 → 14 → 13 → 12 → OutD0
7	OutD1 → 23 → 16 → 21 → 14 → 17 → OutD1
8	OutD1 → 23 → 16 → 15 → OutD1
2	OutD1 → 23 → 17 → 14 → 16 → OutD1
0	OutD1 → 17 → 22 → 16 → 14 → 21 → 15 → OutD1

| **orders_10_mean_5_sku_360_a** (Mixed) |
ID	Route
0	OutD0 → 61 → 66 → 71 → 159 → 151 → OutD0
3	OutD0 → 64 → 66 → 67 → 103 → 173 → 140 → 159 → 151 → OutD0
5	OutD0 → 211 → 193 → 102 → 159 → 125 → 151 → OutD0
1	OutD0 → 151 → 159 → 163 → 140 → 102 → 66 → 64 → OutD0
2	OutD1 → 232 → 225 → 254 → 140 → 178 → OutD1
4	OutD1 → 234 → 232 → 196 → 130 → 102 → 73 → 103 → 140 → 173 → 175 → OutD1

orders_10_mean_5_sku_360_b (Mixed)	
ID	Route
0	OutD0 → 61 → 64 → 69 → 71 → 73 → 74 → 159 → 122 → OutD0
4	OutD0 → 337 → 307 → 310 → 341 → 300 → 274 → 270 → OutD0
3	OutD0 → 12 → 42 → 43 → 102 → 69 → 66 → 64 → 92 → OutD0
2	OutD1 → 178 → 175 → 174 → 173 → 102 → 103 → 196 → OutD1
1	OutD1 → 269 → 286 → 193 → 225 → 196 → 232 → 238 → OutD1

orders_10_mean_5_sku_360 (Mixed)	
ID	Route
1	OutD0 → 193 → 74 → 103 → 163 → 130 → 159 → 125 → 151 → OutD0
4	OutD0 → 193 → 73 → 159 → 125 → 122 → 151 → OutD0
2	OutD0 → 125 → 159 → 43 → 102 → 71 → 69 → 64 → 92 → OutD0
3	OutD0 → 159 → 73 → 101 → 69 → 66 → 61 → OutD0
0	OutD1 → 269 → 260 → 257 → 294 → 196 → 235 → 237 → OutD1

orders_20_mean_5_sku_360_a (Mixed)	
ID	Route
0	OutD0 → 211 → 193 → 159 → 125 → 124 → 151 → OutD0
7	OutD0 → 66 → 69 → 101 → 102 → 73 → 130 → 125 → OutD0
8	OutD0 → 69 → 102 → 73 → 196 → 193 → 282 → 251 → 247 → 274 → 270 → OutD0
6	OutD0 → 125 → 159 → 73 → 102 → 101 → 67 → 64 → 61 → OutD0
3	OutD0 → 69 → 102 → 103 → 74 → 140 → 159 → 122 → OutD0
4	OutD0 → 151 → 125 → 130 → 140 → 101 → 69 → 64 → 92 → OutD0
2	OutD0 → 211 → 193 → 74 → 73 → 101 → 71 → 64 → 92 → 151 → OutD0
1	OutD1 → 87 → 114 → 112 → 159 → 160 → 130 → 140 → 175 → 178 → OutD1
5	OutD1 → 53 → 140 → 173 → 175 → 178 → OutD1

orders_20_mean_5_sku_360_b (Mixed)	
ID	Route
0	OutD0 → 337 → 300 → 246 → 247 → 249 → 251 → 282 → 196 → 211 → OutD0
1	OutD0 → 122 → 71 → 102 → 101 → 69 → 66 → 92 → OutD0
4	OutD0 → 122 → 246 → 270 → OutD0
5	OutD0 → 61 → 64 → 66 → 69 → 73 → 159 → OutD0
6	OutD0 → 93 → 69 → 102 → 103 → 73 → 43 → 12 → OutD0
7	OutD0 → 130 → 102 → 71 → 66 → 64 → 61 → 122 → OutD0
9	OutD0 → 69 → 71 → 73 → 103 → 159 → 125 → 151 → OutD0
3	OutD0 → 61 → 66 → 67 → 71 → 102 → 163 → 122 → OutD0
2	OutD0 → 211 → 193 → 73 → 103 → 163 → 130 → 122 → 151 → OutD0
8	OutD1 → 178 → 174 → 140 → 286 → 294 → 295 → OutD1

orders_20_mean_5_sku_360	
ID	Route
0	OutD0 → 71 → 101 → 67 → 64 → 61 → 122 → 151 → OutD0
2	OutD0 → 159 → 130 → 43 → 73 → 102 → 66 → 64 → 92 → 61 → OutD0
3	OutD0 → 69 → 71 → 73 → 102 → 66 → 64 → 151 → OutD0
4	OutD0 → 151 → 61 → 64 → 92 → OutD0
5	OutD0 → 66 → 102 → 73 → 43 → 133 → 122 → 151 → OutD0
6	OutD0 → 64 → 69 → 71 → 101 → 102 → 73 → 159 → 125 → 124 → OutD0
7	OutD0 → 61 → 69 → 102 → 74 → 43 → 133 → OutD0
8	OutD0 → 43 → 102 → 101 → 69 → 67 → 66 → 92 → 61 → OutD0
10	OutD0 → 193 → 74 → 73 → 163 → 159 → 151 → OutD0
1	OutD0 → 125 → 173 → 140 → 102 → 69 → 66 → 64 → 61 → OutD0