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EN TALLERES HÍBRIDOS

Appendices for “Benefits of robust multiobjective  
optimization for flexible automotive assembly line  
balancing”

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# Appendices for “Managerial and industrial benefits of using robust multiobjective optimization for balancing an automotive assembly line”

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## **Appendix A. Appendix with additional configuration lines tables**

In this Appendix A we present the assembly line balancing solutions obtained by the standard (i.e., non-robust) and robust multiobjective methods presented in the paper. Tables A.1 and A.2 shows two line configurations of 18 stations and linear area of 5.5, obtained by standard and robust methods, respectively. Later, Tables A.3 and A.4 show assembly lines configurations of 21 and linear area of 4.5 obtained by standard and robust methods, respectively.

$k$	$j \in S_k : \text{stations workload}$												
1	1	3	10	13									
2	4	5	6	8	11	12							
3	9	14	15	16	17	18	19	21					
4	7	20	22	23	24	25	26	27	28				
5	2	29	30	31	32	34	36						
6	33	35	37	38	39	40	41	43					
7	42	44	45	46	47	48	49	52					
8	50	51	53	54	55	56	57	59	60	63			
9	58	61	62	64	65	66	67	70					
10	68	69	71	72	73	74	79						
11	75	76	77	78	80	81	82	83	84	86			
12	85	87	88	89	90	91	92	99					
13	93	94	95	96	98	100	101	103					
14	102	104	105	106	107	108	109	110	111	112	113	114	115
15	116	117	118	119	120	121							
16	122	123	124	125	126	128	129	131					
17	97	127	130	132	133	134	135	136	138				
18	137	139	140										

Table A.1: Assembly configuration line with objectives  $m = 18$  and  $A = 5.5$  and found by a standard (non-robust) multiobjective method.

$k$	$j \in S_k$ : stations workload												
1	1	7	8	9	11								
2	3	4	5	10	13	14							
3	6	12	16	17	19	20	21						
4	15	18	22	23	24	25	26	27	28				
5	2	29	30	31	32	34	36						
6	33	35	37	38	39	40	41	43					
7	42	44	45	46	47	48	49	59	60				
8	50	51	52	53	54	55	56	57	58				
9	61	62	63	64	65	66	67	70					
10	68	69	71	72	73	74	75						
11	76	77	78	79	80	81	82	83	84	86			
12	85	87	88	89	90	91	92	99					
13	93	94	95	96	98	100	101	103					
14	102	104	105	106	107	108	109	110	111	112	113	114	115
15	116	117	118	119	120	131							
16	121	122	123	128	132	134	135	136					
17	97	124	125	126	127	129	137	138	139				
18	130	133	140										

Table A.2: Assembly configuration line with objectives  $m = 18$  and  $A = 5.5$  and found by a robust multiobjective method.

$k$	$j \in S_k$ : <b>stations workload</b>												
1	1	3	5	9									
2	4	8	10	11	12	13	14						
3	15	16	17	18	19	20	21						
4	7	22	23	24	25	26	27						
5	6	28	29	30	31								
6	32	33	34	35	36								
7	2	37	38	39	40	41	59						
8	42	43	44	45	60								
9	46	47	48	49	50	51	52	53	54				
10	55	56	57	58	61	62	63	64	65				
11	66	67	68	69	72								
12	70	71	73	74	75	77							
13	76	78	79	80	81	82	83	84					
14	85	86	87	88	89	90	91	92	94				
15	93	98	99	100	101	106							
16	95	102	103	104	105	107	108	109	110	111	112	113	114
17	115	116	117	118	119	120							
18	121	122	123	124	125	126							
19	127	128	129	130	131								
20	132	133	134	135	136	138							
21	96	97	137	139	140								

Table A.3: Assembly configuration line with objectives  $m = 21$  and  $A = 4.5$  and found by a standard (non-robust) multiobjective method.

$k$	$j \in S_k$ : stations workload												
1	1	5	9	10									
2	3	4	7	8	11	13							
3	6	14	17	19	20	21							
4	15	16	18	23	24	25	26	27					
5	22	28	29	30	31	32							
6	2	33	34	36									
7	12	35	37	38	39	40	43						
8	41	42	44	45									
9	46	47	48	49	51	54	55	56	59	60			
10	50	52	53	57	58	61	62	64					
11	63	65	66	67	68	69	71						
12	70	72	73	74	75								
13	76	77	78	80	81								
14	82	83	84	85	86	87	88	89	91				
15	90	92	98	99	100								
16	101	102	103	104	105	106	108						
17	93	94	95	97	107	109	110	111	112	113	114	115	116
18	96	117	118	119	120	121	122	123					
19	124	125	128	131	132	134	135						
20	126	127	129	130	136	137	138						
21	79	133	139	140									

Table A.4: Assembly configuration line with objectives  $m = 21$  and  $A = 4.5$  and found by a robust multiobjective method.

## Appendix B. Appendix with additional tables of stations workloads

This Appendix B presents the information about all the assembly line configurations for all the defined production plans and corresponding overloads. Tables B.5 and B.6 have the processing times of the tasks of a line configuration which 18 workstations with a linear area of 5.5, for a non-robust and robust line configuration, respectively. Later, Tables B.7 and B.8 have the processing times for the non-robust and robust line configuration, respectively, of 21 stations and linear area of 4.5.

$k$	$t_{plan1}(S_k)$	$t_{plan2}(S_k)$	$t_{plan3}(S_k)$	$t_{plan6}(S_k)$	$t_{plan9}(S_k)$	$t_{plan12}(S_k)$	$t_{plan18}(S_k)$	$\sum_{\epsilon} y_{k\epsilon}^c$	$\Delta_c$
1	125.00	124.40	123.76	125.06	125.70	124.38	125.08	0	0.00
2	180.00	180.11	178.67	181.57	183.01	179.60	182.34	4	3.01
3	176.00	175.41	175.33	175.49	175.58	175.57	175.25	0	0.00
4	164.00	164.28	164.55	164.00	163.73	164.27	164.00	0	0.00
5	160.00	160.12	161.01	159.26	158.37	160.39	158.88	0	0.00
6	140.00	139.54	139.68	139.40	139.27	139.74	139.11	0	0.00
7	175.00	175.46	175.29	175.59	175.75	175.28	175.90	0	0.00
8	165.00	165.18	165.47	164.89	164.60	165.22	164.84	0	0.00
9	165.00	164.97	166.23	163.71	162.45	165.39	163.07	0	0.00
10	170.00	169.74	169.38	170.13	170.50	169.68	170.19	0	0.00
11	135.00	135.29	135.90	134.70	134.09	135.38	134.54	0	0.00
12	180.00	179.63	179.52	179.77	179.88	179.73	179.64	0	0.00
13	175.00	174.64	173.49	175.83	176.97	174.33	176.22	0	0.00
14	175.00	175.12	174.77	175.47	175.81	174.95	175.70	0	0.00
15	180.00	179.62	178.98	180.25	180.90	179.53	180.39	3	0.90
16	180.00	179.97	180.73	179.21	178.45	180.26	178.81	2	0.73
17	180.00	180.33	180.30	180.37	180.40	180.23	180.55	6	0.55
18	165.00	165.74	166.10	165.33	164.96	165.67	165.51	0	0.00
$c_{max}$	180.00	180.33	180.73	181.57	183.01	180.26	182.34		183.01

Table B.5: Station workloads per plan and overloaded values for each station in a non-robust assembly line configuration with 18 stations and linear area of 5.5.

$k$	$t_{plan1}(S_k)$	$t_{plan2}(S_k)$	$t_{plan3}(S_k)$	$t_{plan6}(S_k)$	$t_{plan9}(S_k)$	$t_{plan12}(S_k)$	$t_{plan18}(S_k)$	$\sum_{\epsilon} y_{k\epsilon}^c$	$\Delta_c$
1	150.00	149.24	148.36	150.15	151.03	149.20	150.21	0	0.00
2	155.00	154.66	154.38	155.00	155.28	154.65	154.97	0	0.00
3	178.00	178.21	177.32	179.08	179.97	177.83	179.63	0	0.00
4	162.00	162.10	162.25	161.88	161.72	162.15	161.85	0	0.00
5	160.00	160.12	161.01	159.26	158.37	160.39	158.88	0	0.00
6	140.00	139.54	139.68	139.40	139.27	139.74	139.11	0	0.00
7	170.00	170.42	170.45	170.39	170.36	170.31	170.59	0	0.00
8	160.00	160.11	159.92	160.31	160.50	160.01	160.46	0	0.00
9	175.00	175.07	176.62	173.50	171.94	175.57	172.76	0	0.00
10	165.00	164.82	164.56	165.10	165.36	164.78	165.14	0	0.00
11	140.00	140.21	140.71	139.73	139.23	140.29	139.58	0	0.00
12	180.00	179.63	179.52	179.77	179.88	179.73	179.64	0	0.00
13	175.00	174.64	173.49	175.83	176.97	174.33	176.22	0	0.00
14	175.00	175.12	174.77	175.47	175.81	174.95	175.70	0	0.00
15	175.00	174.87	175.02	174.72	174.57	174.97	174.58	0	0.00
16	175.00	175.06	174.24	175.92	176.74	174.76	176.36	0	0.00
17	180.00	179.56	179.48	179.60	179.67	179.69	179.41	0	0.00
18	175.00	176.18	177.37	174.92	173.72	176.26	174.91	0	0.00
$c_{max}$	180.00	179.63	179.52	179.77	179.97	179.73	179.64	180	

Table B.6: Station workloads per plan and overloaded values for each station in a robust assembly line configuration with 18 stations and linear area of 5.5.



$k$	$t_{plan1}(S_k)$	$t_{plan2}(S_k)$	$t_{plan3}(S_k)$	$t_{plan6}(S_k)$	$t_{plan9}(S_k)$	$t_{plan12}(S_k)$	$t_{plan18}(S_k)$	$\sum_{\epsilon} y_{k\epsilon}^c$	$\Delta_c$
1	120.00	119.15	119.13	119.23	119.26	119.42	118.82	0	0.00
2	155.00	154.84	153.91	155.80	156.73	154.57	156.18	0	0.00
3	151.00	150.69	150.43	150.93	151.19	150.70	150.91	0	0.00
4	129.00	129.33	129.50	129.14	128.97	129.27	129.22	0	0.00
5	125.00	125.17	124.63	125.70	126.25	124.95	126.06	0	0.00
6	85.00	84.87	84.56	85.22	85.53	84.80	85.31	0	0.00
7	170.00	169.80	171.01	168.57	167.36	170.30	167.87	0	0.00
8	100.00	100.04	99.48	100.61	101.17	99.84	100.91	0	0.00
9	180.00	180.61	180.62	180.59	180.58	180.44	180.89	6	0.89
10	180.00	180.41	182.85	177.95	175.51	181.09	176.93	3	2.85
11	105.00	104.75	104.84	104.66	104.58	104.87	104.49	0	0.00
12	130.00	129.76	128.56	130.99	132.19	129.41	131.47	0	0.00
13	100.00	100.03	100.70	99.36	98.68	100.23	99.04	0	0.00
14	180.00	180.08	180.21	179.99	179.86	180.10	179.96	3	0.21
15	165.00	164.34	163.75	164.99	165.59	164.31	164.96	0	0.00
16	180.00	180.02	178.88	181.16	182.30	179.62	181.74	4	2.30
17	155.00	154.69	154.33	155.07	155.44	154.66	155.10	0	0.00
18	130.00	129.72	129.74	129.69	129.66	129.83	129.53	0	0.00
19	135.00	135.10	135.69	134.51	133.92	135.28	134.26	0	0.00
20	135.00	135.30	134.99	135.60	135.90	135.12	135.90	0	0.00
21	180.00	180.84	181.35	180.28	179.78	180.79	180.45	5	1.35
$c_{max}$	180.00	180.84	182.85	181.16	182.30	181.09	181.74		182.85

Table B.7: Station workloads per plan and overloaded values for each station in a non-robust assembly line configuration with 21 stations and linear area of 4.5.

$k$	$t_{plan1}(S_k)$	$t_{plan2}(S_k)$	$t_{plan3}(S_k)$	$t_{plan6}(S_k)$	$t_{plan9}(S_k)$	$t_{plan12}(S_k)$	$t_{plan18}(S_k)$	$\sum_{\epsilon} y_{k\epsilon}^c$	$\Delta_c$
1	130.00	129.57	129.28	129.91	130.20	129.61	129.84	0	0.00
2	165.00	164.40	163.44	165.40	166.36	164.26	165.58	0	0.00
3	165.00	165.05	164.32	165.77	166.50	164.78	166.16	0	0.00
4	133.00	133.23	133.27	133.14	133.11	133.19	133.24	0	0.00
5	87.00	86.78	87.03	86.55	86.30	86.93	86.31	0	0.00
6	140.00	140.01	140.18	139.85	139.69	140.08	139.77	0	0.00
7	65.00	65.06	64.81	65.32	65.57	64.94	65.48	0	0.00
8	125.00	124.90	125.44	124.34	123.80	125.13	124.02	0	0.00
9	175.00	175.47	175.72	175.21	174.96	175.41	175.32	0	0.00
10	175.00	175.15	176.71	173.59	172.03	175.63	172.88	0	0.00
11	140.00	140.02	140.38	139.64	139.28	140.16	139.47	0	0.00
12	115.00	114.65	113.96	115.35	116.03	114.50	115.51	0	0.00
13	60.00	60.44	60.70	60.21	59.95	60.37	60.30	0	0.00
14	160.00	160.07	160.76	159.41	158.72	160.27	159.10	0	0.00
15	175.00	174.07	173.33	174.87	175.61	174.10	174.78	0	0.00
16	125.00	125.44	125.17	125.69	125.96	125.20	126.04	0	0.00
17	175.00	174.17	172.72	175.64	177.08	173.94	175.94	0	0.00
18	170.00	170.10	170.04	170.17	170.23	170.06	170.25	0	0.00
19	155.00	155.38	155.85	154.94	154.47	155.41	154.89	0	0.00
20	180.00	179.68	179.41	179.94	180.21	179.71	179.91	1	0.21
21	175.00	175.90	176.63	175.10	174.37	175.92	175.18	0	0.00
$c_{max}$	180.00	179.68	179.41	179.94	180.21	179.71	179.91	180.21	

Table B.8: Station workloads per plan and overloaded values for each station in a robust assembly line configuration with 21 stations and linear area of 4.5.

## Appendix C. Appendix with information about Nissan instance tasks

This Appendix C has the information about the 140 tasks of the Nissan engine instance. This information is shown in Tables C.9, C.10, C.11, and C.12.

Task	Precedence	Production plans							$a_j$
$j$	tasks	$\bar{t}_{plan1}$	$\bar{t}_{plan2}$	$\bar{t}_{plan3}$	$\bar{t}_{plan6}$	$\bar{t}_{plan9}$	$\bar{t}_{plan12}$	$\bar{t}_{plan18}$	
1	–	6000	5956	5876	6038	6118	5944	6056	300
2	3, 31	7500	7503	7544	7460	7418	7518	7440	200
3	1	2000	1978	2011	1946	1913	1996	1918	50
4	3, 5	6000	5990	5902	6081	6169	5963	6120	100
5	1	2000	1999	2033	1967	1932	2010	1949	50
6	4, 5	6000	6026	5933	6117	6210	5988	6176	150
7	1	4500	4495	4480	4513	4528	4491	4518	100
8	1	1000	1001	1009	993	985	1003	989	50
9	1	2000	1982	1993	1973	1963	1991	1959	50
10	1	3000	3020	3027	3013	3007	3015	3020	50
11	1	1500	1490	1479	1499	1510	1490	1500	50
12	11	1500	1505	1511	1500	1495	1505	1500	50
13	1	1500	1486	1463	1509	1532	1483	1513	100
14	1, 13	1000	993	1002	984	975	998	976	50
15	9, 10, 11, 13, 14	800	810	806	814	817	805	820	100
16	9, 10, 11, 13, 14	800	803	791	816	828	798	823	50
17	9, 10, 11, 13, 14	8000	7980	8000	7960	7940	7991	7940	100
18	9, 10, 11, 13, 14	4000	3970	3950	3988	4009	3976	3984	50
19	9, 10, 11, 13, 14	500	501	497	505	509	499	508	50
20	9, 10, 11, 13, 14	500	503	505	501	499	503	501	50
21	9, 10, 11, 13, 14	500	502	494	510	517	499	515	50
22	26, 27	700	697	690	704	712	696	706	50
23	26, 27	700	700	699	701	702	700	701	50
24	26, 27	3000	3014	3027	2998	2986	3014	2999	50
25	26, 27	3000	3029	3072	2986	2943	3034	2979	50
26	15, 16, 17, 18, 19, 20, 21	500	496	488	504	512	495	506	50
27	15, 16, 17, 18, 19, 20, 21	500	500	494	508	514	498	511	50
28	22, 23, 24, 25	3000	2992	3000	2985	2977	2998	2977	100
29	28	1000	998	1006	990	982	1001	985	50

Table C.9: Tasks information for all the production plans.

30	29	1500	1498	1503	1494	1489	1500	1491	100
31	6, 7, 8, 30	1000	1002	1020	985	967	1007	977	0
32	31	1500	1490	1484	1497	1503	1491	1495	50
33	32	3000	2977	2930	3025	3072	2968	3037	100
34	32	1000	1011	1014	1007	1004	1008	1011	50
35	36	500	499	498	499	499	499	499	50
36	32	2500	2510	2529	2494	2475	2514	2490	100
37	32, 35	1500	1504	1489	1519	1534	1497	1529	0
38	33, 34, 36, 37	500	501	492	511	520	498	516	50
39	33, 34, 36, 37	500	500	501	499	498	500	498	50
40	33, 34, 36, 37	500	499	503	495	491	501	492	50
41	38, 39, 40	6000	5976	6067	5883	5793	6016	5826	50
42	38, 39, 40	1500	1507	1496	1518	1529	1501	1527	150
43	38, 39, 40	1500	1499	1488	1509	1519	1495	1514	150
44	41, 42, 43	2500	2487	2454	2519	2552	2481	2529	50
45	41, 42, 43	2500	2520	2528	2514	2506	2515	2520	50
46	44, 45	500	504	507	500	497	504	500	50
47	46	3500	3538	3551	3525	3513	3529	3538	50
48	46	3500	3499	3538	3460	3422	3514	3441	50
49	42, 43	500	498	484	511	525	494	517	50
50	47, 48, 49	1500	1489	1467	1513	1536	1485	1519	50
51	47, 48, 49	2500	2517	2522	2511	2505	2513	2517	0
52	47, 48, 49	3000	2993	2972	3011	3032	2990	3018	0
53	47, 48, 49	1500	1502	1503	1502	1501	1502	1502	0
54	47, 48, 49	1500	1522	1518	1524	1527	1513	1537	0
55	47, 48, 49	2000	1988	1978	1999	2009	1989	1998	0
56	47, 48, 49	1000	992	987	998	1004	993	997	0
57	50, 51, 52, 53, 54, 55, 56	1000	992	1001	984	975	998	975	50
58	57, 59, 60	2000	2016	2044	1989	1960	2020	1982	50
59	41	500	498	506	490	483	501	485	0
60	42, 43	2000	1991	1982	2001	2010	1992	2001	50
61	57, 58	4500	4497	4585	4408	4320	4528	4362	100
62	61	3000	3018	3079	2959	2899	3032	2938	50
63	57	3000	3026	3083	2967	2909	3038	2951	50
64	57	1000	1007	1021	994	980	1009	990	50
65	61, 62, 63, 64	500	503	508	498	493	504	497	0
66	61, 62, 63, 64	1000	1001	975	1026	1051	992	1039	50
67	66	1500	1480	1462	1499	1517	1481	1498	50
68	65, 67	6000	5987	6036	5938	5889	6008	5907	150
69	68	1000	1010	994	1025	1041	1001	1038	50

Table C.10: (continuation) Tasks information for all the production plans.

70	67	3000	2974	2949	2999	3025	2974	2999	100
71	68	1000	995	979	1011	1027	992	1017	50
72	68	1000	998	1017	978	959	1005	968	50
73	71, 72	4000	4020	3984	4059	4095	3999	4087	150
74	68, 69, 70, 73	2500	2473	2447	2499	2524	2473	2498	50
75	74	1000	1000	1000	1000	1000	1000	1000	50
76	74	1000	1006	1027	985	964	1011	977	100
77	75	1500	1514	1497	1531	1548	1504	1546	50
78	79	1500	1513	1501	1525	1537	1504	1538	50
79	74	1500	1492	1481	1503	1514	1491	1505	50
80	76, 77, 78	1000	1008	1030	985	963	1013	978	50
81	76, 77, 78	1000	1004	1015	994	984	1006	991	100
82	80, 81	1000	1000	1009	991	982	1003	987	0
83	82	2000	1978	2011	1946	1913	1996	1918	50
84	83	1000	1001	996	1006	1012	1000	1010	0
85	75, 84	2000	1990	1979	2003	2014	1989	2003	50
86	82	2500	2504	2504	2506	2507	2502	2508	50
87	82	2000	2007	2014	2000	1993	2007	2000	50
88	84	1500	1503	1517	1489	1475	1507	1483	25
89	88	2000	2030	2043	2015	2001	2025	2023	50
90	88	3000	2980	2973	2987	2993	2985	2980	50
91	85, 86, 87, 88	2000	1993	2003	1985	1975	1998	1977	50
92	89, 90, 91	2500	2501	2494	2510	2517	2499	2514	50
93	92	1000	997	974	1020	1043	990	1030	50
94	89, 90, 91	500	499	494	505	511	498	508	50
95	94	2000	1998	1971	2026	2052	1990	2038	50
96	93, 95, 99	1000	1008	1022	994	981	1010	992	50
97	93, 95, 99	500	502	503	501	500	501	502	50
98	92	8000	7962	7908	8021	8074	7952	8028	0
99	89, 90, 91	3000	2959	2929	2989	3020	2963	2984	0
100	98, 99	1000	1005	1028	981	957	1011	971	50
101	98, 99	1000	1004	1008	999	995	1004	999	50
102	100, 101	2000	2016	1999	2033	2050	2004	2049	50
103	100, 101	3000	2991	2944	3037	3084	2978	3056	50
104	102, 103	500	502	503	501	501	502	502	0
105	106	3000	3023	3040	3005	2988	3022	3008	50
106	100, 101	2500	2508	2528	2489	2469	2511	2483	50
107	100, 101, 104	500	500	501	499	498	500	498	0
108	100, 101, 104	500	500	496	505	509	499	507	0
109	108	500	497	495	499	501	497	499	50

Table C.11: (continuation) Tasks information for all the production plans.

110	108	500	505	508	502	499	505	503	0
111	11, 109	1000	1002	983	1022	1041	995	1032	0
112	11, 109	1000	997	999	994	992	998	992	0
113	108	1500	1487	1474	1500	1512	1487	1500	50
114	113	2000	1984	1975	1994	2003	1986	1991	0
115	113	2000	1990	1977	2005	2018	1989	2007	0
116	111, 112, 114, 115	4500	4459	4418	4497	4537	4458	4496	100
117	118	2000	2011	2056	1968	1923	2022	1951	50
118	116	2500	2538	2523	2553	2568	2520	2580	0
119	116	2500	2481	2469	2493	2505	2483	2489	0
120	119	2000	1991	1990	1992	1992	1994	1988	50
121	105, 107, 117, 120	4500	4483	4442	4523	4565	4476	4535	150
122	121	1500	1508	1519	1497	1486	1509	1496	50
123	122	1000	991	984	997	1003	991	996	50
124	123	1000	1008	1013	1003	998	1006	1004	0
125	124	2000	1997	2029	1964	1933	2009	1947	100
126	125	3000	2986	2988	2984	2982	2992	2976	50
127	126	1000	991	997	985	980	996	978	50
128	117, 12	2500	2499	2527	2472	2444	2508	2457	50
129	126	3000	3002	2968	3034	3068	2991	3052	50
130	127, 128, 129	3000	3010	3031	2991	2970	3014	2985	75
131	117, 12	4000	4008	4046	3970	3931	4020	3954	50
132	131	2500	2502	2491	2516	2528	2497	2523	100
133	130	2500	2515	2546	2481	2450	2522	2473	50
134	132	2000	2016	1977	2055	2094	1998	2083	50
135	134	1500	1509	1503	1514	1520	1504	1521	50
136	135	2000	1999	1981	2017	2035	1994	2026	50
137	136	3000	2991	2974	3007	3023	2987	3011	50
138	136	3000	2989	3001	2976	2963	2997	2964	50
139	137, 138	1500	1491	1476	1505	1520	1489	1508	100
140	133, 139	12000	12093	12160	12020	11953	12091	12033	0

Table C.12: (continuation) Tasks information for all the production plans.