Nick Morris
Bikram Singh

Block Maximal Master Scheduling

Overview

The block maximal master scheduling method develops a set of sequential production cycles (ie. blocks) of SKU's within a product family. This method of choice is useful when changing production from one SKU to the next has expensive costs of time and money. This means that production setup cost is far more expensive relative to holding cost. The block maximal method must produce as much of an SKU as possible once it has been set up, but also must set up and produce other SKU's in time before sales are lost. This means that the length of each production cycle is maximized up to the limit of decreasing inventory, to ultimately minimize the total setup cost.

The two main assumptions that must be met for block maximal to be an effective method for generating a master schedule are the following:

1. Setup Cost >> Holding Cost
2. Backorders are not allowed

This report will go over the implementation of block maximal master scheduling for a production plan that consists of five SKU's and two resources over 26 periods. The first section will show the data that will be used for this implementation, which was generated from an aggregate plan. The second section will go over how an optimization based heuristic for block maximal master scheduling was automated using the R programming language to handle single and multiple resource master scheduling. The third and fourth sections will show the performance of the heuristic for single and multiple resource master scheduling respectively. Finally, the fifth section will conclude on the overall results, as well as the limitations of the this method for master scheduling.

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The Data

Figure 1 below shows the production capacity and demand rates across 26 periods for each resource and SKU. It is clear that the demand rates are always below the production capacity, but it is important to note that all SKUs must share the production capacity of each resource. This means that if the entire production capacity of a resource during a period is completely dedicated to one SKU, then there is no longer any production capacity leftover for the other SKUs in that period. Figure 2 on the following page will give a more realistic perspective on the relationship between production capacity and demand rates.

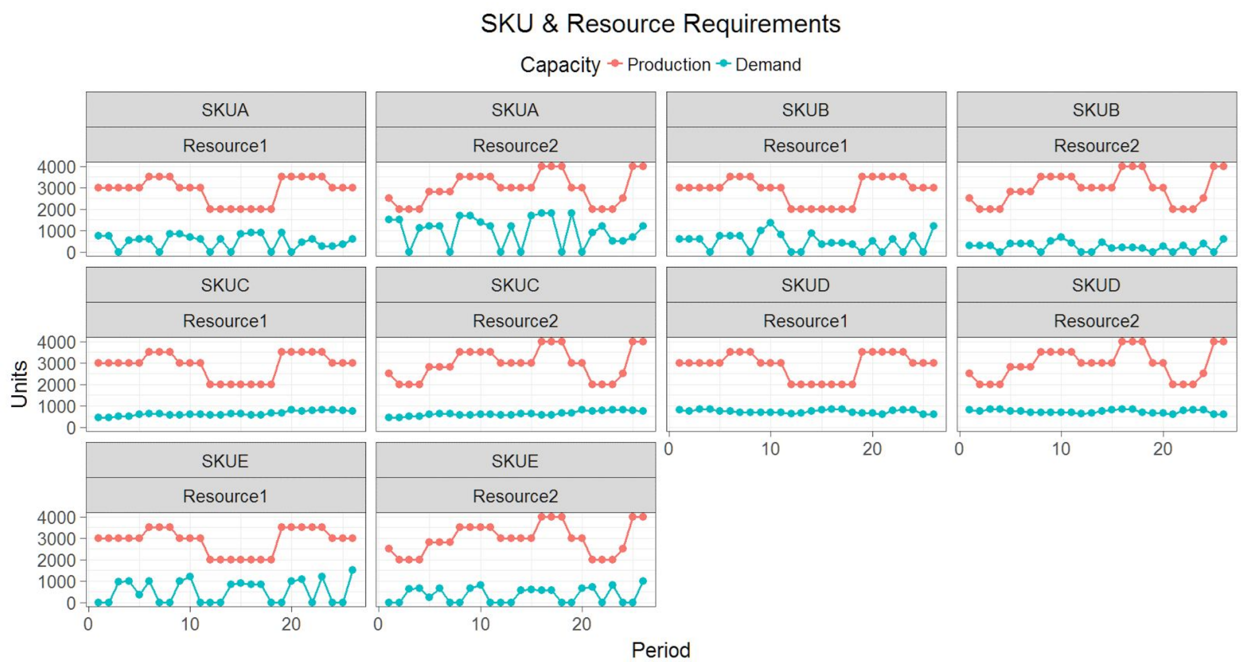

Figure 1: Production Capacity v. SKU Demand

Figure 2 below shows the total demand, that is the sum of demand across all SKUs, compared to the production capacity for each resource across the 26 periods. It is clear that there are segments of concern in these plots, for example periods 14-17 for Resource1, where the total demand is much larger than the production capacity. Alternatively, there are segments where production capacity is much higher than the total demand, for example periods 19-23 for Resource1. This means that extra inventory will need to be built during favorable periods to offset the unfavorable periods. When comparing Resource1 and Resource2, it appears that Resource2 will have more difficulty dealing with its demand rates than Resource1. Overall, the period by period difference between production capacity and total demand may be due to a less conservative aggregate plan, making for a feasible master schedule more difficult to find.

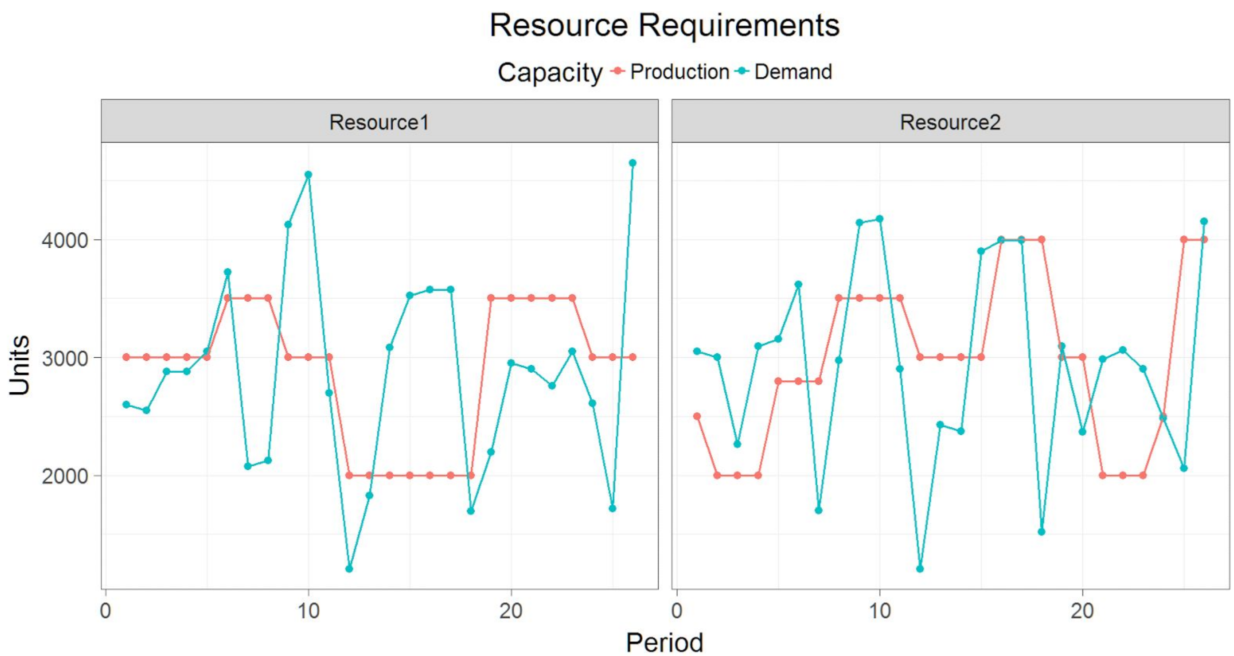

Figure 2: Production Capacity v. Total Demand

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Automation

The details of the automation of our optimization based heuristic are commented throughout the provided Block-Maximal.R script file. This implementation is generalized to handle any number of resources, where it will produce a single or a multiple resource plan if given a single or multiple resource file(s) respectively. An outline of the procedure that our script file follows is shown below.

1. Import a csv file for each resource
2. Aggregate all csv files together into one table in long format
3. Define control parameters if necessary → See Table 1
4. Compute the runout times for each SKU and Resource
5. Extract the minimum runout time for each SKU as that SKU's runout time
6. Compute an initial estimate of the cycle length
    a. This has an upper bound of: the number of remaining periods to satisfy
7. Compute the average demand rate and average production rate for each SKU across the estimate of cycle length
    a. These average rates are of the constraining resource (ie. the resource that had the minimum runout time in step 5)
    b. The average demand rate has an upper bound of the average production rate for each SKU
8. Solve for the start times of each SKU while maximizing the cycle length, using a linear program
9. Go back to step 7
    a. Only go onto step 10 when convergence on a maximum cycle length has been found
10. Compute the total number of units produced for each SKU and resource using the timestamps in the output of the final linear program
11. Compute the total demand experienced for each SKU and resource using the cycle length in the output of the final linear program
12. Compute the new inventory levels for each SKU and resource at the end of the cycle length
13. Truncate the data table by removing all rows corresponding to fully satisfied periods and reducing the production and demand values in rows corresponding to partially satisfied periods
14. Go back to step 5
    a. End the heuristic when the data table has truncated to the point where the remaining rows only correspond to the inventory at the end of 26 periods.

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Single Resource Performance

This section will show two single resource plans for each of the resources. The first plan uses Resource1 and the second plan uses Resource2.

The inventory levels at the end of each cycle for each SKU are shown below in Figure 3. The plots below show that four production cycles were necessary to satisfy the entire 26 periods. given by the four data points. It is important to note that the inventory levels between two successive points don't show the true inventory levels during those periods. The exact values of end of cycle inventory for each SKU for this figure are shown in Table 2 in the Appendix.

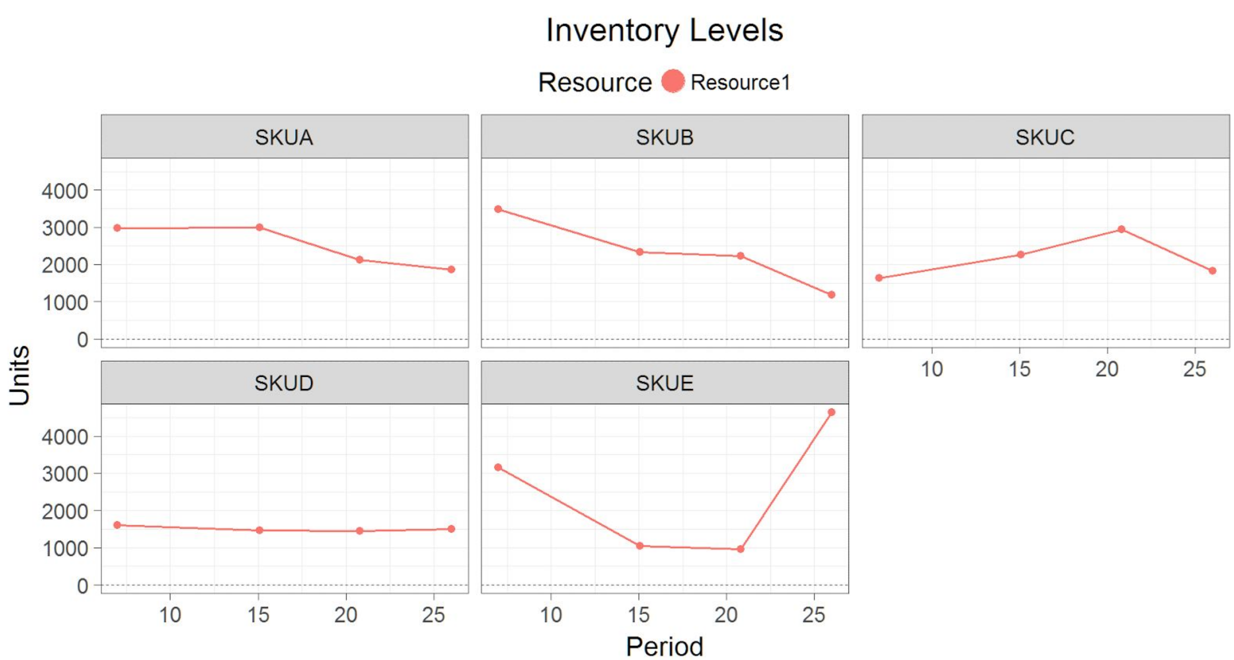

Figure 3: Inventory Plan for a Resource 1 Master Schedule

The production order and time of each SKU during each cycle is shown below in Figure 4. This figure shows that a total of 19 setups are required to satisfy the demand of 26 periods with the given production capacity of Resource1. The production time and quantity for each SKU during each cycle for this figure are shown in Table 2 in the Appendix.

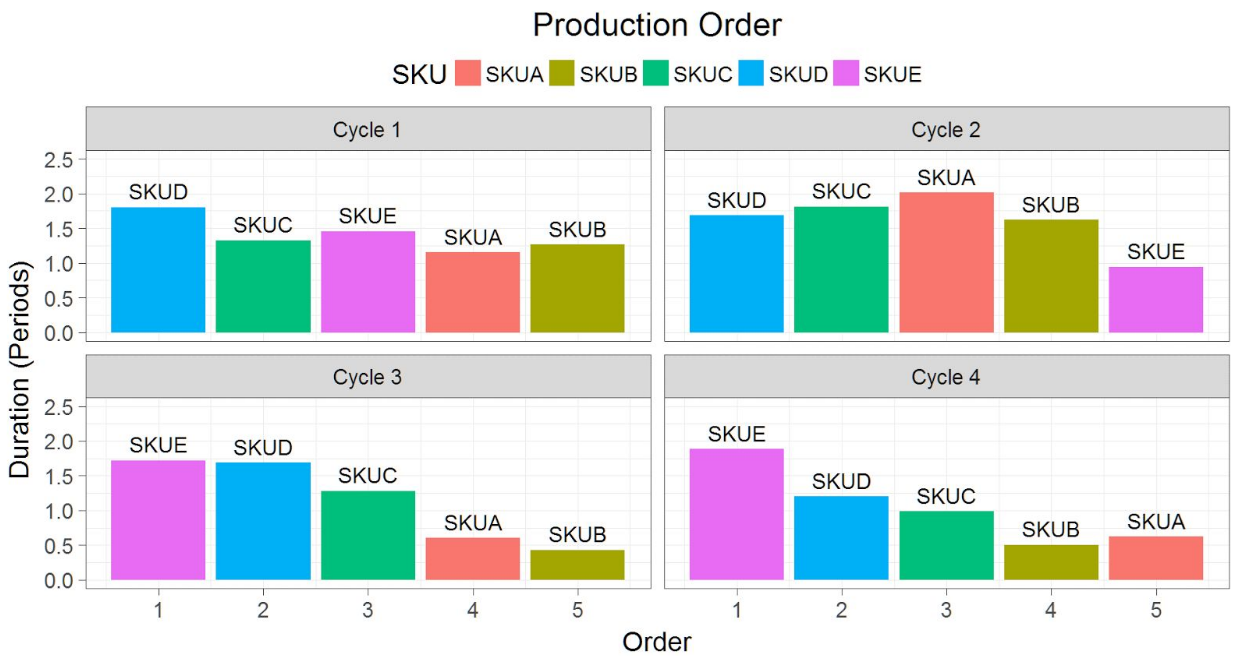

Figure 4: Production Plan for a Resource 1 Master Schedule

The inventory levels at the end of each cycle for each SKU are shown below in Figure 5. The plots below show that six production cycles were necessary to satisfy the entire 26 periods. It is important to note that the inventory levels between two successive points don't show the true inventory levels during those periods. The exact values of end of cycle inventory for each SKU for this figure are shown in Table 3 in the Appendix.

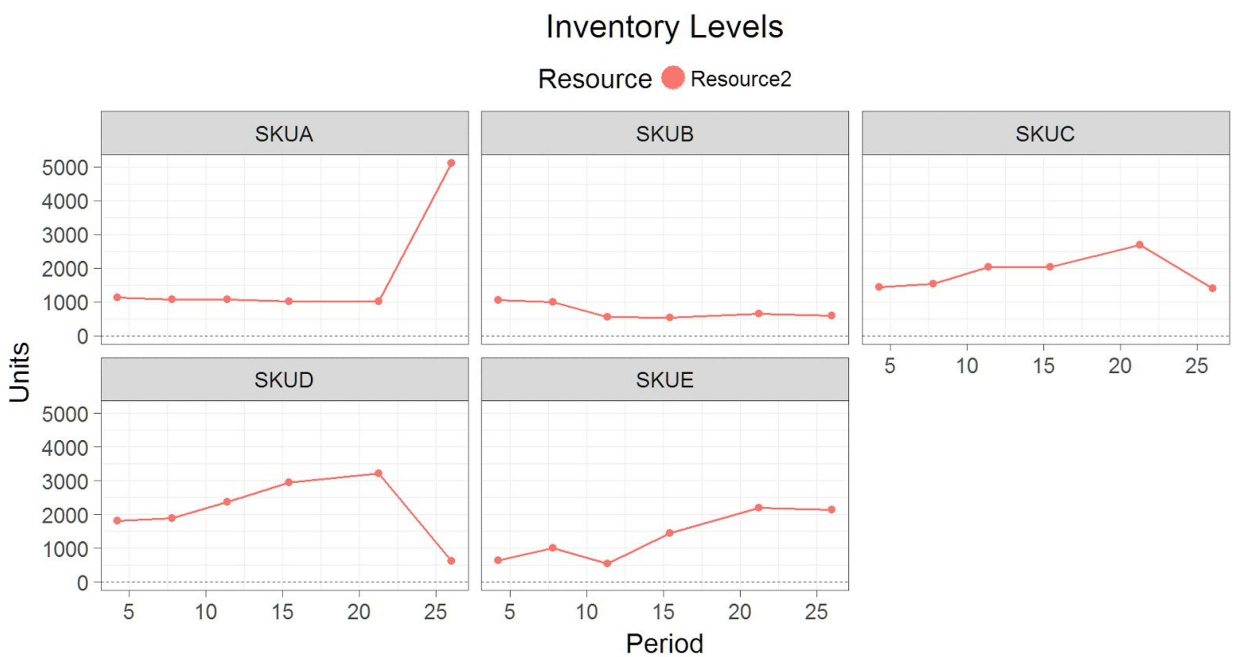

Figure 5: Inventory Plan for a Resource 2 Master Schedule

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The production order and time of each SKU during each cycle is shown below in Figure 6. This figure shows that a total of 28 setups are required to satisfy the demand of 26 periods with the given production capacity of Resource2. These are a much more setups when compared to the Resource1 single resource production plan in Figure 4. This exposes the behavior in Figure 2 where Resource2 has a less favorable production capacity to total demand relationship in comparison to Resource1. The production time and quantity for each SKU during each cycle for this figure are shown in Table 2 in the Appendix.

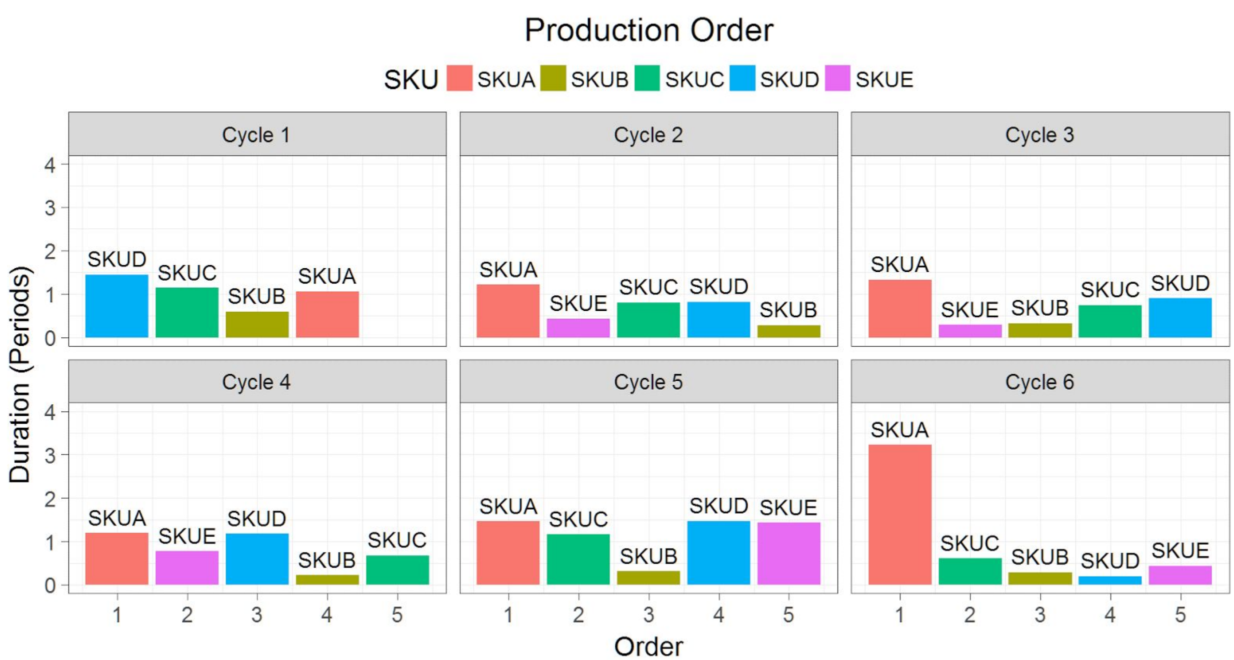

Figure 6: Production Plan for a Resource 2 Master Schedule

Multiple Resource Performance

The inventory levels at the end of each cycle for each SKU and resource are shown below in Figure 7. The plots below show that three production cycles were computed before the heuristic failed just before period 10. This failure was due to multiple inventory levels of different SKUs reaching zero, in this case SKU B, C and E. When multiple SKUs run out of inventory simultaneously, the heuristic has no way of producing in sequential order anymore and stops running. It is important to note that the inventory levels between two successive points don't show the true inventory levels during those periods. The exact values of end of cycle inventory for each SKU and resource for this figure are shown in Table 4 in the Appendix.

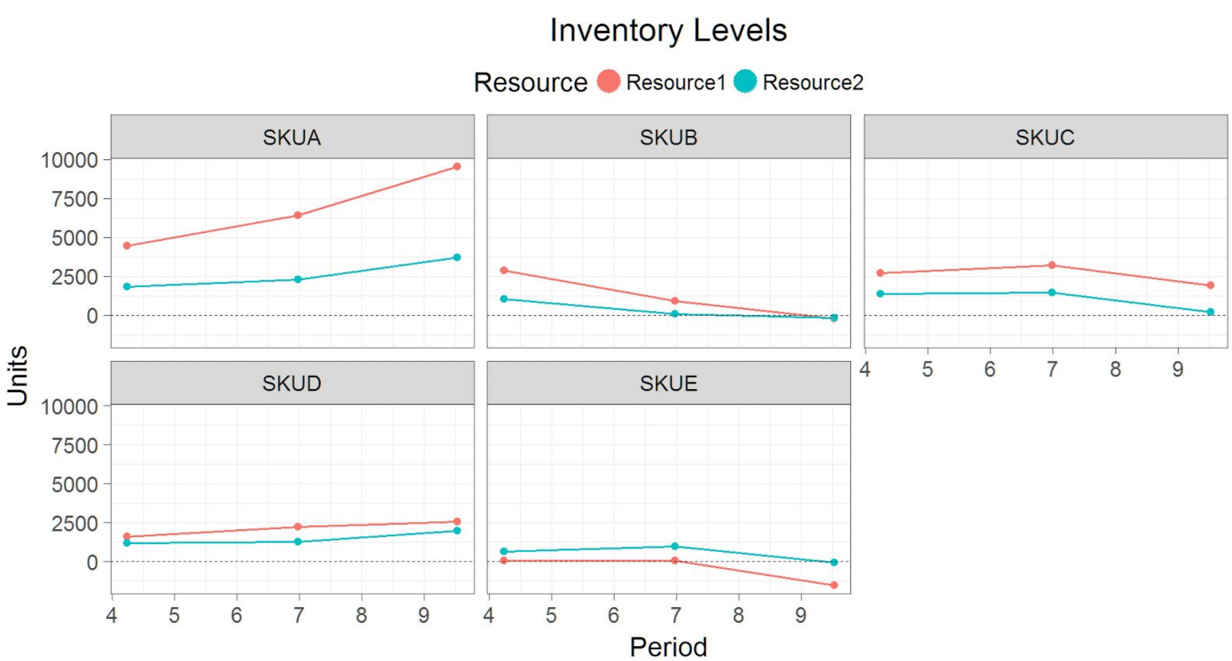

Figure 7: Infeasible Inventory Plan for a Multi-Resource Master Schedule

The production order and time of each SKU during each cycle is shown below in Figure 8. This figure shows that a total of 14 setups were computed before the heuristic failed. The production time and quantity for each SKU during each cycle for this figure are shown in Table 4 in the Appendix.

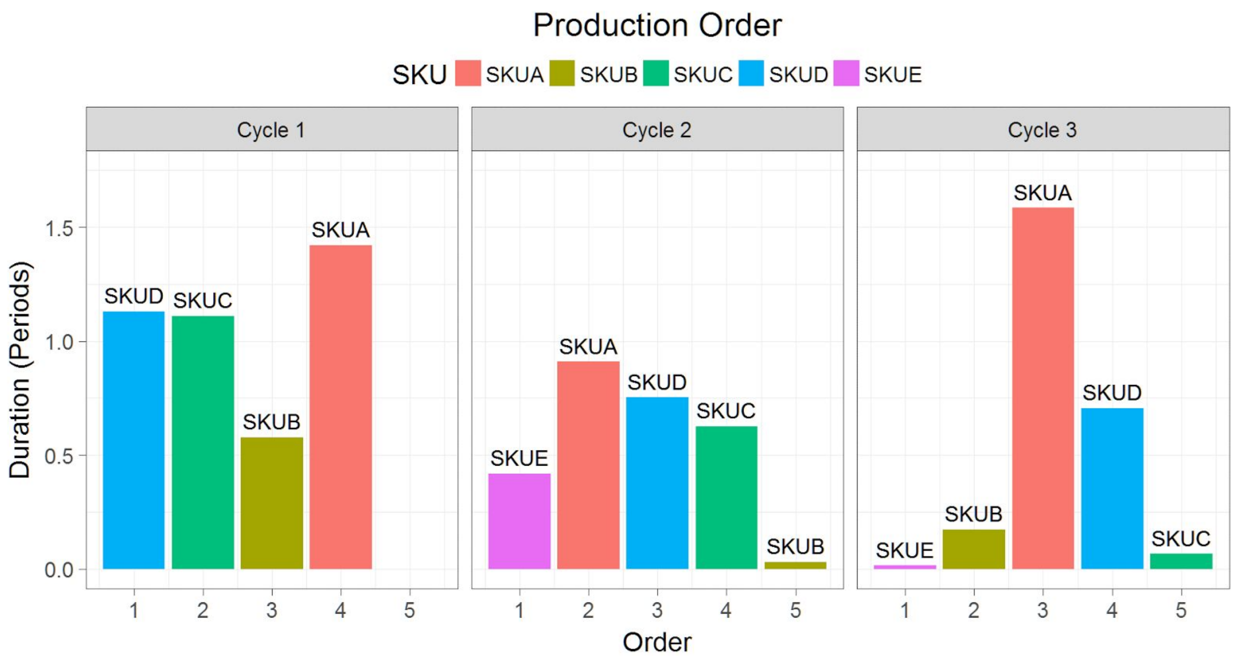

Figure 8: Infeasible Production Plan for a Multi-Resource Master Schedule

The failure of the heuristic for a multi-resource plan created the need for the control parameters in Table 1 on the next page. All of these control parameters manipulate the data going into the linear program to incentivise solutions that build extra inventory during favorable periods when production capacity is larger than total demand. “Max Usage” is the maximum proportion of production capacity that an SKU can use. This control was put in place so the linear program wouldn’t focus on just one or two SKUs in any given cycle. “Next” is the proportion of the next nonzero future demand to replace a period of zero demand with, across all SKUs. This control was put in place because you can see in Figure 1 that there are many instances of zero demands for SKU A, B, and E followed by spikes which causes varying levels of stress on the heuristic. “P” is the percentage to increase the average demand rate by. This control was put in place to directly increase the demand so the linear program would create more production than needed, allowing for inventory to build. “Boost” is a vector of periods for which the parameter “P” can be applied to. This was put in place to see if focusing on particular periods would be better, in this case all periods were boosted. “Num” is the number of SKUs that can have the parameters “Boost” and “P” applied to, where the “Num” SKUs corresponds to the “Num” lowest runouts for a cycle. This was put in place to see if boosting only the SKUs with immediate inventory needs would be better than boosting all SKUs, in this case just the SKU with the highest need for inventory was boosted.

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Table 1: Control Parameters

Parameter	Value
Max Usage	34%
Next	34%
P	66%
Boost	[1, 2, … , 26]
Num	1

The inventory levels at the end of each cycle for each SKU and resource are shown below in Figure 9. The plots below show that 14 production cycles were necessary to reach the end of 26 periods. In all of the plots below there is at least one resource that trails along the zero production line indicating that the control parameters were sufficient in create a master schedule that reaches the end of period 26. These control parameters are not perfect, but were the best found after much searching. Their imperfection is shown in the plot for SKU A, where there are a handful of data points below the zero inventory line, indicating lost sales. There was a total of 4124 units of lost sales for SKU A, and only SKU A, which is 16% of the total demand for SKU A. The cycles of lost sales for SKU A are cycles 3 - 7, and 11 - 12. It is important to note that the inventory levels between two successive points don’t show the true inventory levels during those periods. The exact values of end of cycle inventory for each SKU and resource for this figure are shown in Tables 5 - 9 in the Appendix.

Figure 9: Inventory Plan for a Multi-Resource Master Schedule with Lost Sales

The production order and time of each SKU during each cycle is shown below in Figure 10. This figure shows that a total of 60 setups are required to satisfy the demand of 26 periods, except for 16% of SKU A's demand, with the given production capacity of Resource1 and Resource2. It is clear that SKU A was the frontrunner for most cycles, but this was not enough to prevent lost sales. The production time and quantity for each SKU during each cycle for this figure are shown in Tables 5 - 9 in the Appendix.

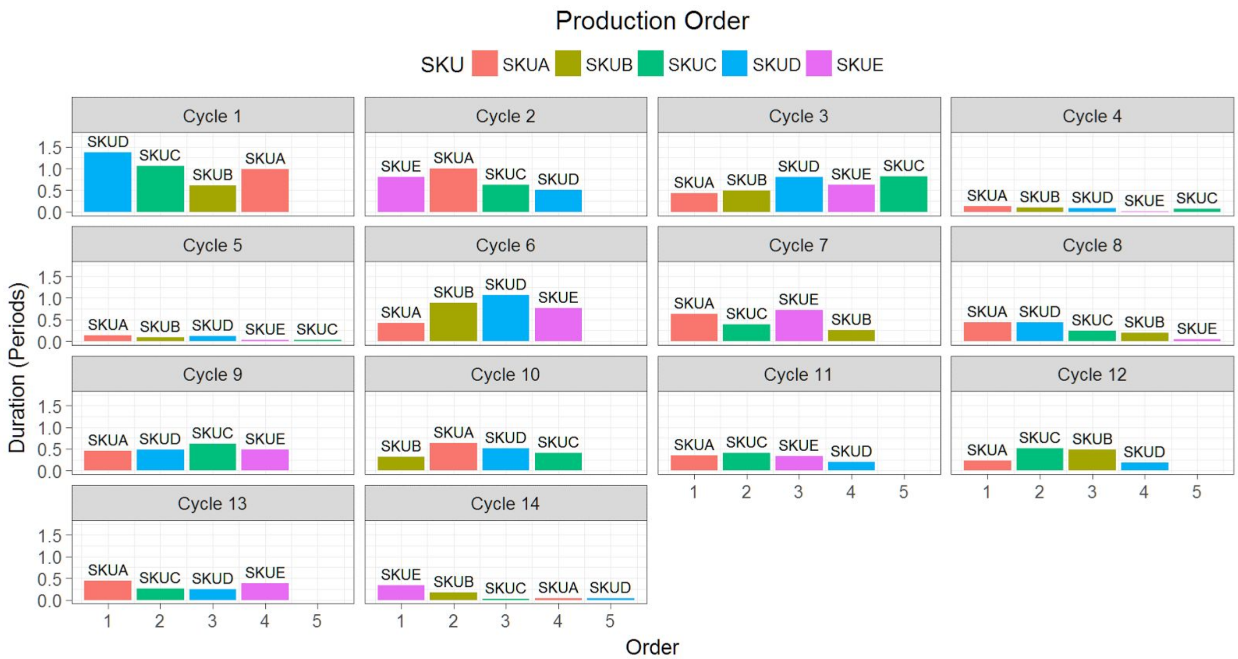

Figure 10: Production Plan for a Multi-Resource Master Schedule with Lost Sales

Conclusion

The results of our implementation show that for single resource planning, this heuristic worked well and returns a solution very quickly without the need for any control parameters. Multi-Resource planning on the other hand shows to be a much bigger challenge for this heuristic, which is a concern given that multiple resources required for a production plan is very common in industry. Despite the expected lost sales of SKU A in the multi-resource plan, it is important to remember that the master schedule as well as the aggregate planning model, which feeds into this heuristic, are continuously updated period by period when the true demand and true production capacity have been realized. This means that the only deterministic aspect of our master schedule is the first period, so the opportunity for improvement always exists when updating the master schedule and the aggregate plan so that lost sales never occur, or occur rarely.

The limitations of the block maximal heuristic are outlined below.
The block maximal heuristic depends on the results of the aggregate planning model. An aggregate plan that is not very well defined, or chooses to aggregate demand in a way that runs a higher risk of insufficient resources, might give improper input to the master schedule which can result in lost sales. This might occur when the average production rate, as determined by the aggregate planning model is not able to keep up with the average demand of a SKU over a given cycle length. The block maximal heuristic doesn't have a mechanism to determine a production order when multiple runout times converge on the same value.

The linear program is very sensitive to any change in the constraints of the block maximal heuristic model. Additional constraints, such as limiting the start time of all SKUs to be less than or equal to the cycle length would result in an insufficient solution of no production.

The block maximal heuristic results in a production sequence of SKUs, so it does not consider the possibility of parallel production of different SKUs. Depending on whether we have sufficient resources available to cater the demands of two or more SKUs over a cycle length, creating a master schedule with parallel production may result in a better production plan.

It's worth comparing how a block maximal heuristic would compare against a generalized mixed-integer programming disaggregate planning model. A pure optimization program would be expected to consider the all 26 periods and their information regarding demand and production capacity. This full scope would enable the MIP model to know exactly when to take advantage of favorable periods of higher production capacity to alleviate the unfavorable periods of higher demand without building excessive inventory. Recall from Figure 9 that the inventory levels of SKU A and SKU E drastically increases as it approaches the end of the 26 weeks. The main assumption required to use block maximal is that setup costs are much larger than holding costs but an unrealistic amount of inventory will eventually catch up to set up costs. This optimal balance of setup and inventory cost would be an element of an MIP disaggregate formulation even if the setups are much larger in cost.

Appendix

Table 2: Resource 1 Master Schedule

Resource	Cycle	SKU	Start	End	Inventory	Quantity
Resource1	1	SKUD	0	1.80158	1596	5404
Resource1	1	SKUC	1.80158	3.12691	1627	3975
Resource1	1	SKUE	3.12691	4.58207	3165	4365
Resource1	1	SKUA	4.58207	5.73333	2970	3820
Resource1	1	SKUB	5.73333	6.99815	3478	4426
Resource1	2	SKUD	6.99815	8.68243	1462	5553
Resource1	2	SKUC	8.68243	10.4938	2259	5434
Resource1	2	SKUA	10.4938	12.5058	2987	4530
Resource1	2	SKUB	12.5058	14.1278	2331	3243
Resource1	2	SKUE	14.1278	15.0709	1041	1886
Resource1	3	SKUE	15.0709	16.7906	960	3439
Resource1	3	SKUD	16.7906	18.482	1447	4105
Resource1	3	SKUC	18.482	19.7626	2941	4482
Resource1	3	SKUA	19.7626	20.369	2112	2122
Resource1	3	SKUB	20.369	20.8003	2218	1509
Resource1	4	SKUE	20.8003	22.6838	4631	6591
Resource1	4	SKUD	22.6838	23.8845	1507	3760
Resource1	4	SKUC	23.8845	24.8716	1832	2961
Resource1	4	SKUB	24.8716	25.376	1181	1513
Resource1	4	SKUA	25.376	26	1854	1872

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Table 3: Resource 2 Master Schedule

Resource	Cycle	SKU	Start	End	Inventory	Quantity
Resource2	1	SKUD	0	1.44623	1802	3392
Resource2	1	SKUC	1.44623	2.58713	1437	2281
Resource2	1	SKUB	2.58713	3.18182	1049	1189
Resource2	1	SKUA	3.18182	4.24031	1121	2309
Resource2	1	SKUE	NA	NA	644	0
Resource2	2	SKUA	4.24031	5.45673	1077	3405
Resource2	2	SKUE	5.45673	5.88525	998	1199
Resource2	2	SKUC	5.88525	6.68857	1528	2249
Resource2	2	SKUD	6.68857	7.50917	1886	2654
Resource2	2	SKUB	7.50917	7.7867	985	971
Resource2	3	SKUA	7.7867	9.11748	1071	4657
Resource2	3	SKUE	9.11748	9.40455	535	1004
Resource2	3	SKUB	9.40455	9.73257	558	1148
Resource2	3	SKUC	9.73257	10.48	2027	2616
Resource2	3	SKUD	10.48	11.379	2357	2957
Resource2	4	SKUA	11.379	12.5722	1010	3578
Resource2	4	SKUE	12.5722	13.3416	1444	2308
Resource2	4	SKUD	13.3416	14.5161	2942	3523
Resource2	4	SKUB	14.5161	14.7376	535	664
Resource2	4	SKUC	14.7376	15.4107	2030	2430
Resource2	5	SKUA	15.4107	16.8732	1008	5849
Resource2	5	SKUC	16.8732	18.0327	2692	4604
Resource2	5	SKUB	18.0327	18.3424	649	929
Resource2	5	SKUD	18.3424	19.8126	3213	4410
Resource2	5	SKUE	19.8126	21.2423	2188	3046
Resource2	6	SKUA	21.2423	24.4688	5108	7890
Resource2	6	SKUC	24.4688	25.0767	1391	2431
Resource2	6	SKUB	25.0767	25.3646	597	1151
Resource2	6	SKUD	25.3646	25.5635	616	795
Resource2	6	SKUE	25.5635	26	2134	1746

Table 4: Infeasible Multi-Resource Master Schedule

Resource	Cycle	SKU	Start	End	Inventory	Quantity
Resource1	1	SKUD	0	1.13044	1601	3391
Resource1	1	SKUC	1.13044	2.24161	2689	3333
Resource1	1	SKUB	2.24161	2.81998	2855	1735
Resource1	1	SKUA	2.81998	4.24114	4469	4263
Resource1	1	SKUE	NA	NA	66	0
Resource2	1	SKUD	0	1.13044	1170	2760
Resource2	1	SKUC	1.13044	2.24161	1378	2222
Resource2	1	SKUB	2.24161	2.81998	1016	1156
Resource2	1	SKUA	2.81998	4.24114	1846	3035
Resource2	1	SKUE	NA	NA	643	0
Resource1	2	SKUE	4.24114	4.65924	53	1253
Resource1	2	SKUA	4.65924	5.56931	6427	3014
Resource1	2	SKUD	5.56931	6.32229	2230	2635
Resource1	2	SKUC	6.32229	6.94933	3190	2194
Resource1	2	SKUB	6.94933	6.98056	909	109
Resource2	2	SKUE	4.24114	4.65924	969	1170
Resource2	2	SKUA	4.65924	5.56931	2282	2547
Resource2	2	SKUD	5.56931	6.32229	1272	2108
Resource2	2	SKUC	6.32229	6.94933	1440	1755
Resource2	2	SKUB	6.94933	6.98056	76	87
Resource1	3	SKUE	6.98056	6.9956	-1528	52
Resource1	3	SKUB	6.9956	7.16968	-209	609
Resource1	3	SKUA	7.16968	8.75504	9529	5171
Resource1	3	SKUD	8.75504	9.46167	2566	2119
Resource1	3	SKUC	9.46167	9.52802	1910	199
Resource2	3	SKUE	6.98056	6.9956	-79	41
Resource2	3	SKUB	6.9956	7.16968	-182	606
Resource2	3	SKUA	7.16968	8.75504	3691	5548
Resource2	3	SKUD	8.75504	9.46167	1962	2473
Resource2	3	SKUC	9.46167	9.52802	193	232

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Table 5: Multi-Resource Master Schedule with Lost Sales (Cycles: 1 - 3)

Resource	Cycle	SKU	Start	End	Inventory	Quantity
Resource1	1	SKUD	0	1.374	2481	4121
Resource1	1	SKUC	1.374	2.44237	2681	3205
Resource1	1	SKUB	2.44237	3.05458	3106	1836
Resource1	1	SKUA	3.05458	4.04117	3285	2959
Resource1	1	SKUE	NA	NA	136	0
Resource2	1	SKUD	0	1.374	1807	3247
Resource2	1	SKUC	1.374	2.44237	1412	2136
Resource2	1	SKUB	2.44237	3.05458	1159	1224
Resource2	1	SKUA	3.05458	4.04117	1057	2006
Resource2	1	SKUE	NA	NA	690	0
Resource1	2	SKUE	4.04117	4.84162	1200	2400
Resource1	2	SKUA	4.84162	5.8486	5554	3445
Resource1	2	SKUC	5.8486	6.48143	3081	2214
Resource1	2	SKUD	6.48143	6.9817	2074	1750
Resource1	2	SKUB	NA	NA	900	0
Resource2	2	SKUE	4.04117	4.84162	2039	2240
Resource2	2	SKUA	4.84162	5.8486	1525	2819
Resource2	2	SKUC	5.8486	6.48143	1369	1771
Resource2	2	SKUD	6.48143	6.9817	1050	1400
Resource2	2	SKUB	NA	NA	56	0
Resource1	3	SKUA	6.9817	7.4185	4579	1528
Resource1	3	SKUB	7.4185	7.90745	110	1711
Resource1	3	SKUD	7.90745	8.7195	2323	2482
Resource1	3	SKUE	8.7195	9.345	876	1876
Resource1	3	SKUC	9.345	10.1721	3697	2481
Resource2	3	SKUA	6.9817	7.4185	-1966	1515
Resource2	3	SKUB	7.4185	7.90745	517	1711
Resource2	3	SKUD	7.90745	8.7195	1659	2842
Resource2	3	SKUE	8.7195	9.345	2761	2189
Resource2	3	SKUC	9.345	10.1721	2398	2894

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Table 6: Multi-Resource Master Schedule with Lost Sales (Cycles: 4 - 6)

Resource	Cycle	SKU	Start	End	Inventory	Quantity
Resource1	4	SKUA	10.1721	10.3094	4748	411
Resource1	4	SKUB	10.3094	10.4173	110	323
Resource1	4	SKUD	10.4173	10.4982	2282	242
Resource1	4	SKUE	10.4982	10.5036	892	16
Resource1	4	SKUC	10.5036	10.5761	3672	217
Resource2	4	SKUA	10.1721	10.3094	-5	480
Resource2	4	SKUB	10.3094	10.4173	732	377
Resource2	4	SKUD	10.4173	10.4982	1659	283
Resource2	4	SKUE	10.4982	10.5036	2780	19
Resource2	4	SKUC	10.5036	10.5761	2409	253
Resource1	5	SKUA	10.5761	10.7132	4917	411
Resource1	5	SKUB	10.7132	10.7991	44	257
Resource1	5	SKUD	10.7991	10.9242	2375	375
Resource1	5	SKUE	10.9242	10.9498	968	76
Resource1	5	SKUC	10.9498	10.9795	3518	88
Resource2	5	SKUA	10.5761	10.7132	-5	479
Resource2	5	SKUB	10.7132	10.7991	871	300
Resource2	5	SKUD	10.7991	10.9242	1814	437
Resource2	5	SKUE	10.9242	10.9498	2869	89
Resource2	5	SKUC	10.9498	10.9795	2270	103
Resource1	6	SKUA	10.9795	11.4009	5064	862
Resource1	6	SKUB	11.4009	12.2852	893	1768
Resource1	6	SKUD	12.2852	13.3543	2377	2138
Resource1	6	SKUE	13.3543	14.1203	1542	1532
Resource1	6	SKUC	NA	NA	1645	0
Resource2	6	SKUA	10.9795	11.4009	-156	1273
Resource2	6	SKUB	11.4009	12.2852	3063	2652
Resource2	6	SKUD	12.2852	13.3543	2885	3207
Resource2	6	SKUE	13.3543	14.1203	4528	2298
Resource2	6	SKUC	NA	NA	397	0

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Table 7: Multi-Resource Master Schedule with Lost Sales (Cycles: 7 - 9)

Resource	Cycle	SKU	Start	End	Inventory	Quantity
Resource1	7	SKUA	14.1203	14.7553	4575	1269
Resource1	7	SKUC	14.7553	15.1424	1224	774
Resource1	7	SKUE	15.1424	15.8642	1239	1443
Resource1	7	SKUB	15.8642	16.123	653	517
Resource1	7	SKUD	NA	NA	719	0
Resource2	7	SKUA	14.1203	14.7553	-1613	1904
Resource2	7	SKUC	14.7553	15.1424	505	1303
Resource2	7	SKUE	15.1424	15.8642	6251	2887
Resource2	7	SKUB	15.8642	16.123	3719	1034
Resource2	7	SKUD	NA	NA	1227	0
Resource1	8	SKUA	16.123	16.5615	4662	877
Resource1	8	SKUD	16.5615	17	521	877
Resource1	8	SKUC	17	17.2371	890	474
Resource1	8	SKUB	17.2371	17.4308	525	387
Resource1	8	SKUE	17.4308	17.4706	572	79
Resource2	8	SKUA	16.123	16.5615	175	1754
Resource2	8	SKUD	16.5615	17	1906	1754
Resource2	8	SKUC	17	17.2371	645	948
Resource2	8	SKUB	17.2371	17.4308	4235	774
Resource2	8	SKUE	17.4308	17.4706	5912	159
Resource1	9	SKUA	17.4706	17.9226	4665	903
Resource1	9	SKUD	17.9226	18.4024	731	1563
Resource1	9	SKUC	18.4024	19.026	1677	2182
Resource1	9	SKUE	19.026	19.5111	1758	1697
Resource1	9	SKUB	NA	NA	84	0
Resource2	9	SKUA	17.4706	17.9226	182	1807
Resource2	9	SKUD	17.9226	18.4024	2069	1516
Resource2	9	SKUC	18.4024	19.026	1120	1870
Resource2	9	SKUE	19.026	19.5111	7027	1455
Resource2	9	SKUB	NA	NA	4015	0

Table 8: Multi-Resource Master Schedule with Lost Sales (Cycles: 10 - 12)

Resource	Cycle	SKU	Start	End	Inventory	Quantity
Resource1	10	SKUB	19.5111	19.8299	724	1115
Resource1	10	SKUA	19.8299	20.4624	6198	2213
Resource1	10	SKUD	20.4624	20.9707	1292	1778
Resource1	10	SKUC	20.9707	21.3834	1680	1444
Resource1	10	SKUE	NA	NA	169	0
Resource2	10	SKUB	19.5111	19.8299	4732	955
Resource2	10	SKUA	19.8299	20.4624	256	1434
Resource2	10	SKUD	20.4624	20.9707	1868	1016
Resource2	10	SKUC	20.9707	21.3834	504	825
Resource2	10	SKUE	NA	NA	5967	0
Resource1	11	SKUA	21.3834	21.7351	6889	1230
Resource1	11	SKUC	21.7351	22.1408	2076	1419
Resource1	11	SKUE	22.1408	22.476	528	1172
Resource1	11	SKUD	22.476	22.6777	975	706
Resource1	11	SKUB	NA	NA	354	0
Resource2	11	SKUA	21.3834	21.7351	-119	703
Resource2	11	SKUC	21.7351	22.1408	292	811
Resource2	11	SKUE	22.1408	22.476	6095	670
Resource2	11	SKUD	22.476	22.6777	1248	403
Resource2	11	SKUB	NA	NA	4547	0
Resource1	12	SKUA	22.6777	22.9055	7329	797
Resource1	12	SKUC	22.9055	23.4139	2519	1572
Resource1	12	SKUB	23.4139	23.8963	1051	1447
Resource1	12	SKUD	23.8963	24.0792	418	548
Resource1	12	SKUE	NA	NA	141	0
Resource2	12	SKUA	22.6777	22.9055	-260	455
Resource2	12	SKUC	22.9055	23.4139	386	1223
Resource2	12	SKUB	23.4139	23.8963	5377	1205
Resource2	12	SKUD	23.8963	24.0792	719	576
Resource2	12	SKUE	NA	NA	5837	0

Block Maximal Master Scheduling

Table 9: Multi-Resource Master Schedule with Lost Sales (Cycles: 13 - 14)

Resource	Cycle	SKU	Start	End	Inventory	Quantity
Resource1	13	SKUA	24.0792	24.5171	8089	1313
Resource1	13	SKUC	24.5171	24.7752	2276	774
Resource1	13	SKUD	24.7752	25.0208	362	736
Resource1	13	SKUE	25.0208	25.3985	677	1133
Resource1	13	SKUB	NA	NA	573	0
Resource2	13	SKUA	24.0792	24.5171	646	1751
Resource2	13	SKUC	24.5171	24.7752	401	1032
Resource2	13	SKUD	24.7752	25.0208	909	982
Resource2	13	SKUE	25.0208	25.3985	6949	1510
Resource2	13	SKUB	NA	NA	5138	0
Resource1	14	SKUE	25.3985	25.7328	776	1002
Resource1	14	SKUB	25.7328	25.9087	378	527
Resource1	14	SKUC	25.9087	25.9367	1907	83
Resource1	14	SKUA	25.9367	25.9678	7821	93
Resource1	14	SKUD	25.9678	26	97	96
Resource2	14	SKUE	25.3985	25.7328	7683	1336
Resource2	14	SKUB	25.7328	25.9087	5480	703
Resource2	14	SKUC	25.9087	25.9367	60	111
Resource2	14	SKUA	25.9367	25.9678	48	124
Resource2	14	SKUD	25.9678	26	676	128