

CS 471 - Project 5

Andrew Dunn

Instructor: Dr. Donald Davendra

Central Washington University

Ellensburg, Washington

May 31, 2019

Abstract

In this document we will first introduce you to the problems that were tested and our test methodology. We will then display the results we gathered, and explain our conclusions based on the data analysis.

1 Introduction

For this experiment we are testing the NEH algorithm to solve three different types of flow shop problems: Flow shop scheduling, flow shop with blocking, and flow shop with no wait. In general, the flow shop problem aims to optimize the order of a set of jobs that are each processed by another set of machines such that the the departure time of the last job in the last machine is minimal (The cmax value). The three different flow shop problems place different constraints on the job order. For example, flow shop with with no wait requires that no job sits on a machine for longer than it's processing time. Since the flow shop problem is intractable, finding the actual minimal cmax is very difficult and time consuming. The NEH algorithm is designed to find a cmax value that is close to the actual optimal in a fraction of the time required compared to a a more brute-force solution.

The testing hardware we used for this experiment is a desktop computer running Ubuntu 19.10 with an Intel(R) Core(TM) i7-3770K CPU @ 3.50GHz and 32 GB of DDR3 @ 1600 MHz. Our testing program was written in C++ and compiled with CMake version 3.12.1 and g++ version 8.2.0.

2 Methods

In order to test the NEH algorithm, we are using the Taillard Data Sets from: <http://mistic.heig-vd.ch/taillard/problemes.dir/ordonnancement.dir/ordonnancement.html>. Each of the 120 data sets contain the processing times for a number of machines and jobs. In addition to the input data sets, the author has also supplied the optimal values for the flow shop scheduling problem, which we will compare in our results section. In table1 you can find all data set ranges and their respective machine and job counts. Data set 0 is an additional small data set supplied by Dr. Davendra that was used for debugging purposes.

Table 1: Data Set Machine and Job Counts

Data Set	# Machines	# Jobs
0	4	5
1-10	5	20
11-20	10	20
21-30	20	20
31-40	5	50
41-50	10	50
51-60	20	50
61-70	5	100
71-80	10	100
81-90	20	100
91-100	10	200
101-110	20	200
111-120	20	500

3 Results

In this section you will find the tables containing all experiment results for all data sets. The NEH algorithm was ran once for each of the three flow shop problem types on every data set. The flow shop scheduling results tables include additional columns for comparison with the known optimal values of each data set. Unfortunately we do not have the optimal value data for flow shop with blocking or flow shop with no wait.

Table 2: NEH Results - Flow Shop Scheduling - Data Sets 0 to 40

Data Set	cMax	Best Cmax	% Diff	TFT	Func Calls	Execution Time (ms)
0	32	N/A	N/A	130	14	0.03
1	1289	1278	-0.853%	15325	209	0.39
2	1365	1359	-0.440%	16436	209	0.36
3	1132	1081	-4.505%	15136	209	0.39
4	1350	1293	-4.222%	17219	209	0.36
5	1305	1235	-5.364%	17012	209	0.40
6	1251	1195	-4.476%	15868	209	0.25
7	1257	1234	-1.830%	16993	209	0.42
8	1223	1206	-1.390%	15735	209	0.24
9	1284	1230	-4.206%	16324	209	0.37
10	1127	1108	-1.686%	14849	209	0.32
11	1681	1582	-5.889%	23486	209	0.56
12	1764	1659	-5.952%	24888	209	0.59
13	1562	1496	-4.225%	22401	209	0.55
14	1428	1377	-3.571%	20560	209	0.56
15	1502	1419	-5.526%	20343	209	0.61
16	1456	1397	-4.052%	21268	209	0.53
17	1545	1484	-3.948%	20357	209	0.55
18	1620	1538	-5.062%	22592	209	0.55
19	1638	1593	-2.747%	23053	209	0.56
20	1642	1591	-3.106%	23236	209	0.59
21	2443	2297	-5.976%	37353	209	0.95
22	2148	2099	-2.281%	34245	209	0.90
23	2429	2326	-4.240%	37565	209	0.92
24	2262	2223	-1.724%	33315	209	0.92
25	2370	2291	-3.333%	37379	209	1.05
26	2349	2226	-5.236%	34487	209	0.90
27	2383	2273	-4.616%	36160	209	0.99
28	2249	2200	-2.179%	34881	209	0.96
29	2306	2237	-2.992%	35898	209	1.09
30	2277	2178	-4.348%	35107	209	0.91
31	2729	2724	-0.183%	86213	1274	4.96
32	2843	2834	-0.317%	83557	1274	4.49
33	2650	2621	-1.094%	78351	1274	4.57
34	2782	2751	-1.114%	82278	1274	4.50
35	2868	2863	-0.174%	86156	1274	4.82
36	2842	2829	-0.457%	85190	1274	13.37
37	2769	2725	-1.589%	80724	1274	4.23
38	2695	2683	-0.445%	81800	1274	4.55
39	2587	2552	-1.353%	79239	1274	4.56
40	2800	2782	-0.643%	86865	1274	6.17

Table 3: NEH Results - Flow Shop Scheduling - Data Sets 41 to 80

Data Set	cMax	Best Cmax	% Diff	TFT	Func Calls	Execution Time (ms)
41	3170	2991	-5.647%	101444	1274	6.54
42	3047	2867	-5.907%	95727	1274	6.37
43	2972	2839	-4.475%	92589	1274	6.70
44	3166	3063	-3.253%	101178	1274	6.48
45	3174	2976	-6.238%	103143	1274	6.51
46	3146	3006	-4.450%	99573	1274	8.95
47	3268	3093	-5.355%	102674	1274	7.30
48	3140	3037	-3.280%	101174	1274	9.08
49	2999	2897	-3.401%	94508	1274	12.09
50	3208	3065	-4.458%	103825	1274	8.84
51	4073	3850	-5.475%	141035	1274	10.84
52	3969	3704	-6.677%	135952	1274	10.94
53	3857	3640	-5.626%	127973	1274	26.74
54	3932	3723	-5.315%	133029	1274	11.32
55	3875	3611	-6.813%	133979	1274	20.02
56	3913	3681	-5.929%	134887	1274	12.49
57	3910	3704	-5.269%	135023	1274	10.76
58	3918	3691	-5.794%	136492	1274	10.74
59	3951	3743	-5.264%	135476	1274	11.17
60	4043	3756	-7.099%	140173	1274	11.70
61	5514	5493	-0.381%	337137	5049	34.28
62	5284	5268	-0.303%	316268	5049	32.98
63	5220	5175	-0.862%	311358	5049	31.89
64	5023	5014	-0.179%	305389	5049	35.50
65	5261	5250	-0.209%	313389	5049	34.31
66	5152	5135	-0.330%	306270	5049	32.69
67	5269	5246	-0.437%	312522	5049	77.45
68	5105	5094	-0.215%	293713	5049	32.98
69	5489	5448	-0.747%	316868	5049	31.89
70	5346	5322	-0.449%	325420	5049	33.15
71	5903	5770	-2.253%	350695	5049	45.28
72	5453	5349	-1.907%	329115	5049	44.61
73	5767	5676	-1.578%	354000	5049	44.89
74	5945	5781	-2.759%	349233	5049	45.31
75	5654	5467	-3.307%	330044	5049	44.97
76	5443	5303	-2.572%	327594	5049	44.23
77	5661	5595	-1.166%	344598	5049	93.04
78	5731	5617	-1.989%	341960	5049	59.70
79	6010	5871	-2.313%	356006	5049	48.67
80	5911	5845	-1.117%	349748	5049	44.64

Table 4: NEH Results - Flow Shop Scheduling - Data Sets 81 to 120

Data Set	cMax	Best Cmax	% Diff	TFT	Func Calls	Execution Time (ms)
81	6600	6202	-6.030%	418861	5049	129.25
82	6603	6183	-6.361%	420448	5049	77.88
83	6583	6271	-4.739%	414996	5049	95.41
84	6571	6269	-4.596%	417757	5049	77.71
85	6659	6314	-5.181%	418681	5049	71.90
86	6691	6364	-4.887%	420725	5049	83.25
87	6632	6268	-5.489%	417028	5049	80.72
88	6807	6401	-5.964%	433660	5049	139.55
89	6621	6275	-5.226%	418057	5049	70.99
90	6697	6434	-3.927%	429592	5049	70.34
91	10942	10862	-0.731%	1261549	20099	368.84
92	10671	10480	-1.790%	1248157	20099	331.15
93	11061	10922	-1.257%	1264164	20099	459.30
94	11057	10889	-1.519%	1270368	20099	425.81
95	10683	10524	-1.488%	1237304	20099	446.81
96	10426	10329	-0.930%	1209878	20099	385.84
97	10965	10854	-1.012%	1255262	20099	368.75
98	10831	10730	-0.933%	1265660	20099	332.61
99	10608	10438	-1.603%	1211757	20099	351.24
100	10799	10675	-1.148%	1253664	20099	342.14
101	11632	11195	-3.757%	1361991	20099	527.67
102	11811	11203	-5.148%	1421504	20099	519.26
103	11813	11281	-4.504%	1421285	20099	528.88
104	11749	11275	-4.034%	1400795	20099	554.68
105	11712	11259	-3.868%	1370320	20099	515.84
106	11663	11176	-4.176%	1390794	20099	670.50
107	11828	11360	-3.957%	1427777	20099	537.28
108	11818	11334	-4.095%	1382894	20099	514.35
109	11704	11192	-4.375%	1409600	20099	518.00
110	11844	11284	-4.728%	1409785	20099	572.77
111	26824	26040	-2.923%	7553622	125249	8880.70
112	27052	26520	-1.967%	7719706	125249	9004.29
113	26919	26371	-2.036%	7536964	125249	9005.56
114	27033	26456	-2.134%	7590623	125249	8927.32
115	26758	26334	-1.585%	7594043	125249	8717.17
116	26977	26477	-1.853%	7591169	125249	8890.67
117	26843	26389	-1.691%	7582806	125249	8803.62
118	27184	26560	-2.295%	7705764	125249	8715.05
119	26658	26005	-2.450%	7559664	125249	5543.27
120	26946	26457	-1.815%	7653057	125249	5572.12

Table 5: NEH Results - Flow Shop With Blocking - Data Sets 0 to 40

Data Set	cMax	Total Flow Time	Func Calls	Execution Time (ms)
0	32	112	14	0.028281
1	1437	16969	209	0.418452
2	1461	18594	209	0.406089
3	1342	15681	209	0.413421
4	1552	18068	209	0.254141
5	1401	15860	209	0.37133
6	1471	16307	209	0.414447
7	1452	17685	209	0.383492
8	1508	16998	209	0.392888
9	1458	16599	209	0.253221
10	1332	15509	209	0.396923
11	1798	24043	209	0.553203
12	1903	25117	209	0.537968
13	1772	23492	209	0.563092
14	1625	21412	209	0.579404
15	1726	22717	209	0.355485
16	1671	22166	209	0.586087
17	1738	22346	209	0.331626
18	1814	23162	209	0.547113
19	1849	23688	209	0.561543
20	1854	24525	209	0.550775
21	2530	37584	209	0.845005
22	2285	35451	209	0.699037
23	2575	38478	209	0.950961
24	2399	34738	209	0.883068
25	2538	38667	209	0.935034
26	2472	35932	209	0.885
27	2502	36496	209	0.572447
28	2411	36972	209	1.034111
29	2416	36711	209	0.957171
30	2407	35218	209	0.897522
31	3314	88937	1274	4.375476
32	3499	92506	1274	5.240739
33	3267	82466	1274	3.137543
34	3370	87100	1274	4.416707
35	3461	97658	1274	4.48291
36	3408	90454	1274	4.299576
37	3265	90777	1274	2.643569
38	3311	85193	1274	3.968975
39	3133	84446	1274	4.717711
40	3396	89773	1274	4.384844

Table 6: NEH Results - Flow Shop With Blocking - Data Sets 41 to 80

Data Set	cMax	Total Flow Time	Func Calls	Execution Time (ms)
41	3967	114575	1274	5.76589
42	3742	111026	1274	22.340103
43	3769	107147	1274	6.358928
44	3987	110993	1274	6.349345
45	3920	114119	1274	6.505762
46	3828	109959	1274	5.160057
47	3916	115333	1274	7.219695
48	3773	110679	1274	6.931242
49	3833	108504	1274	6.392312
50	3918	110717	1274	6.338661
51	4885	157179	1274	10.335115
52	4646	144418	1274	26.120082
53	4669	142576	1274	19.112857
54	4618	144106	1274	11.125673
55	4475	141193	1274	12.585454
56	4545	143446	1274	10.114874
57	4577	147470	1274	14.304112
58	4748	153268	1274	14.176837
59	4563	145413	1274	10.426843
60	4828	152718	1274	12.344412
61	6753	365104	5049	28.471926
62	6564	341476	5049	40.296586
63	6451	339413	5049	36.716739
64	6199	338986	5049	30.567565
65	6514	318495	5049	44.918887
66	6312	336992	5049	34.719487
67	6507	342732	5049	35.611495
68	6317	323801	5049	55.004704
69	6642	336855	5049	29.839739
70	6633	354420	5049	30.713071
71	7532	412279	5049	48.853089
72	7309	396518	5049	50.917574
73	7360	392393	5049	44.51531
74	7634	426586	5049	42.042782
75	7396	392177	5049	41.710419
76	7122	398623	5049	46.809506
77	7302	380874	5049	144.224654
78	7293	401148	5049	46.290843
79	7564	417318	5049	44.794751
80	7453	417565	5049	47.149095

Table 7: NEH Results - Flow Shop With Blocking - Data Sets 81 to 120

Data Set	cMax	Total Flow Time	Func Calls	Execution Time (ms)
81	8422	499987	5049	67.676404
82	8220	468254	5049	72.935461
83	8397	480415	5049	66.170712
84	8282	484455	5049	76.131938
85	8193	477901	5049	93.57296
86	8312	473378	5049	75.099783
87	8451	490500	5049	74.398731
88	8576	500957	5049	68.613788
89	8376	481195	5049	66.694743
90	8493	495861	5049	71.752481
91	14361	1504826	20099	431.32623
92	14466	1471288	20099	385.872407
93	14563	1533463	20099	334.386863
94	14472	1486723	20099	308.305491
95	14465	1516179	20099	337.743374
96	14214	1440543	20099	379.470782
97	14644	1482801	20099	332.346724
98	14480	1476820	20099	438.304235
99	14342	1524301	20099	310.385849
100	14517	1533836	20099	434.743815
101	15634	1691995	20099	663.199419
102	16033	1728890	20099	562.33619
103	15914	1739178	20099	717.614057
104	15965	1716117	20099	624.800289
105	15744	1675845	20099	591.189015
106	15909	1697817	20099	481.318127
107	16061	1745352	20099	512.866734
108	15891	1694836	20099	574.689127
109	16000	1733095	20099	522.531068
110	15909	1719240	20099	515.998562
111	38324	9621666	125249	8688.647146
112	38725	9964971	125249	8895.183638
113	38215	9730410	125249	9062.941966
114	38542	10122111	125249	8577.71303
115	38269	9841676	125249	8594.591067
116	38616	9822998	125249	8741.708222
117	38077	9717104	125249	8378.209422
118	38327	9806473	125249	8846.500751
119	38132	9981988	125249	5026.552347
120	38635	9824886	125249	4913.538977

Table 8: NEH Results - Flow Shop With No Waiting - Data Sets 0 to 40

Data Set	cMax	Total Flow Time	Func Calls	Execution Time (ms)
0	32	111	14	0.023464
1	1525	16558	209	0.461555
2	1599	19564	209	0.402557
3	1523	17841	209	2.947999
4	1638	19386	209	0.433327
5	1476	17497	209	0.315445
6	1555	17667	209	0.367282
7	1562	19136	209	0.434398
8	1584	17215	209	0.405013
9	1500	17124	209	0.431973
10	1432	17090	209	0.364457
11	2118	26597	209	0.564499
12	2210	28122	209	0.724273
13	1992	23962	209	0.604674
14	1862	22985	209	0.57075
15	2021	25227	209	0.694038
16	1990	24186	209	0.364142
17	2028	25033	209	0.621571
18	2153	25680	209	0.543424
19	2043	25497	209	0.736461
20	2115	25700	209	0.558472
21	3051	40739	209	1.010018
22	2950	39974	209	0.986419
23	3148	43247	209	0.964181
24	3100	39597	209	1.423094
25	3081	40791	209	1.198209
26	3137	42497	209	1.013727
27	3174	41753	209	0.973555
28	2888	40622	209	0.978325
29	3053	39936	209	0.622587
30	3079	40408	209	1.085858
31	3522	100340	1274	4.590529
32	3671	91098	1274	4.334233
33	3482	95660	1274	4.398494
34	3622	98093	1274	3.922132
35	3631	93457	1274	4.593312
36	3548	95531	1274	5.95224
37	3418	92965	1274	4.43533
38	3471	92405	1274	8.586686
39	3254	90966	1274	4.435345
40	3563	98149	1274	4.420945

Table 9: NEH Results - Flow Shop With No Waiting - Data Sets 41 to 80

Data Set	cMax	Total Flow Time	Func Calls	Execution Time (ms)
41	4480	124126	1274	7.533302
42	4418	127389	1274	4.333748
43	4445	120789	1274	6.729157
44	4615	121984	1274	7.895332
45	4625	126262	1274	26.661643
46	4569	125869	1274	6.88832
47	4692	124025	1274	6.678523
48	4483	121012	1274	7.843245
49	4407	122759	1274	6.499916
50	4518	128382	1274	17.736126
51	6580	189943	1274	12.309713
52	6177	177042	1274	11.806379
53	6219	177691	1274	11.630498
54	6181	177270	1274	14.955272
55	6219	178386	1274	15.472727
56	6152	173583	1274	26.201383
57	6289	186109	1274	12.418505
58	6249	182004	1274	11.917331
59	6130	178661	1274	11.663838
60	6225	181700	1274	24.250888
61	6985	359522	5049	56.847007
62	6779	343011	5049	30.895903
63	6687	362370	5049	32.720094
64	6428	357961	5049	31.138445
65	6652	363511	5049	29.088467
66	6551	345834	5049	38.211577
67	6779	347506	5049	43.899551
68	6707	329803	5049	32.223237
69	6871	356463	5049	30.691551
70	6857	373126	5049	32.154991
71	8676	456604	5049	44.186648
72	8421	446620	5049	47.717258
73	8452	440408	5049	53.418501
74	8769	464713	5049	107.693495
75	8564	452621	5049	44.384463
76	8333	428721	5049	46.357889
77	8469	442265	5049	46.754591
78	8419	434400	5049	45.830157
79	8672	447173	5049	43.942092
80	8867	467985	5049	47.484823

Table 10: NEH Results - Flow Shop With No Waiting - Data Sets 81 to 120

Data Set	cMax	Total Flow Time	Func Calls	Execution Time (ms)
81	11113	626927	5049	78.883916
82	11110	597537	5049	80.390819
83	11188	611812	5049	142.479697
84	11277	613065	5049	81.988466
85	10994	590960	5049	79.460083
86	11255	615833	5049	82.46578
87	11502	630752	5049	88.956695
88	11341	615070	5049	97.4654
89	11360	616210	5049	87.661273
90	11240	602519	5049	77.547919
91	16163	1709591	20099	348.154558
92	16368	1655289	20099	414.839129
93	16337	1664248	20099	463.135563
94	16465	1688465	20099	353.143506
95	16332	1693668	20099	477.878944
96	16206	1706121	20099	450.973213
97	16559	1694040	20099	347.875223
98	16360	1682177	20099	439.041479
99	16272	1739441	20099	418.348087
100	16312	1673468	20099	367.682177
101	20933	2159297	20099	641.824902
102	21270	2248252	20099	643.752333
103	21137	2240933	20099	699.270759
104	21031	2190176	20099	683.883508
105	20884	2177710	20099	657.373507
106	21365	2246492	20099	730.926807
107	21144	2237195	20099	681.893696
108	21115	2204353	20099	609.569296
109	20999	2191446	20099	639.61879
110	21174	2209566	20099	692.590229
111	49735	12808057	125249	10730.45842
112	49624	12612263	125249	11261.30268
113	49347	12583149	125249	11630.87069
114	49931	12615706	125249	11110.35429
115	49702	12719832	125249	10997.48723
116	49991	12735526	125249	10858.62619
117	49398	12786188	125249	10957.13108
118	49821	12493730	125249	10930.04067
119	49724	12781482	125249	6713.639949
120	49759	12586413	125249	6331.754966

4 Gantt Charts

In this section you will find a gantt chart for each of the data set sizes for each of the three flow shop problems. Note that due to the large number of jobs in most of these charts the legend has been removed because it was too large and did not fit on the page. The charts show the start and departure times of all jobs from left to right, in all machines top to bottom. To better see the details in the charts please open the raw chart images that have been supplied along with this report.

Figure 1: Gantt Chart of NEH Result - FSS - Data Set 0

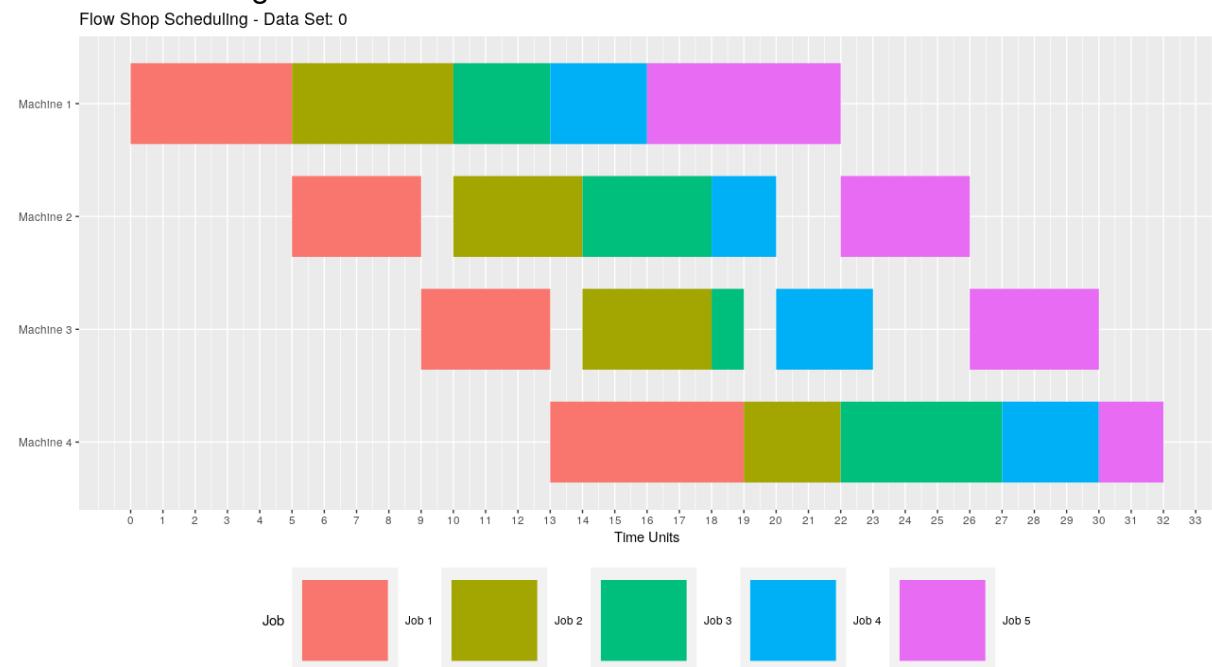


Figure 2: Gantt Chart of NEH Result - FSS - Data Set 1

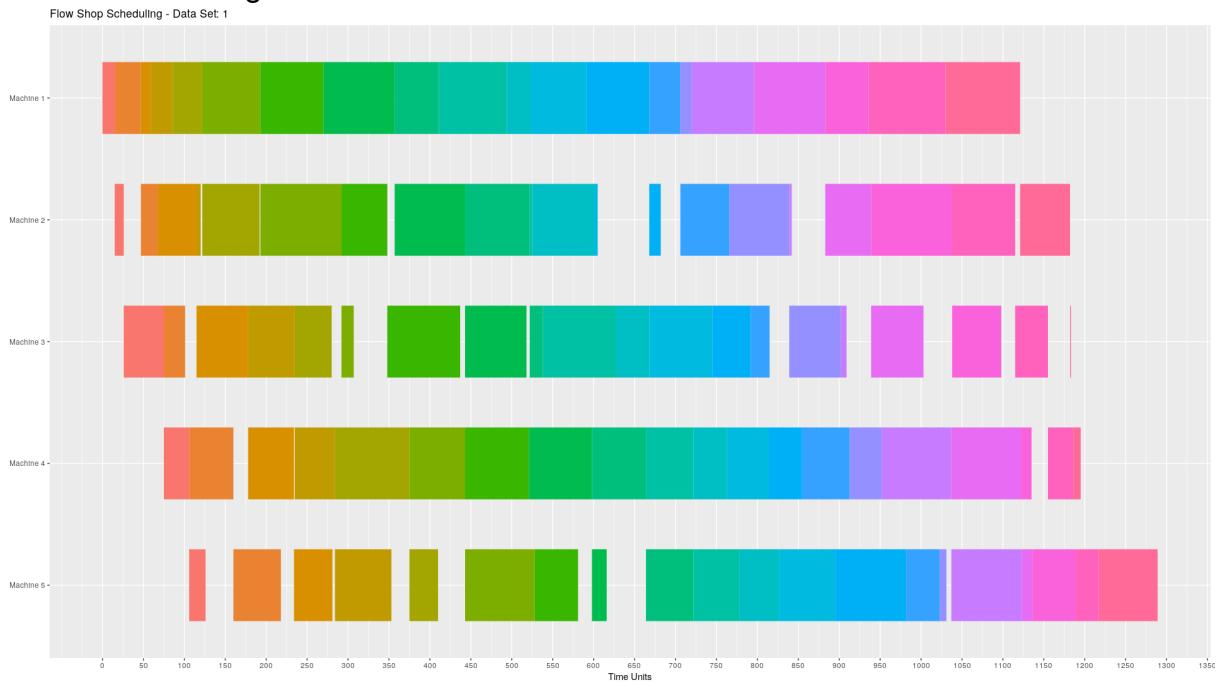


Figure 3: Gantt Chart of NEH Result - FSS - Data Set 11

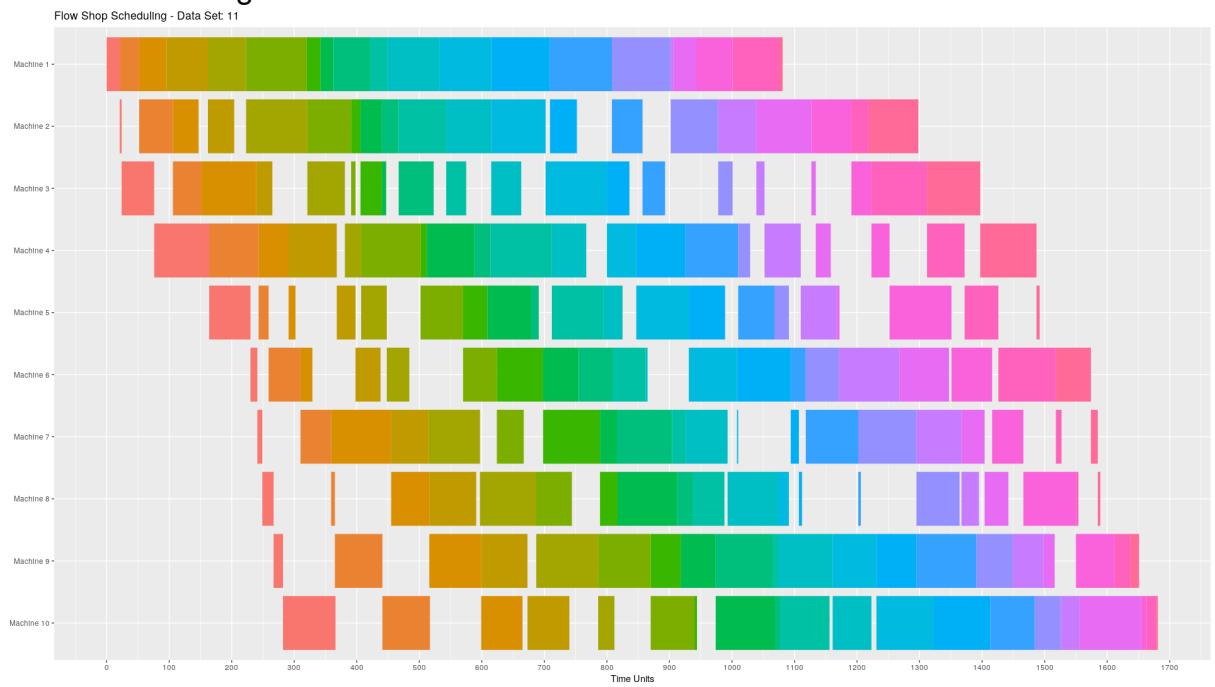


Figure 4: Gantt Chart of NEH Result - FSS - Data Set 21

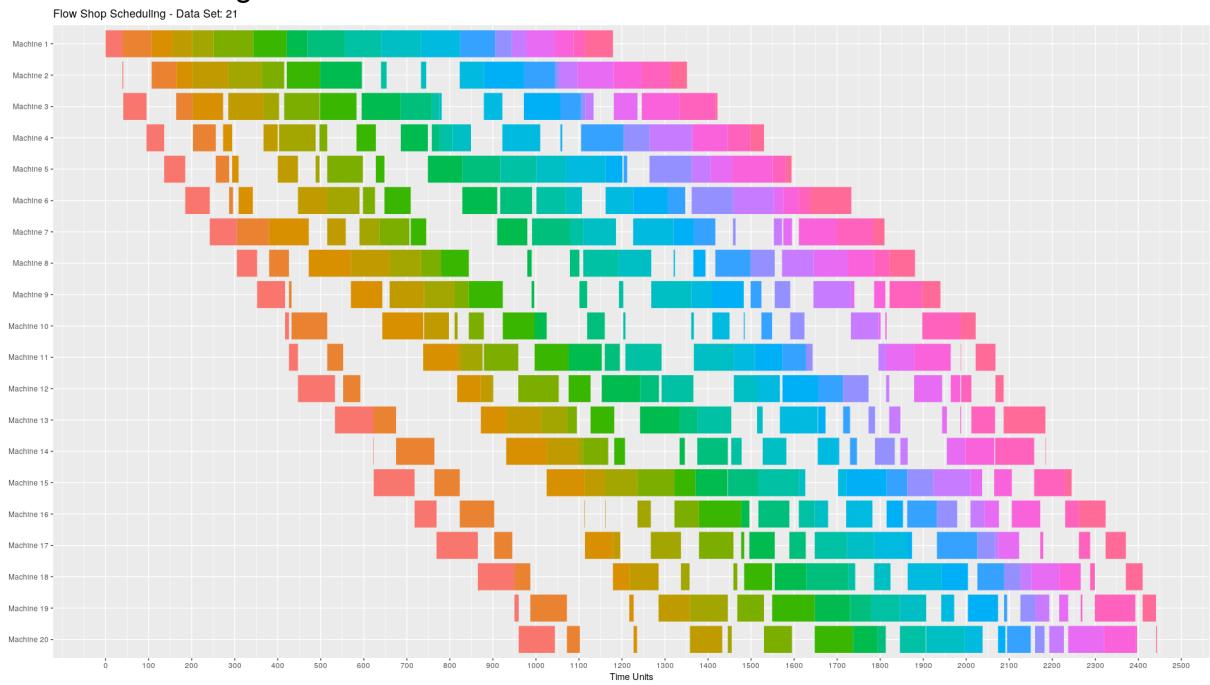


Figure 5: Gantt Chart of NEH Result - FSS - Data Set 31

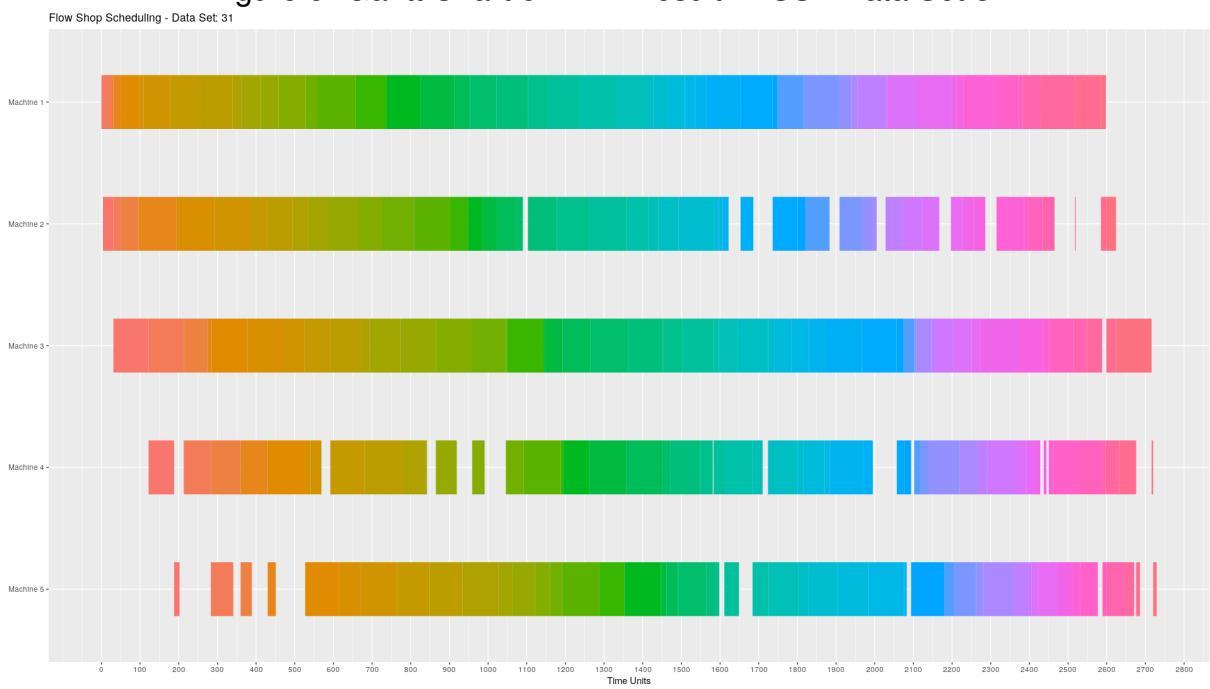


Figure 6: Gantt Chart of NEH Result - FSS - Data Set 41

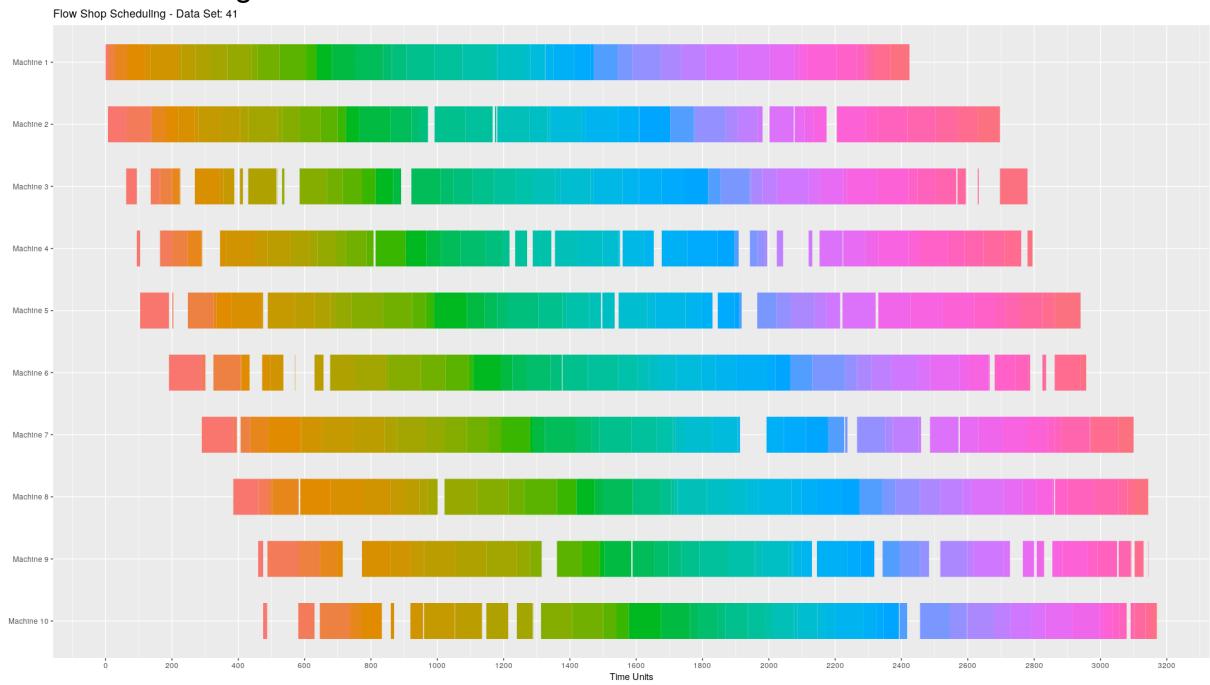


Figure 7: Gantt Chart of NEH Result - FSS - Data Set 51

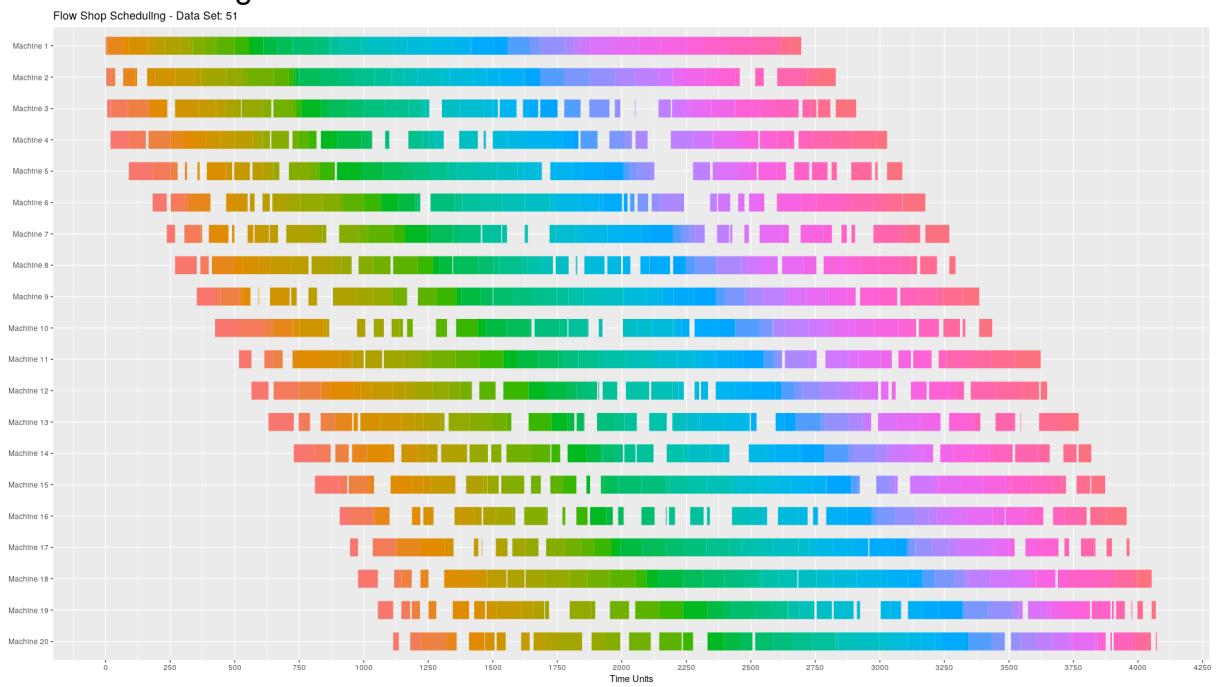


Figure 8: Gantt Chart of NEH Result - FSS - Data Set 61

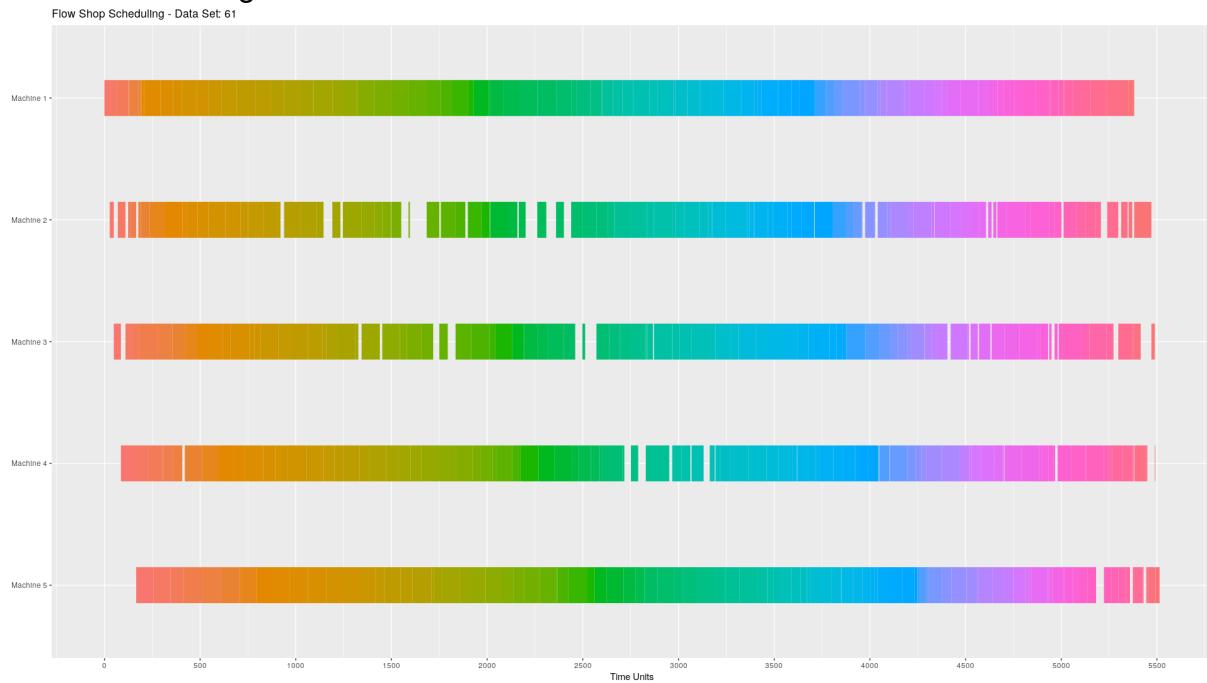


Figure 9: Gantt Chart of NEH Result - FSS - Data Set 71

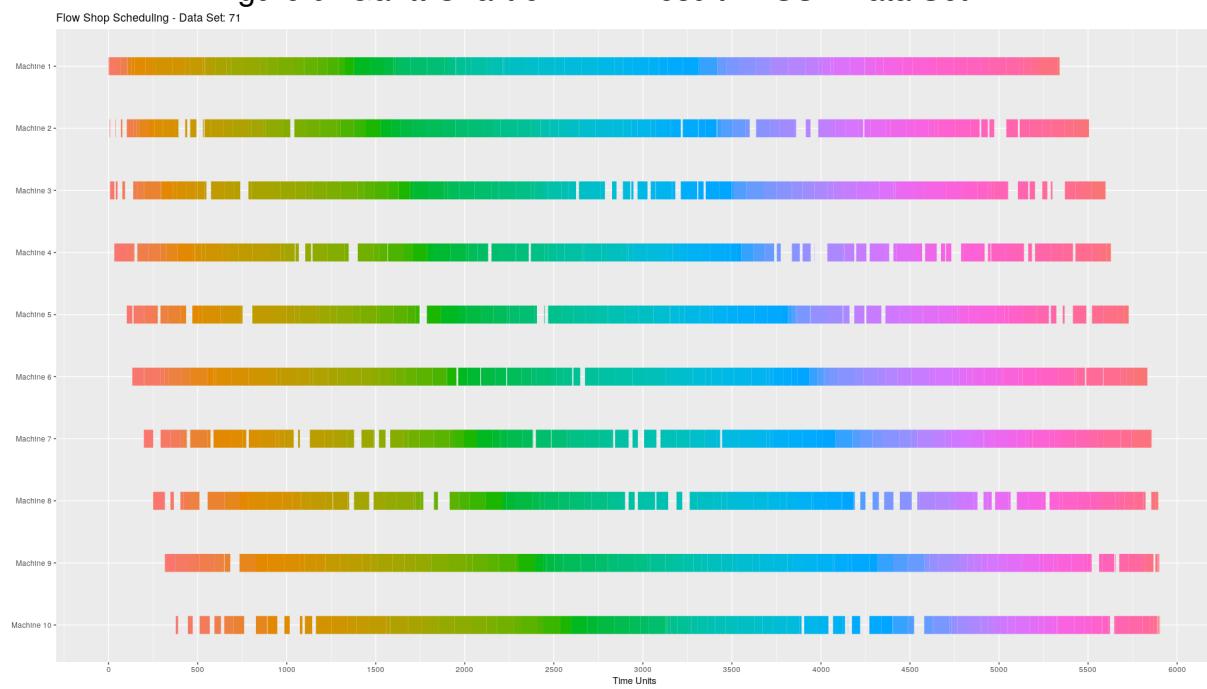


Figure 10: Gantt Chart of NEH Result - FSS - Data Set 81

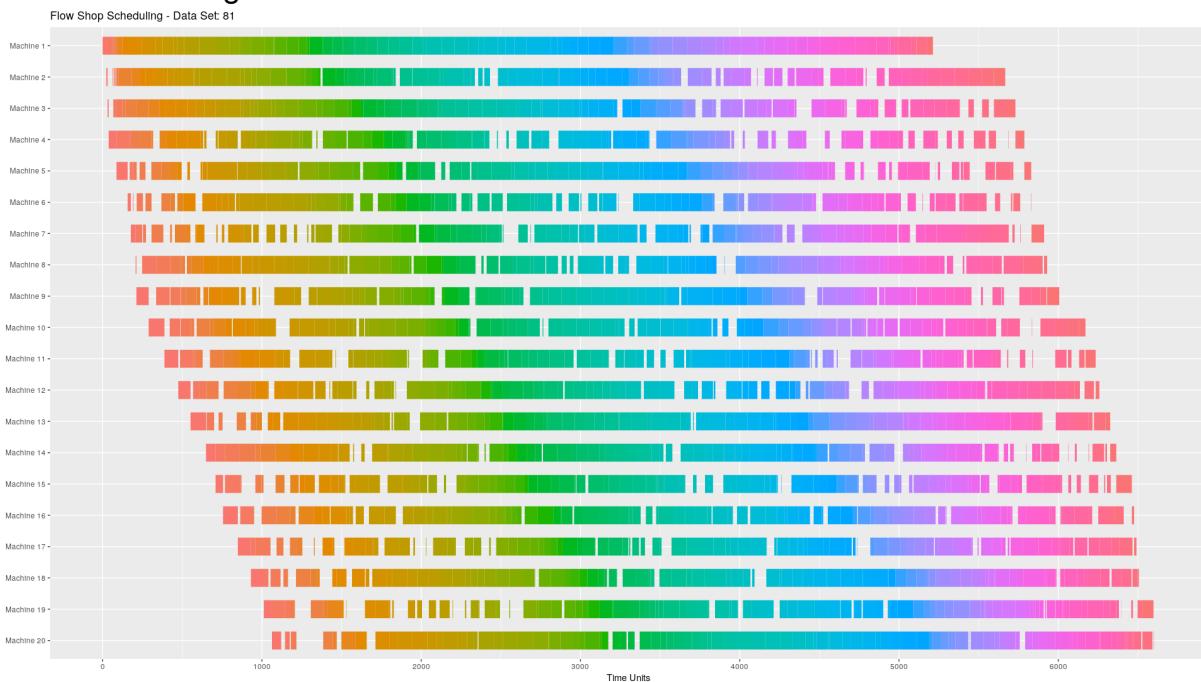


Figure 11: Gantt Chart of NEH Result - FSS - Data Set 91

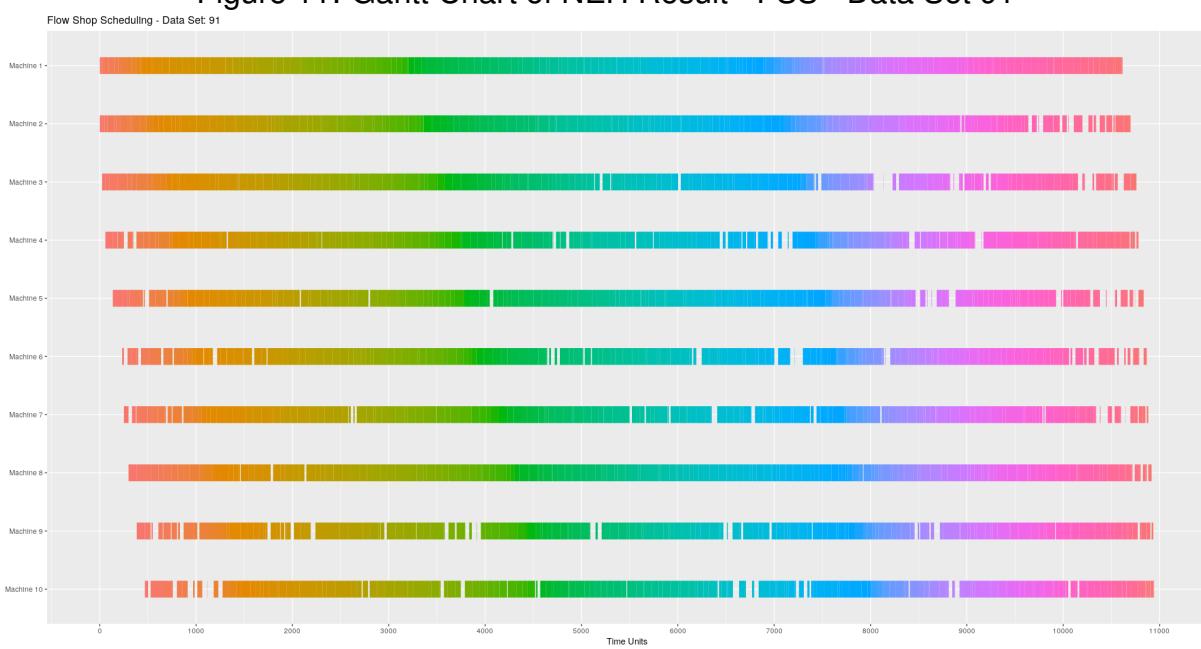


Figure 12: Gantt Chart of NEH Result - FSS - Data Set 101

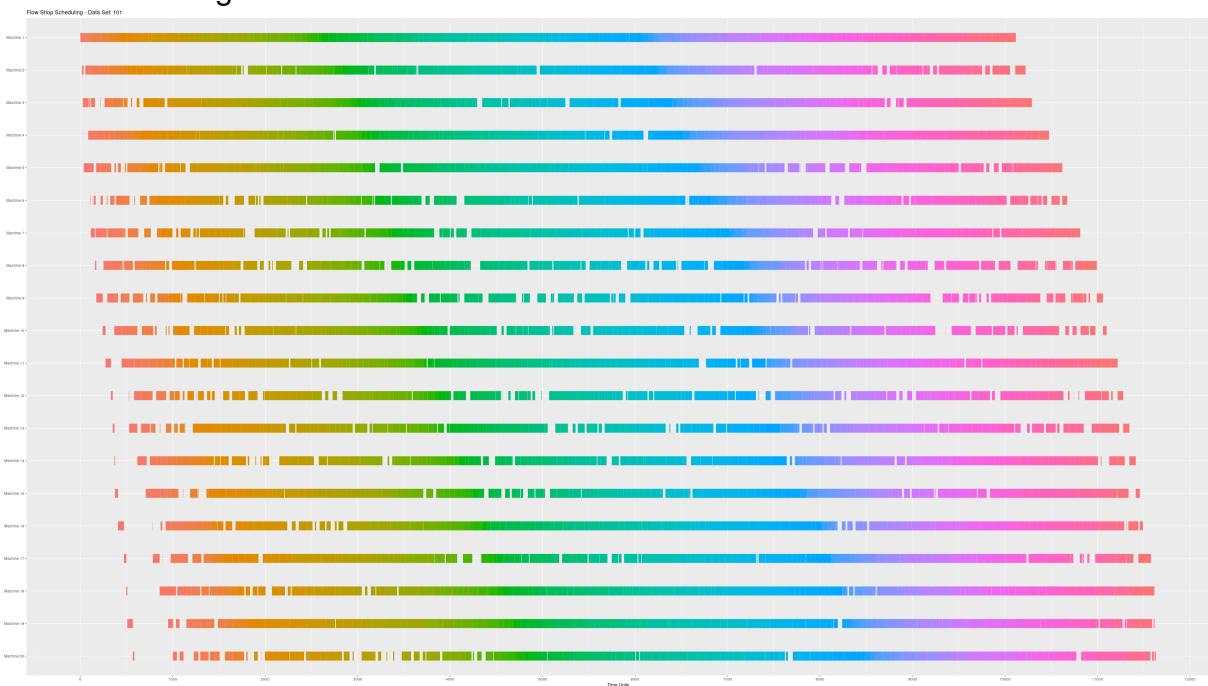


Figure 13: Gantt Chart of NEH Result - FSS - Data Set 120

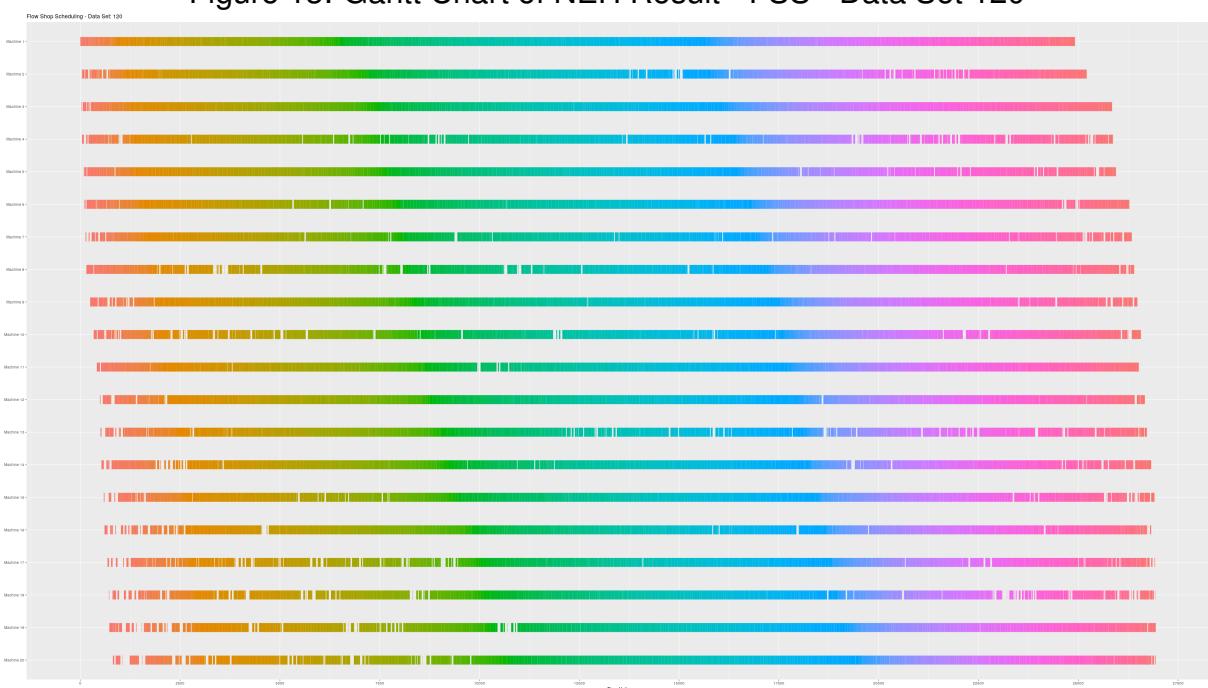


Figure 14: Gantt Chart of NEH Result - FSB - Data Set 0

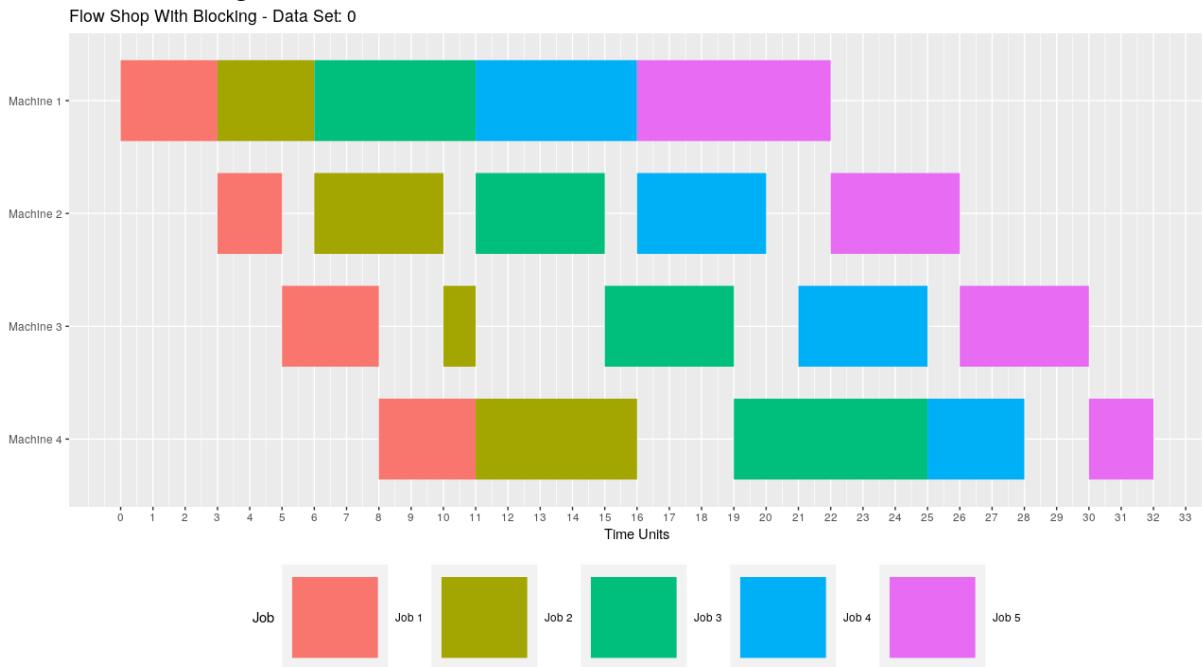


Figure 15: Gantt Chart of NEH Result - FSB - Data Set 1

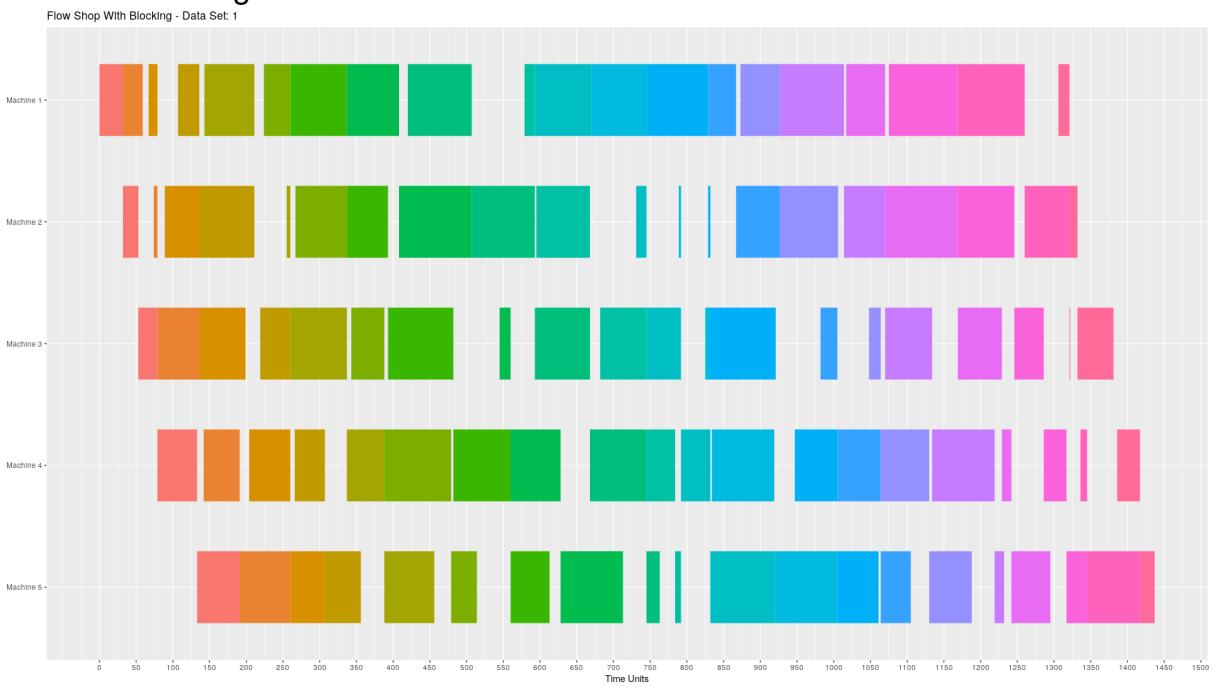


Figure 16: Gantt Chart of NEH Result - FSB - Data Set 11

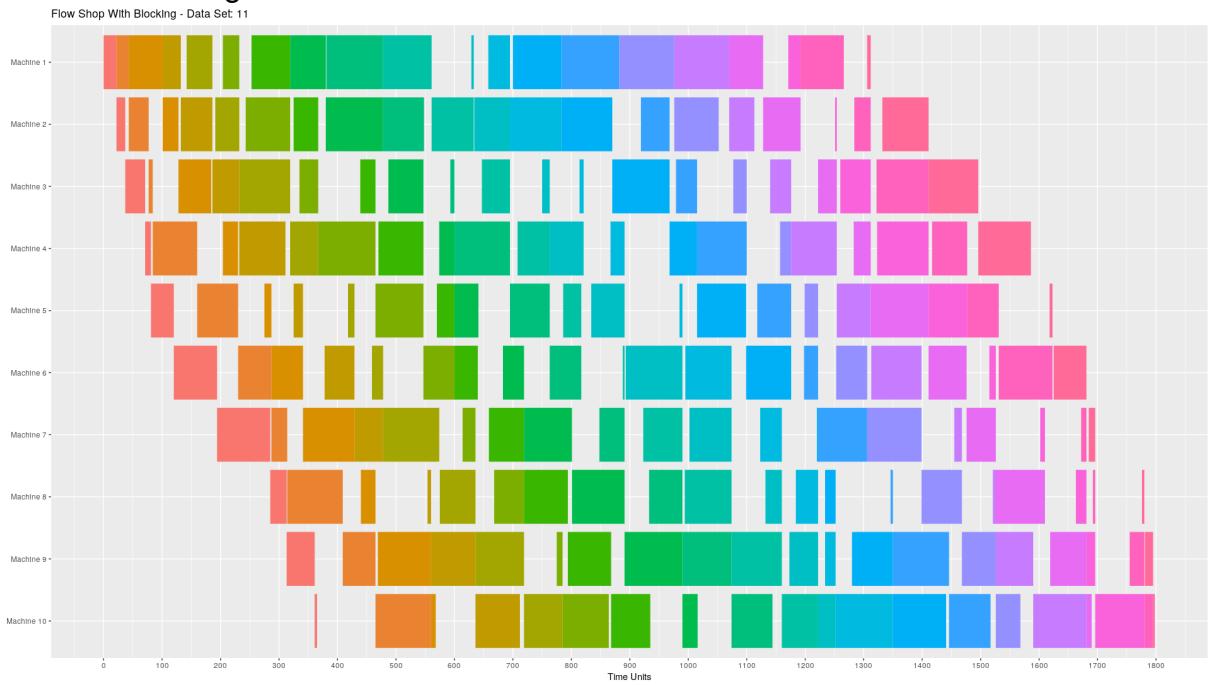


Figure 17: Gantt Chart of NEH Result - FSB - Data Set 21

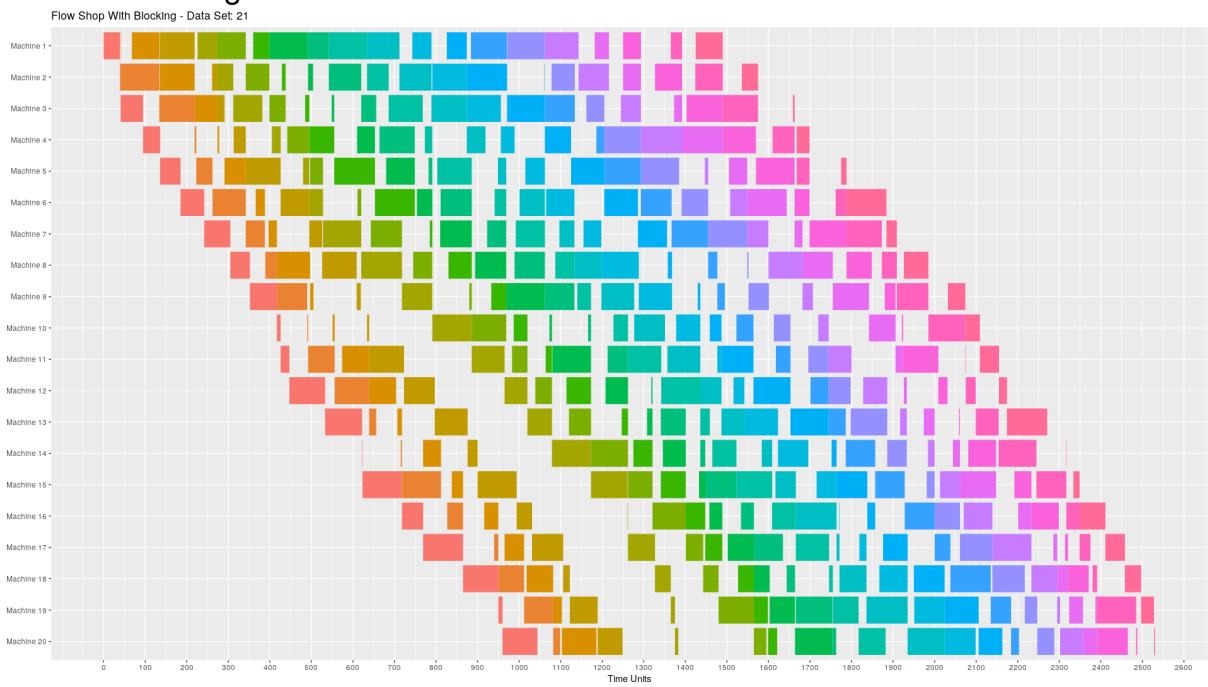


Figure 18: Gantt Chart of NEH Result - FSB - Data Set 31

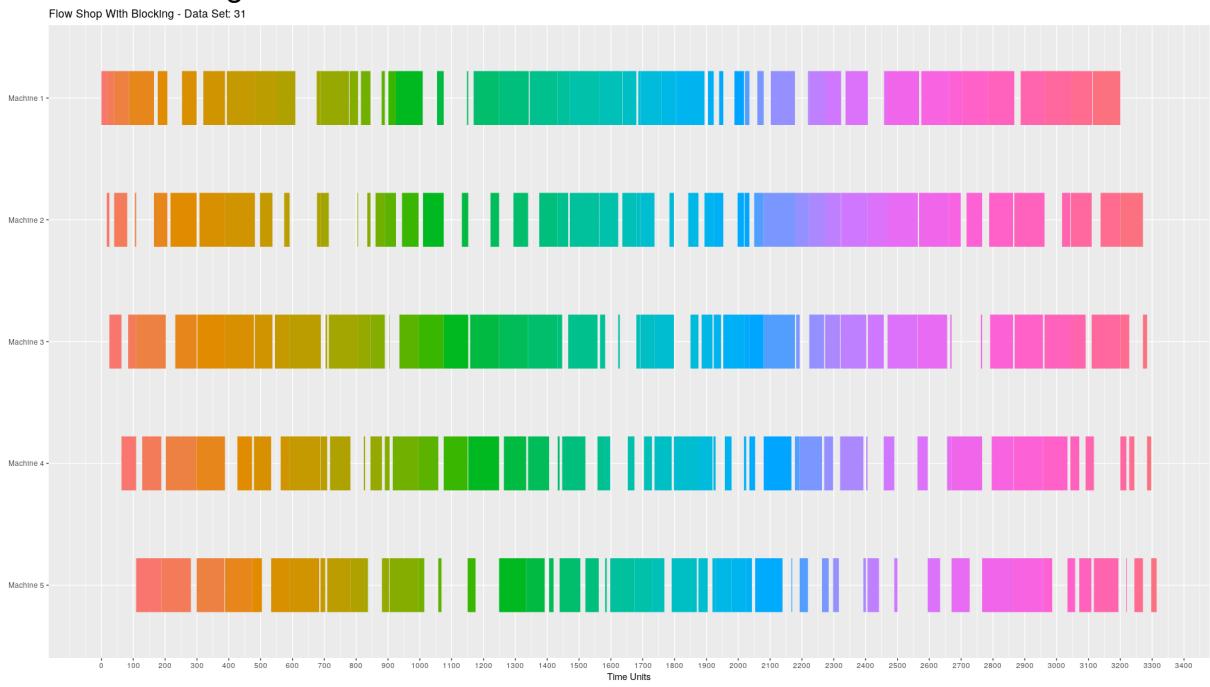


Figure 19: Gantt Chart of NEH Result - FSB - Data Set 41

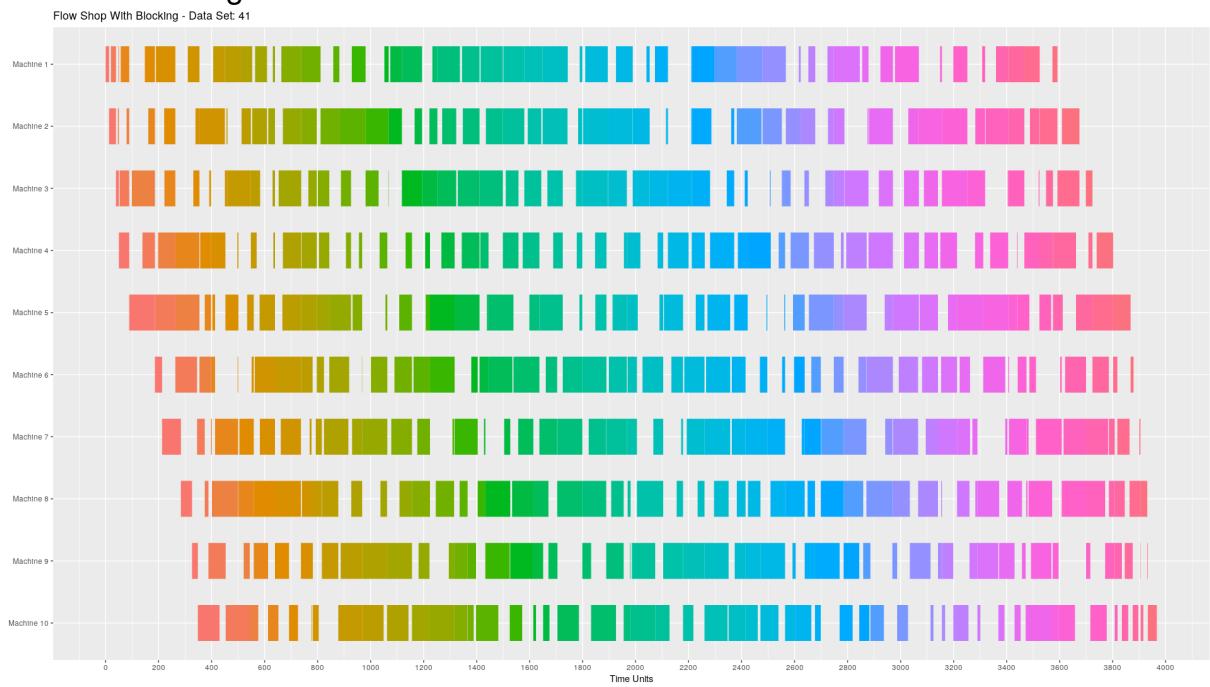


Figure 20: Gantt Chart of NEH Result - FSB - Data Set 51

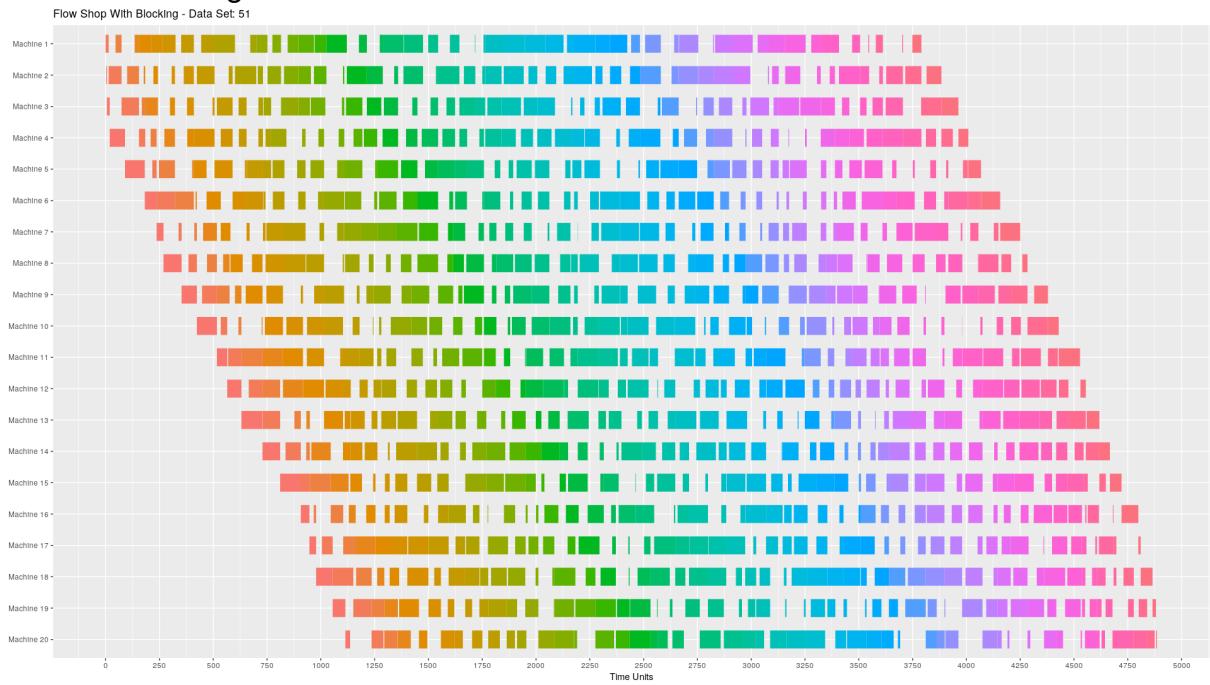


Figure 21: Gantt Chart of NEH Result - FSB - Data Set 61

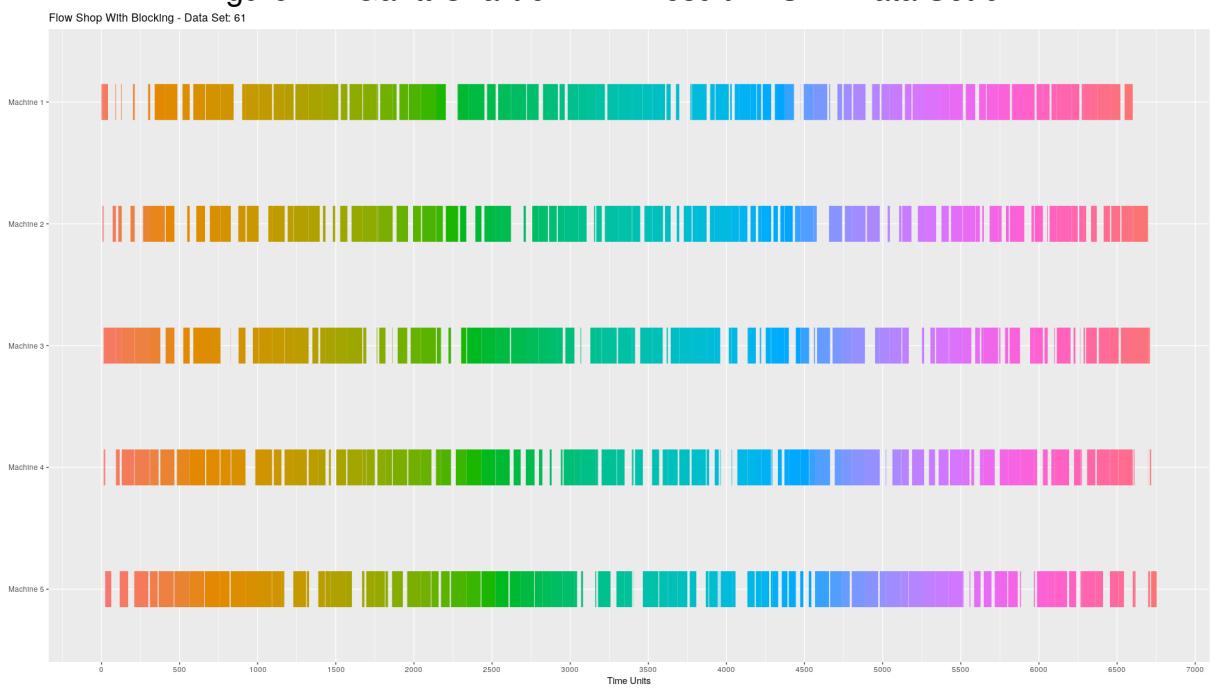


Figure 22: Gantt Chart of NEH Result - FSB - Data Set 71

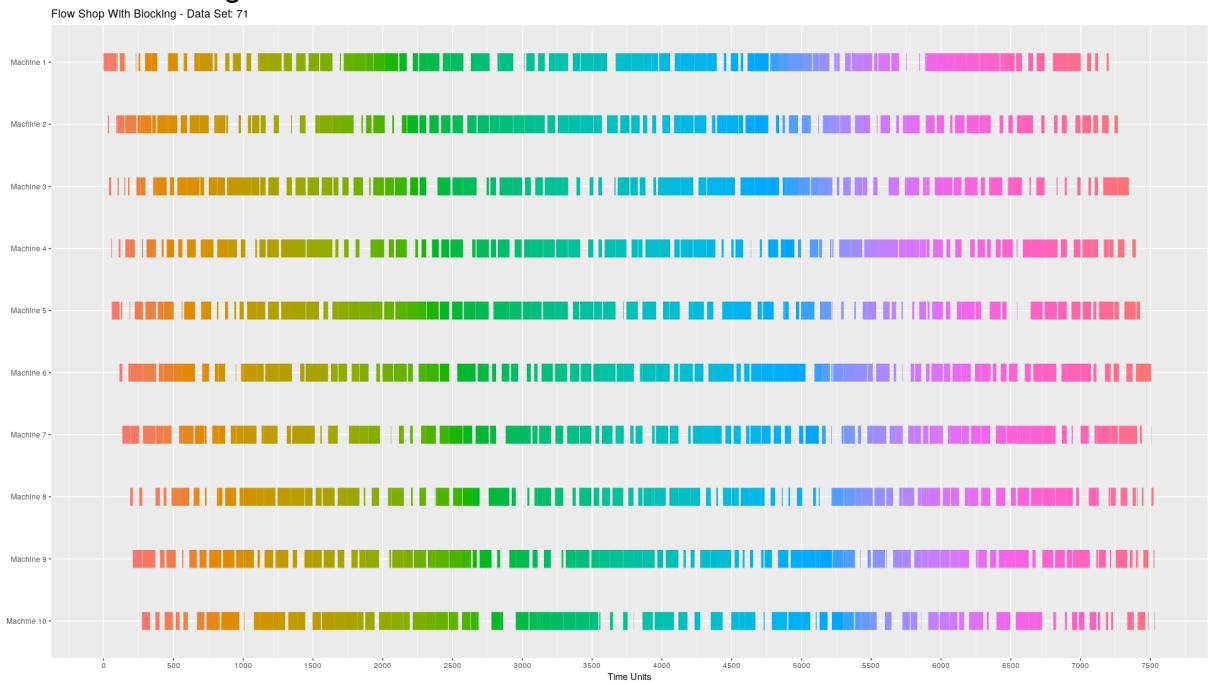


Figure 23: Gantt Chart of NEH Result - FSB - Data Set 81



Figure 24: Gantt Chart of NEH Result - FSB - Data Set 91

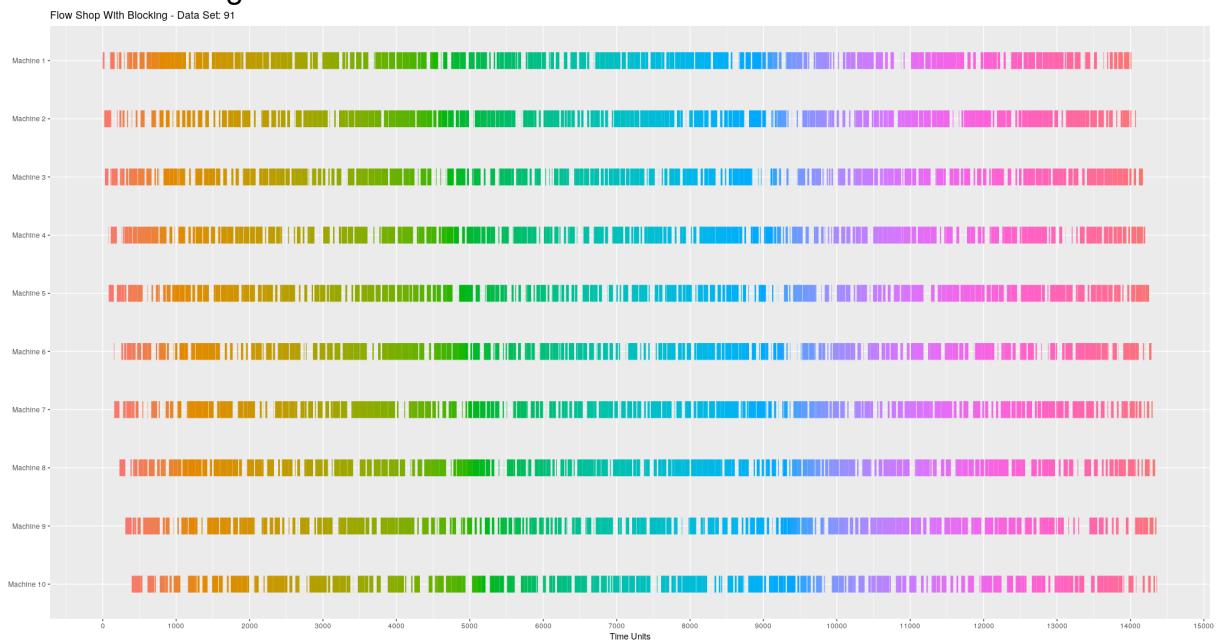


Figure 25: Gantt Chart of NEH Result - FSB - Data Set 101



Figure 26: Gantt Chart of NEH Result - FSB - Data Set 120

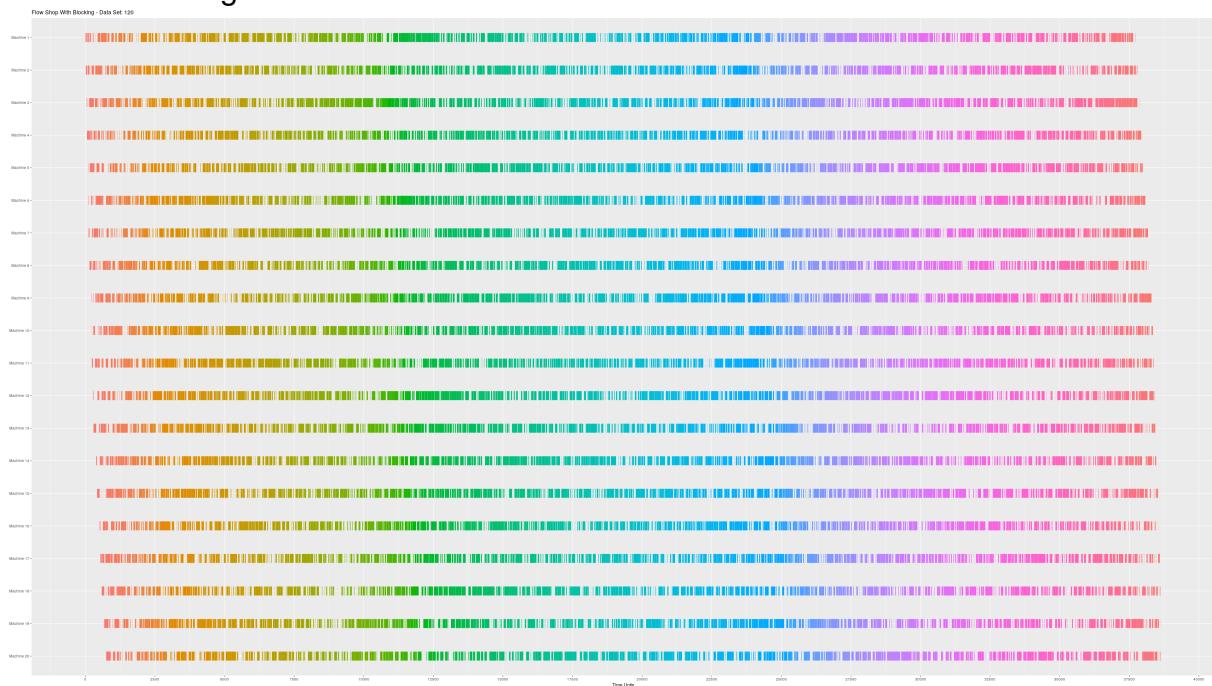


Figure 27: Gantt Chart of NEH Result - FSNW - Data Set 0

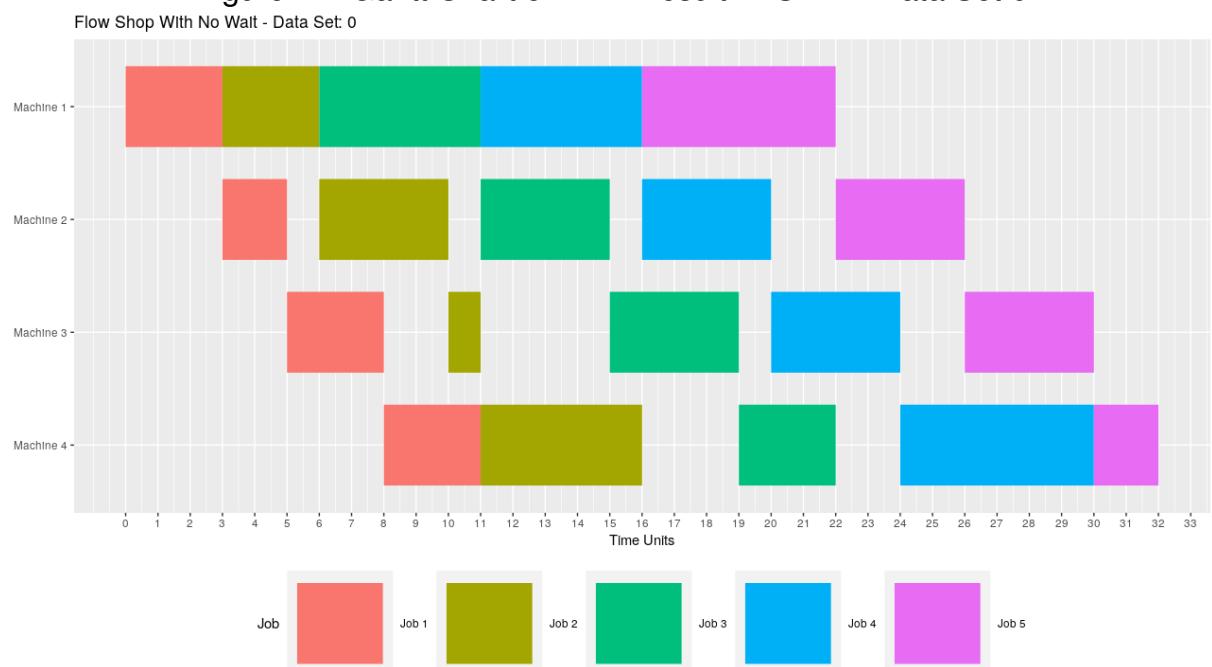


Figure 28: Gantt Chart of NEH Result - FSNW - Data Set 1

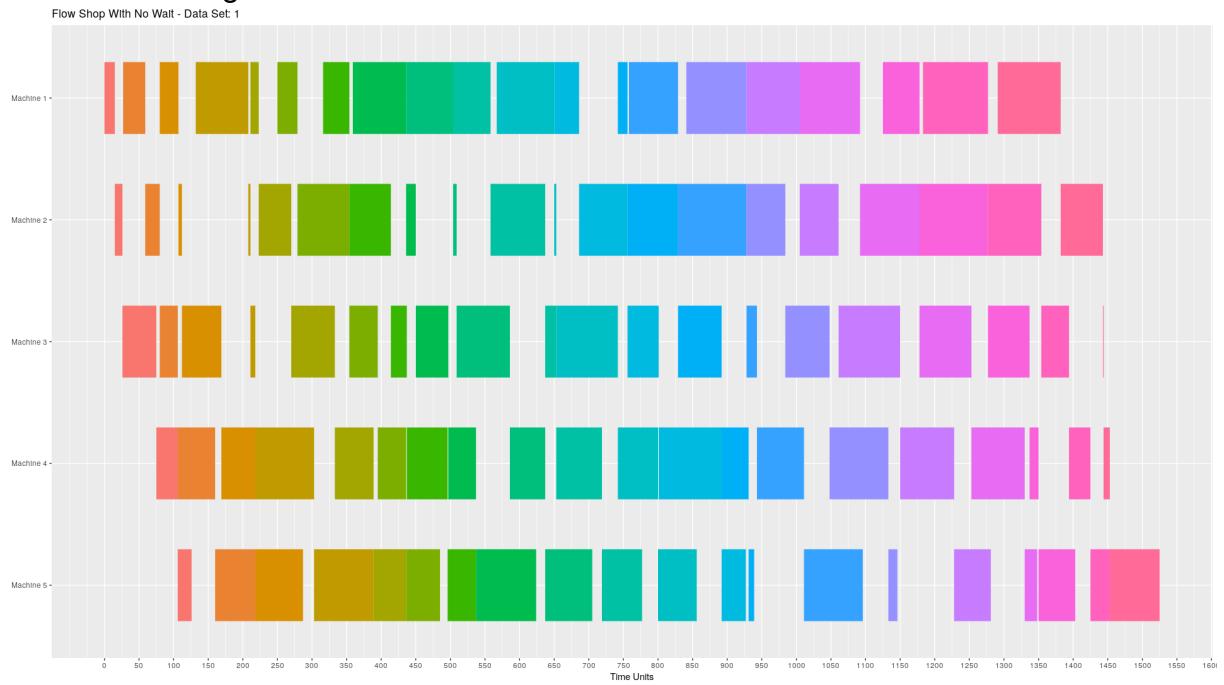


Figure 29: Gantt Chart of NEH Result - FSNW - Data Set 11

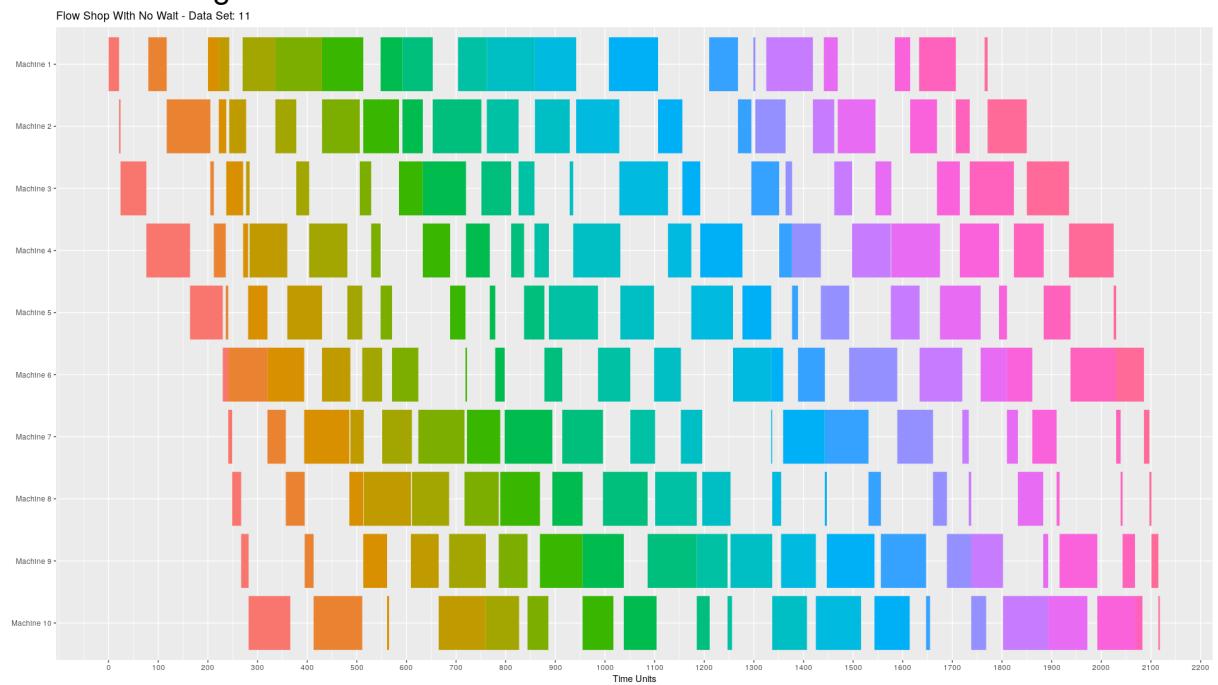


Figure 30: Gantt Chart of NEH Result - FSNW - Data Set 21

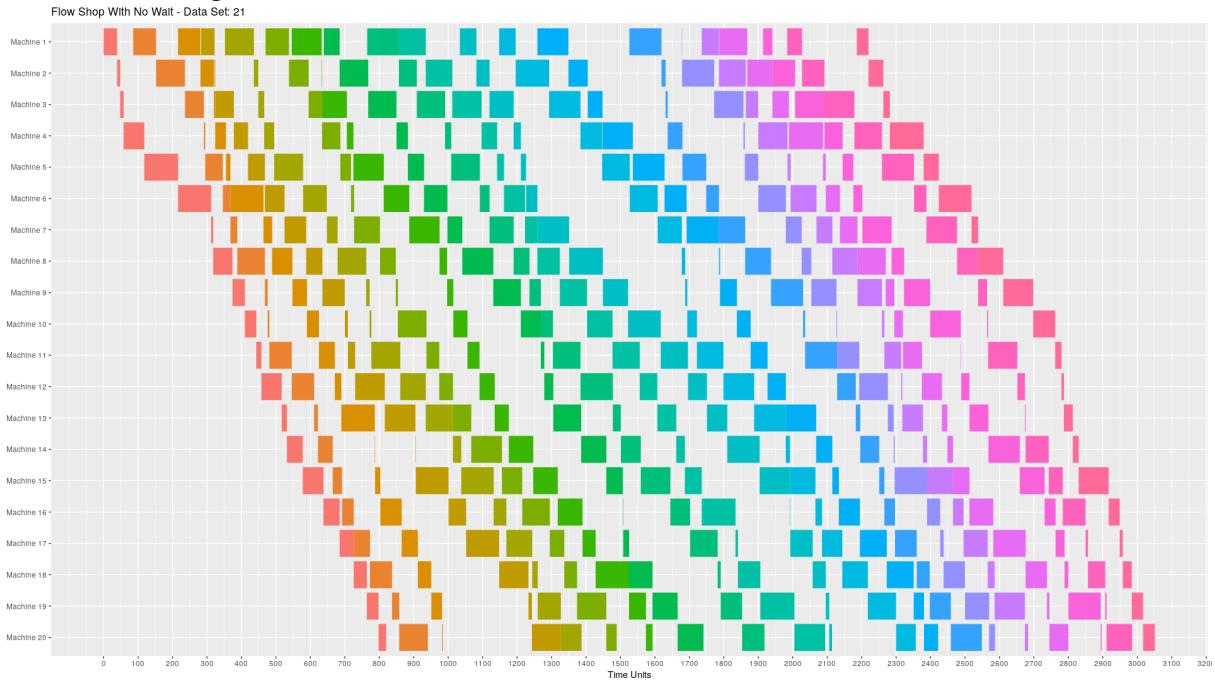


Figure 31: Gantt Chart of NEH Result - FSNW - Data Set 31

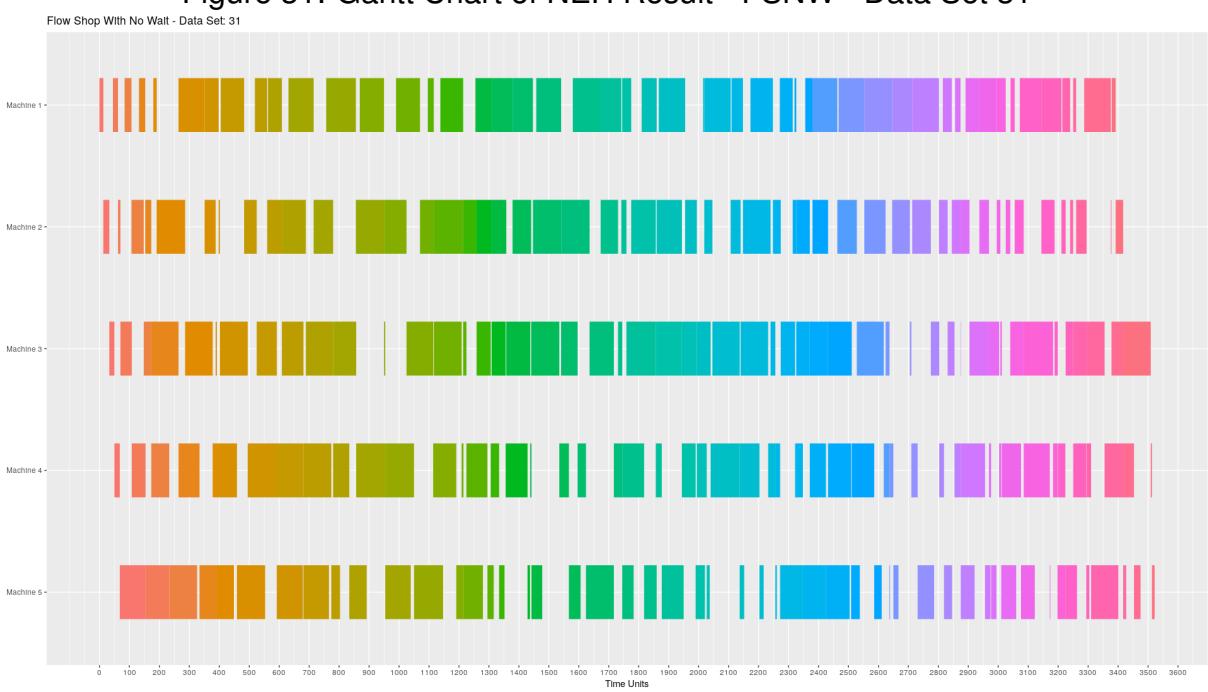


Figure 32: Gantt Chart of NEH Result - FSNW - Data Set 41

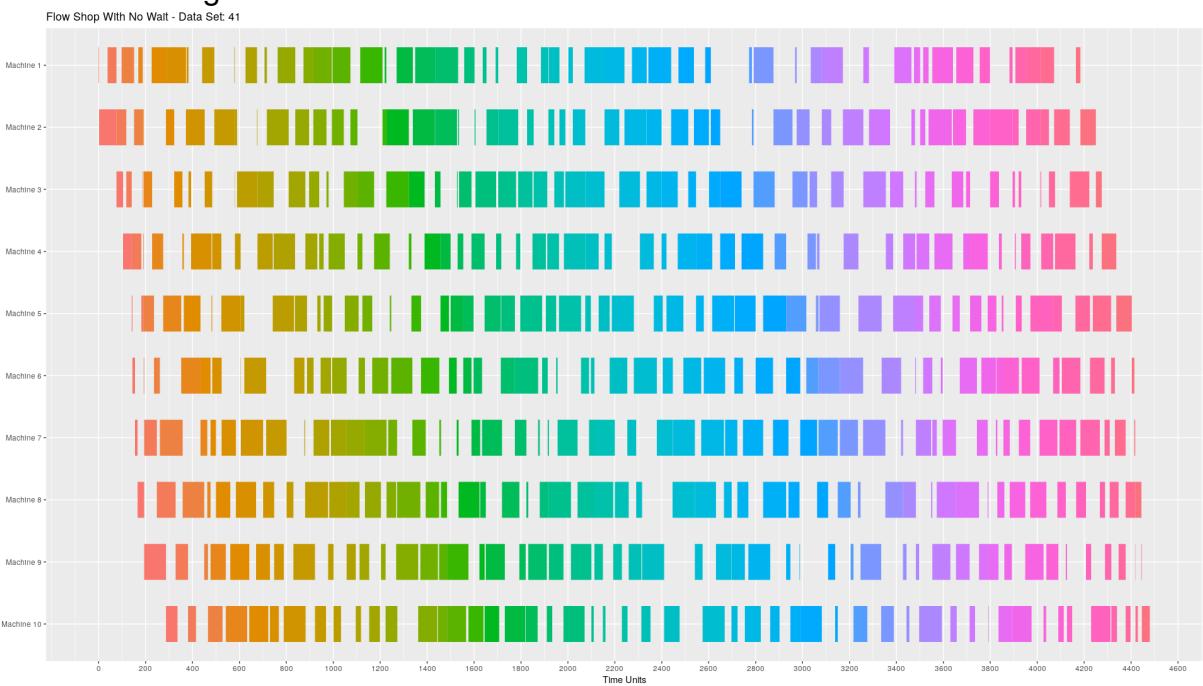


Figure 33: Gantt Chart of NEH Result - FSNW - Data Set 51



Figure 34: Gantt Chart of NEH Result - FSNW - Data Set 61



Figure 35: Gantt Chart of NEH Result - FSNW - Data Set 71

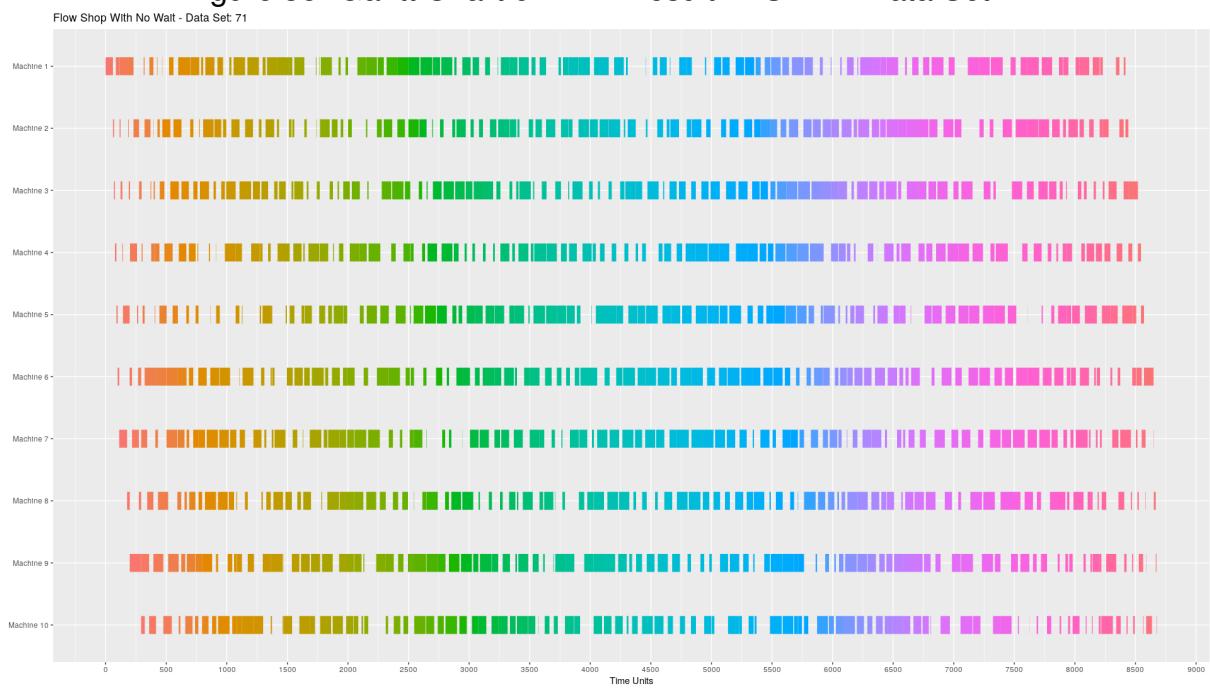


Figure 36: Gantt Chart of NEH Result - FSNW - Data Set 81



Figure 37: Gantt Chart of NEH Result - FSNW - Data Set 91

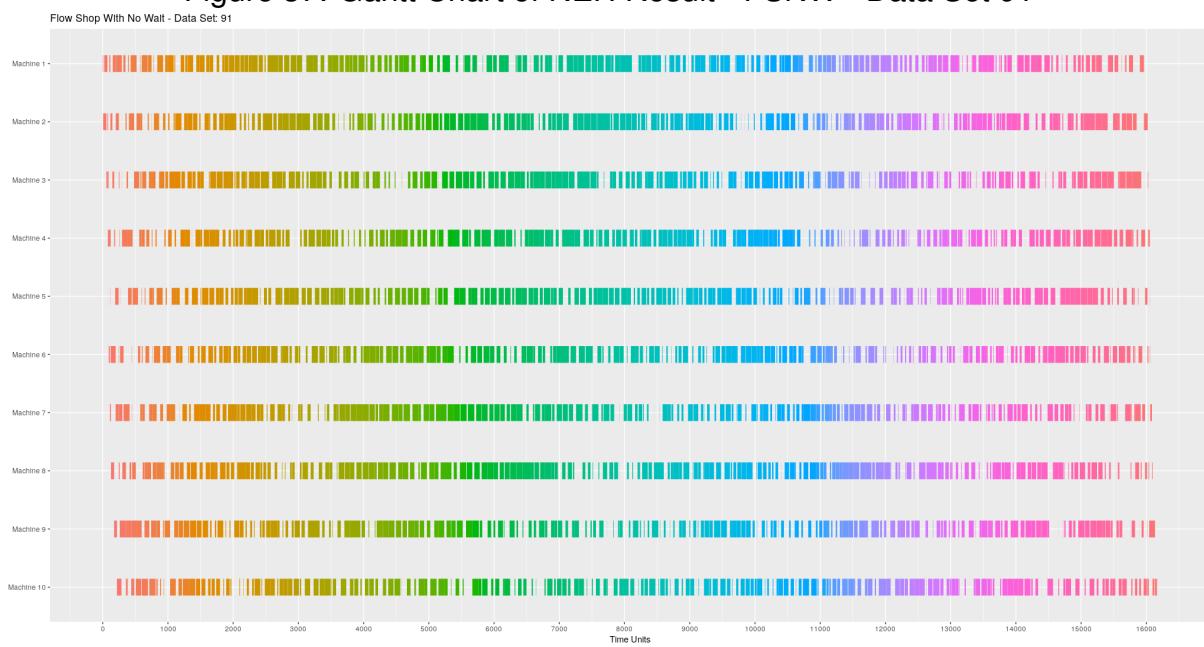


Figure 38: Gantt Chart of NEH Result - FSNW - Data Set 101



Figure 39: Gantt Chart of NEH Result - FSNW - Data Set 120



5 Execution Time Analysis

The first thing we are going to look at is the execution times of the NEH algorithm. When you look at the execution times, you can see the strength of NEH because it is relatively fast considering the complexity of the problem. In addition, the execution times scale nicely with the problem size, the largest data sets taking less than 10 seconds to complete. Along with the execution times we can look at the total number of objective function calls, Data set 0 has 5 jobs, giving a total number of possible job combinations as $5!$, or 120 permutations that would have to be calculated to find the optimal value using a brute force method. The NEH algorithm computed a value in just 14 objective function calls, which is only about 12% of the number required for brute force method. Data set 1 has 20 jobs, giving a total number of permutations at $20!$, or 2,432,902,008,176,640,000 different combinations which a brute force algorithm would have to compute to find the optimal cmax.

NEH on the other hand calculated a close to optimal cmax value for data set 1 in just 209 objective function calls, which is extremely fast in comparison. In general, the number of total objective function calls are solely dependent on the number of jobs and are not influenced by the number of machines. This makes sense because we are trying to optimize the job order. These results show the power of NEH and why it is widely used despite not providing the actual minimal cmax. Finally, there does not seem to be a significant execution time difference between the three flow shop problems. All three performed more or less the same, however flow shop with no wait did perform slightly worse overall than the other two.

6 Results Analysis

Table 11: Flow Shop Scheduling - NEH Results - % Difference from Optimal

Number of Data Sets	% Difference from optimal
21	<1%
46	<2%
59	<3%
71	<4%
92	<5%
114	<6%
119	<7%
120	<8%

In this section we are going to look at the NEH results, and its compare flow shop scheduling results to the known optimal values. Looking at table 11 you can see that the NEH algorithm produced a cmax value for all 120 data sets within 8% of the known optimal value. 114 of the 120 data sets were within 6% of the optimal value. When you consider the huge difference in execution times for NEH vs a brute force solution,

these results are very good.

Looking at the other two flow shop problems, flow shop with blocking and flow shop with no wait, it is clear that in general these problems produce cmax values greater than the standard flow shop scheduling algorithm. In general, flow shop with blocking had a higher cmax value than the standard flow shop scheduling problem, and flow shop with no wait produced the largest cmax values of the three. If you look at the supplied gantt chart diagrams, you can see why this is the case. Flow shop with no wait tends to have many more empty gaps between jobs than the other two problems.

7 Conclusions

In this document we have presented our experiment findings and conclude that the NEH algorithm performs extremely well considering the high complexity of the problem, and allows us to find close to optimal values in a reasonable amount of time when a brute force solution would be unfeasible. For the majority of all 120 data sets, the NEH algorithm produced a cmax value within 5% of the actual known optimal. For the largest data sets, the NEH algorithm never took more than about 12 seconds to compute the final value. Overall NEH has proved to be a very viable option when you need good results quickly.