CS471 Project 5

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1 Introduction

The purpose of this lab was to code an optimization algorithms that use job Scheduling, the NEH algorithm, The NEH Flow shop optimization algorithm uses a two-dimensional array which holds the completion time of each job on each machine. Each row in the array represents a separate machine that each column (job) must process on. To begin the Algorithm each job must be sorted in order of largest total completion time first with the last value being the shortest job. Then each job is inserted into the make span function starting with the longest job first. Then the next largest job is inserted into the schedule at each available slot and tested for best the shortest make span. Once all positions have been tested the schedule with the shortest make span is selected, locking in the order of that schedule, upon which time the process is repeated with the next longest job until all jobs have been placed in the schedule. Once all jobs have been placed into the schedule the resulting schedule should be close to the optimal schedule for the given flow shop.

1.0.1 FLOW SHOPS

A general flowshop scheduling problem is defined as follows.

A set of n jobs, 1,2,...,n available at time zero has to be processed in a shop with m (ordered) machines $M_1, M_2, ... M_m$

Each job is processed first on M_1 , next on M_2 , and so on, and lastly on M_m .

No machine can process more than one job at a time, no preemption is allowed, all setup times are included into the job processing times, and there is unlimited storage between the machines.

2 RESULTS

2.0.1 NEH ALGORITHM

The NEH Algorithm is delivered the known optimal result for FSS consistently when it came to the first functions, however when compared to other published results using the same function there are noticeable differences between those results and the results of this experiment. After analyzing the functions where the results were varied between experiments a pattern emerged, when jobs have the same total completion time as each other but varying completion time and different machines it can result in the NEH algorithm generating different results when using the same data from experiment to experiment. This is because when the algorithm uses the sorted jobs based on total completion time and there is a tie between two or more jobs the order of the jobs will be different between sorts. Since the algorithm does not check for completion time on each machine individually the algorithm might not generate the globally optimal value but instead just an optimal value for that particular sorting. In cases that use fewer than 50 jobs and 10 machines this results in a margin of error of less than 1 percent, but as the number of machines and jobs grow this margin of error grows to the point where in the case of function 120 which has 20 machines and 500 jobs it can result in a margin of error of up to 3 percent.

2.0.2 RESULTS (FLOW SHOP CALLS)

The main drawback of the NEH Algorithm is that the number of calls to the flow shop function grows exponentially with the growth of the number of jobs and machines. Depending on the implementation of the matrix that holds the data for the jobs and machines this can inherently result in much longer execution times.

2.0.3 RESULTS(EXECUTION TIME)

The execution time of the NEH Algorithm is cubic with the number of calls to the flow shop function. However in the data shown in tables 3.1 through 3.4 this is not always the case, with the first 3 tables this is the case, however in the 4th table (3.4) the execution time grows more than cubic. This may be because the data structure used for the matrix to hold the schedule in this experiment was a vector rather than an array. The resulting time change is likely because the vector is required to resize and copy multiple times as the schedule is built as the vector would have to be resized roughly 9 times for every job which could result in a longer execution time due to the frequent resizing and copying of the vector.

3 CONCLUSION

The NEH Algorithm is a very powerful algorithm for determining the make span of a flow shop, however it has some short-falls. The main short-fall of the algorithm is that it does not account for jobs that have the same total completion time such as the case in function one where jobs 2 and 4 have the same total execution time, resulting in the flow shop with no waiting having different results every time the experiment is run. What the algorithm does

do well is producing consistent accurate results, the largest difference generated between this experiment and the known optimum was for function 120 where the result for flow shop with now wait enabled generated a result 2.4 percent deviation for the known minimums found in other published works.

Table 3.1: Computation NEH Problems 1-30

Problem		FFS			FFSB			FFSNW	
	makespan	time	Evaluations	makespan	time	Evaluations	makespan	time	Evaluations
f_1	1286	0.012	209	1435	0.01	209	16394	0.01	209
f_2	1365	0.01	209	1477	0.01	209	18018	0.01	209
f_3	1159	0.01	209	1353	0.011	209	16701	0.012	209
f_4	1325	0.01	209	1552	0.01	209	18963	0.01	209
f_5	1305	0.01	209	1398	0.01	209	16368	0.011	209
f_6	1228	0.011	209	1464	0.011	209	16145	0.011	209
f_7	1278	0.011	209	1458	0.01	209	16728	0.011	209
f_8	1223	0.009	209	1449	0.01	209	16675	0.009	209
f_9	1291	0.01	209	1457	0.012	209	17219	0.011	209
f_{10}	1151	0.011	209	1349	0.011	209	16159	0.011	209
f_{11}	1680	0.012	209	1767	0.012	209	25968	0.012	209
f_{12}	1729	0.011	209	1903	0.011	209	28022	0.016	209
f_{13}	1557	0.012	209	1772	0.013	209	24133	0.012	209
f_{14}	1439	0.011	209	1622	0.012	209	23044	0.012	209
f_{15}	1502	0.012	209	1722	0.012	209	24591	0.012	209
f_{16}	1453	0.011	209	1679	0.012	209	24047	0.013	209
f_{17}	1562	0.011	209	1738	0.013	209	23609	0.012	209
f_{18}	1609	0.011	209	1814	0.014	209	25187	0.012	209
f_{19}	1647	0.011	209	1832	0.014	209	25497	0.013	209
f_{20}	1653	0.011	209	1854	0.014	209	25699	0.012	209
f_{21}	2410	0.017	209	2530	0.016	209	40401	0.016	209
f_{22}	2150	0.016	209	2285	0.018	209	39688	0.016	209
f_{23}	2411	0.015	209	2564	0.017	209	39373	0.018	209
f_{24}	2262	0.015	209	2399	0.017	209	40068	0.016	209
f_{25}	2397	0.015	209	2538	0.017	209	40127	0.017	209
f_{26}	2349	0.016	209	2472	0.017	209	41575	0.018	209
f_{27}	2362	0.016	209	2498	0.019	209	41826	0.02	209
f_{28}	2249	0.016	209	2411	0.017	209	39515	0.016	209
f_{29}	2320	0.015	209	2421	0.017	209	39825	0.017	209
f_{30}	2277	0.016	209	2425	0.016	209	40589	0.016	209

 $^{\rm 1}$, 3.4 GHz Intel core i5-3570K, 8 GB RAM

Table 3.2: Computation NEH Problems 31-60

$ \begin{array}{c ccccccccccccccccccccccccccccccccccc$	Problem		FFS			FFSB			FFSNW	
2733 0.034 1274 3321 0.033 1274 86186 0.033 2843 0.034 1274 3550 0.034 1274 90841 0.034 2643 0.034 1274 3523 0.034 1274 90841 0.034 2868 0.033 1274 3431 0.035 1274 90841 0.034 2868 0.033 1274 3431 0.035 1274 90646 0.033 2869 0.032 1274 3413 0.035 1274 90646 0.033 2869 0.031 1274 3436 0.032 1274 90676 0.033 2694 0.031 1274 3436 0.032 1274 86989 0.033 2787 0.041 1274 3446 0.042 1274 86989 0.033 3178 0.042 1274 3446 0.042 1274 86989 0.033 3178 0.042		makespan	time	Evaluations	makespan	time	Evaluations	makespan	time	Evaluations
2843 0.034 1274 3550 0.034 1274 90841 0.034 2643 0.033 1274 3223 0.035 1274 85678 0.033 2783 0.034 1274 3431 0.035 1274 8678 0.033 2868 0.032 1274 3431 0.035 1274 90450 0.034 2869 0.032 1274 3431 0.035 1274 90676 0.033 2694 0.031 1274 3436 0.032 1274 90676 0.033 2787 0.031 1274 3436 0.032 1274 86989 0.033 2787 0.031 1274 3446 0.032 1274 86989 0.033 3015 0.042 1274 3446 0.042 1274 86989 0.033 3128 0.042 1274 3446 0.042 1274 124042 0.043 3128 0.042	f31	2733	0.034	1274	3321	0.033	1274	86186	0.033	1274
2643 0.033 1274 3223 0.035 1274 85678 0.033 2783 0.034 1274 3421 0.035 1274 90543 0.036 2868 0.033 1274 3431 0.035 1274 90476 0.034 2868 0.032 1274 3433 0.033 1274 86899 0.033 2752 0.032 1274 3266 0.032 1274 86899 0.033 2694 0.031 1274 3366 0.032 1274 86899 0.033 2787 0.031 1274 3446 0.032 1274 86899 0.033 3135 0.042 1274 3446 0.032 1274 86899 0.033 3136 0.041 1274 3446 0.042 1274 91517 0.043 3128 0.041 1274 3889 0.043 1274 12402 0.041 3128 0.041	f_{32}		0.034	1274	3550	0.034	1274	90841	0.034	1274
2783 0.034 1274 3382 0.034 1274 90543 0.036 2868 0.033 1274 3431 0.035 1274 90549 0.033 2850 0.032 1274 3431 0.033 1274 90476 0.033 2752 0.032 1274 3266 0.032 1274 86989 0.033 2564 0.031 1274 3326 0.032 1274 86989 0.033 2576 0.031 1274 3326 0.032 1274 86989 0.032 2787 0.031 1274 346 0.032 1274 86989 0.032 2787 0.042 1274 3446 0.033 1274 9127 0.032 3032 0.042 1274 3489 0.041 1274 12369 0.042 3128 0.041 1274 3887 0.042 1274 12369 0.042 3178 0.042	f_{33}		0.033	1274	3223	0.035	1274	82928	0.033	1274
2868 0.033 1274 3431 0.035 1274 91410 0.034 2850 0.032 1274 3413 0.033 1274 90476 0.033 2752 0.032 1274 3266 0.032 1274 86989 0.033 2576 0.031 1274 3326 0.032 1274 86989 0.033 2576 0.031 1274 3446 0.032 1274 80209 0.032 2576 0.031 1274 3446 0.032 1274 80209 0.032 3135 0.042 1274 3446 0.042 1274 9157 0.033 3032 0.043 1274 3446 0.042 1274 124042 0.041 3128 0.041 1274 3898 0.041 1274 116443 0.042 3128 0.041 1274 3898 0.042 1274 116443 0.042 3128 0.041 <td>f_{34}</td> <td>2783</td> <td>0.034</td> <td>1274</td> <td>3382</td> <td>0.034</td> <td>1274</td> <td>90543</td> <td>0.036</td> <td>1274</td>	f_{34}	2783	0.034	1274	3382	0.034	1274	90543	0.036	1274
2850 0.032 1274 3413 0.033 1274 90676 0.033 2752 0.032 1274 3266 0.032 1274 85490 0.033 2994 0.031 1274 3326 0.032 1274 86989 0.033 2576 0.031 1274 318 0.032 1274 86989 0.032 2787 0.031 1274 3446 0.032 1274 86989 0.032 3135 0.042 1274 3446 0.032 1274 123660 0.033 3135 0.042 1274 3847 0.042 1274 12402 0.043 3128 0.043 1274 3898 0.042 1274 12443 0.042 3128 0.041 1274 3878 0.042 1274 12366 0.043 3128 0.041 1274 3878 0.042 1274 12306 0.042 3128 0.042	f_{35}	2868	0.033	1274	3431	0.035	1274	91410	0.034	1274
2552 0.032 1274 3266 0.032 1274 85490 0.033 2694 0.031 1274 3326 0.032 1274 86989 0.032 2576 0.031 1274 3118 0.033 1274 86989 0.032 2576 0.031 1274 3118 0.032 1274 86989 0.032 3135 0.042 1274 3947 0.042 1274 91517 0.033 3135 0.042 1274 3795 0.041 1274 12360 0.043 3128 0.043 1274 3897 0.041 1274 124042 0.041 3178 0.041 1274 3897 0.043 1274 12526 0.042 3178 0.041 1274 3878 0.042 1274 12346 0.042 3178 0.042 1274 1274 12346 0.042 3174 0.042 1274 1274	f_{36}	2850	0.032	1274	3413	0.033	1274	92906	0.033	1274
2694 0.031 1274 3326 0.032 1274 86989 0.032 2576 0.031 1274 3118 0.033 1274 80209 0.032 2787 0.031 1274 3446 0.032 1274 80209 0.032 3135 0.042 1274 3947 0.042 1274 12360 0.043 3032 0.043 1274 3847 0.042 1274 124042 0.041 318 0.041 1274 3819 0.041 1274 124462 0.041 3128 0.041 1274 3838 0.043 1274 12526 0.042 3178 0.042 1274 3878 0.042 1274 12348 0.042 3178 0.042 1274 3878 0.042 1274 12368 0.042 3178 0.042 1274 3878 0.042 1274 12368 0.042 3174 0.042	f_{37}	2752	0.032	1274	3266	0.032	1274	85490	0.033	1274
2576 0.031 1274 3118 0.033 1274 80209 0.032 2787 0.031 1274 3446 0.032 1274 91517 0.033 3135 0.042 1274 3947 0.042 1274 91517 0.033 3032 0.043 1274 3895 0.041 1274 124042 0.041 3186 0.041 1274 3819 0.043 1274 116443 0.042 3178 0.041 1274 3836 0.043 1274 12369 0.042 3178 0.041 1274 3878 0.042 1274 12369 0.042 3178 0.042 1274 3878 0.042 1274 12369 0.042 3178 0.042 1274 3878 0.042 1274 12369 0.042 3178 0.042 1274 3878 0.042 1274 12368 0.042 3274 0.042 <td>f_{38}</td> <td>2694</td> <td>0.031</td> <td>1274</td> <td>3326</td> <td>0.032</td> <td>1274</td> <td>68698</td> <td>0.032</td> <td>1274</td>	f_{38}	2694	0.031	1274	3326	0.032	1274	68698	0.032	1274
2787 0.031 1274 3446 0.032 1274 91517 0.033 3135 0.042 1274 3947 0.042 1274 123660 0.043 3032 0.043 1274 3795 0.041 1274 124042 0.041 3118 0.04 1274 3819 0.043 1274 116443 0.041 3118 0.041 1274 3838 0.043 1274 123369 0.042 3128 0.041 1274 3828 0.042 1274 125226 0.042 3178 0.041 1274 3828 0.042 1274 125226 0.042 3178 0.042 1274 1274 1274 12346 0.042 3173 0.042 1274 1274 12346 0.042 1274 12346 0.042 3173 0.042 1274 1274 12346 0.042 1274 12346 0.042 3015<	f_{39}	2576	0.031	1274	3118	0.033	1274	80209	0.032	1274
3135 0.042 1274 3947 0.042 1274 123660 0.043 3032 0.043 1274 3795 0.041 1274 124042 0.041 3016 0.04 1274 3819 0.044 1274 116443 0.042 3198 0.041 1274 3838 0.043 1274 123369 0.042 3128 0.04 1274 3887 0.041 1274 125226 0.042 3178 0.041 1274 3828 0.042 1274 123369 0.042 3178 0.042 1274 3878 0.042 1274 123345 0.042 3173 0.042 1274 1274 12346 0.042 3173 0.042 1274 1274 12346 0.042 3174 1274 3878 0.042 1274 12366 0.042 3174 1274 1274 12368 0.042 1274 12368 </th <td>f_{40}</td> <td>2787</td> <td>0.031</td> <td>1274</td> <td>3446</td> <td>0.032</td> <td>1274</td> <td>91517</td> <td>0.033</td> <td>1274</td>	f_{40}	2787	0.031	1274	3446	0.032	1274	91517	0.033	1274
3032 0.043 1274 3795 0.041 1274 124042 0.041 3016 0.04 1274 3819 0.044 1274 116443 0.042 3198 0.041 1274 3938 0.043 1274 123369 0.042 3128 0.04 1274 3828 0.042 1274 12526 0.044 3178 0.041 1274 3828 0.042 1274 12526 0.042 3178 0.043 1274 3878 0.042 1274 12346 0.042 3173 0.042 1274 3975 0.042 1274 12346 0.042 3123 0.042 1274 1274 1274 12346 0.042 3123 0.042 1274 1274 12346 0.042 1274 12366 0.042 3921 0.06 1274 4889 0.062 1274 12368 0.042 3923 0.062	f_{41}	3135	0.042	1274	3947	0.042	1274	123660	0.043	1274
3016 0.04 1274 3819 0.044 1274 116443 0.042 3198 0.041 1274 3938 0.043 1274 123369 0.042 3128 0.04 1274 3897 0.041 1274 125226 0.044 3178 0.041 1274 3828 0.042 1274 125226 0.044 3178 0.042 1274 3975 0.042 1274 123324 0.042 3173 0.042 1274 3794 0.042 1274 123066 0.041 3173 0.042 1274 1274 123067 0.042 3173 0.042 1274 123067 0.042 3174 1274 1274 123067 0.042 3257 0.04 1274 4889 0.062 1274 174576 0.042 3921 0.06 1274 4653 0.064 1274 174576 0.062 3924 <td>f_{42}</td> <td>3032</td> <td>0.043</td> <td>1274</td> <td>3795</td> <td>0.041</td> <td>1274</td> <td>124042</td> <td>0.041</td> <td>1274</td>	f_{42}	3032	0.043	1274	3795	0.041	1274	124042	0.041	1274
3198 0.041 1274 3938 0.043 1274 123369 0.042 3128 0.04 1274 3897 0.041 1274 125226 0.044 3178 0.041 1274 3828 0.042 1274 123345 0.042 3277 0.043 1274 3975 0.042 1274 123067 0.042 3123 0.042 1274 3794 0.042 1274 123067 0.042 3257 0.042 1274 3878 0.043 1274 123067 0.042 3257 0.042 1274 3878 0.043 1274 123067 0.042 4013 0.06 1274 4889 0.062 1274 174576 0.062 3921 0.06 1274 4653 0.061 1274 178970 0.062 3923 0.063 1274 4653 0.065 1274 178973 0.062 3987 0.06	f_{43}	3016	0.04	1274	3819	0.044	1274	116443	0.042	1274
3128 0.04 1274 3897 0.041 1274 12526 0.044 3178 0.041 1274 3828 0.042 1274 12334 0.042 3277 0.042 1274 3975 0.042 1274 123145 0.042 3123 0.042 1274 3794 0.043 1274 123066 0.042 3015 0.042 1274 3878 0.043 1274 123067 0.042 3257 0.042 1274 3843 0.043 1274 123067 0.042 4013 0.06 1274 4889 0.062 1274 123685 0.045 3921 0.06 1274 4889 0.062 1274 17860 0.062 3923 0.062 1274 4557 0.064 1274 17860 0.062 3987 0.062 1274 4716 0.065 1274 17897 0.062 3914 0.062 <td>f_{44}</td> <td>3198</td> <td>0.041</td> <td>1274</td> <td>3938</td> <td>0.043</td> <td>1274</td> <td>123369</td> <td>0.042</td> <td>1274</td>	f_{44}	3198	0.041	1274	3938	0.043	1274	123369	0.042	1274
3178 0.041 1274 3828 0.042 1274 122324 0.042 3277 0.043 1274 3975 0.042 1274 123145 0.042 3123 0.042 1274 3878 0.043 1274 123066 0.042 3015 0.042 1274 3878 0.043 1274 123067 0.042 3257 0.04 1274 4889 0.062 1274 183151 0.045 3921 0.06 1274 4899 0.062 1274 17456 0.062 3923 0.063 1274 4553 0.061 1274 174800 0.062 3987 0.062 1274 4756 0.065 1274 17640 0.062 3987 0.062 1274 4756 0.065 1274 178973 0.062 3914 0.062 1274 4566 0.065 1274 178973 0.061 3952 0.063	f_{45}	3128	0.04	1274	3897	0.041	1274	125226	0.044	1274
3277 0.043 1274 3975 0.042 1274 123145 0.042 3123 0.042 1274 3794 0.044 1274 123066 0.041 3015 0.042 1274 3878 0.043 1274 123067 0.042 3257 0.04 1274 4889 0.062 1274 123685 0.045 4013 0.06 1274 4889 0.062 1274 183151 0.064 3921 0.06 1274 4597 0.061 1274 178800 0.062 3923 0.063 1274 4714 0.065 1274 176460 0.062 3987 0.06 1274 4456 0.065 1274 178973 0.062 3914 0.062 1274 4566 0.063 1274 178973 0.063 3952 0.063 1274 4719 0.061 1274 179363 0.061 3954 0.063	f_{46}	3178	0.041	1274	3828	0.042	1274	122324	0.042	1274
3123 0.042 1274 3794 0.044 1274 123066 0.041 3015 0.042 1274 3878 0.043 1274 123067 0.042 3257 0.04 1274 3843 0.042 1274 123685 0.045 4013 0.06 1274 4889 0.062 1274 183151 0.064 3921 0.06 1274 4653 0.061 1274 174576 0.062 3923 0.063 1274 4714 0.065 1274 178800 0.062 3987 0.062 1274 4714 0.065 1274 17840 0.062 3914 0.062 1274 4456 0.065 1274 172641 0.061 3952 0.063 1274 4576 0.062 1274 173641 0.063 3954 0.063 1274 4719 0.061 1274 174485 0.062 3952 0.063	f_{47}	3277	0.043	1274	3975	0.042	1274	123145	0.042	1274
3015 0.042 1274 3878 0.043 1274 123067 0.042 3257 0.04 1274 3943 0.042 1274 123685 0.045 4013 0.06 1274 4889 0.062 1274 183151 0.064 3921 0.06 1274 4653 0.064 1274 174800 0.062 3923 0.063 1274 4714 0.065 1274 176460 0.062 3987 0.06 1274 4716 0.065 1274 176460 0.062 3914 0.062 1274 4566 0.065 1274 178973 0.062 3952 0.063 1274 4576 0.063 1274 179363 0.061 3952 0.063 1274 4719 0.061 1274 174485 0.062 4016 0.063 1274 4802 0.059 1274 174485 0.063 4016 0.064	f_{48}	3123	0.042	1274	3794	0.044	1274	123066	0.041	1274
3257 0.04 1274 3943 0.042 1274 123685 0.045 4013 0.06 1274 4889 0.062 1274 183151 0.064 3921 0.06 1274 4597 0.061 1274 174576 0.062 3923 0.063 1274 4653 0.064 1274 176460 0.062 3987 0.062 1274 4714 0.065 1274 176460 0.062 3914 0.062 1274 4456 0.065 1274 178973 0.062 3952 0.063 1274 4566 0.063 1274 178044 0.063 3954 0.063 1274 4719 0.061 1274 179363 0.061 3952 0.063 1274 4802 0.059 1274 174485 0.062 4016 0.063 1274 4802 0.059 1274 174485 0.063	f_{49}	3015	0.042	1274	3878	0.043	1274	123067	0.042	1274
4013 0.06 1274 4889 0.062 1274 183151 0.064 3921 0.06 1274 4597 0.061 1274 174576 0.062 3923 0.063 1274 4653 0.064 1274 178800 0.062 3987 0.062 1274 4714 0.065 1274 176460 0.062 3914 0.062 1274 4456 0.063 1274 172641 0.061 3952 0.063 1274 4575 0.062 1274 179363 0.061 3952 0.063 1274 4719 0.061 1274 179363 0.061 4016 0.063 1274 4802 0.059 1274 174485 0.062	f_{50}	3257	0.04	1274	3943	0.042	1274	123685	0.045	1274
3921 0.06 1274 4597 0.061 1274 174576 0.062 3923 0.063 1274 4653 0.064 1274 178800 0.062 3987 0.062 1274 4714 0.065 1274 176460 0.062 3914 0.062 1274 4566 0.063 1274 172641 0.061 3952 0.063 1274 4719 0.061 1274 4719 0.061 3952 0.063 1274 4719 0.061 1274 174485 0.061 4016 0.06 1274 4802 0.059 1274 174485 0.062	f_{51}	4013	90.0	1274	4889	0.062	1274	183151	0.064	1274
3923 0.063 1274 4653 0.064 1274 178800 0.062 3987 0.062 1274 4714 0.065 1274 176460 0.062 3914 0.062 1274 4456 0.063 1274 178973 0.062 3952 0.063 1274 4575 0.062 1274 180844 0.063 3954 0.063 1274 4719 0.061 1274 179363 0.061 3952 0.063 1274 4802 0.059 1274 174485 0.062 4016 0.06 1274 4802 0.059 1274 181715 0.063	f_{52}	3921	90.0	1274	4597	0.061	1274	174576	0.062	1274
3987 0.062 1274 4714 0.065 1274 176460 0.062 3835 0.06 1274 4456 0.063 1274 172641 0.062 3914 0.062 1274 4566 0.063 1274 172641 0.061 3952 0.063 1274 4719 0.061 1274 179363 0.061 3952 0.063 1274 4575 0.061 1274 174485 0.062 4016 0.06 1274 4802 0.059 1274 181715 0.063	f_{53}	3923	0.063	1274	4653	0.064	1274	178800	0.062	1274
3835 0.06 1274 4456 0.065 1274 178973 0.062 3914 0.062 1274 4566 0.063 1274 172641 0.061 3952 0.063 1274 4575 0.061 1274 179363 0.061 3952 0.063 1274 4575 0.061 1274 174485 0.062 4016 0.06 1274 4802 0.059 1274 181715 0.063	f_{54}	3987	0.062	1274	4714	0.065	1274	176460	0.062	1274
3914 0.062 1274 4566 0.063 1274 172641 0.061 3952 0.063 1274 4575 0.062 1274 180844 0.063 3974 0.063 1274 4719 0.061 1274 179363 0.061 3952 0.063 1274 4575 0.061 1274 174485 0.062 4016 0.06 1274 4802 0.059 1274 181715 0.063	f_{55}	3835	0.06	1274	4456	0.065	1274	178973	0.062	1274
3952 0.063 1274 4575 0.062 1274 180844 0.063 3974 0.063 1274 4719 0.061 1274 179363 0.061 3952 0.063 1274 4802 0.061 1274 174485 0.062 4016 0.06 1274 4802 0.059 1274 181715 0.063	f_{56}	3914	0.062	1274	4566	0.063	1274	172641	0.061	1274
3974 0.063 1274 4719 0.061 1274 179363 0.061 1 3952 0.063 1274 4575 0.061 1274 174485 0.062 1 4016 0.06 1274 4802 0.059 1274 181715 0.063	f_{57}	3952	0.063	1274	4575	0.062	1274	180844	0.063	1274
3952 0.063 1274 4575 0.061 1274 174485 0.062 4016 0.06 1274 4802 0.059 1274 181715 0.063	f_{58}	3974	0.063	1274	4719	0.061	1274	179363	0.061	1274
4016 0.06 1274 4802 0.059 1274 181715 0.063	f_{59}	3952	0.063	1274	4575	0.061	1274	174485	0.062	1274
	f_{60}	4016	90.0	1274	4802	0.059	1274	181715	0.063	1274

 $^{\rm 1}$, 3.4 GHz Intel core i5-3570K, 8 GB RAM

Table 3.3: Computation NEH Problems 61-90

Problem		FFS			FFSB			FFSNW	
	makespan	time	Evaluations	makespan	time	Evaluations	makespan	time	Evaluations
f_{61}	5519	0.094	5049	2299	0.096	5049	346551	0.1	5049
f_{62}	5284	0.098	5049	6591	0.091	5049	337898	0.098	5049
f63	5248	0.094	5049	6341	0.095	5049	321373	0.096	5049
f_{64}	5023	0.094	5049	6185	0.093	5049	310277	0.098	5049
f_{65}	5266	0.093	5049	6433	0.093	5049	314738	0.097	5049
f_{66}	5139	0.092	5049	6382	0.094	5049	325058	0.094	5049
f_{67}	5281	0.095	5049	6458	0.092	5049	340579	0.098	5049
f68	5129	0.094	5049	6277	0.099	5049	320482	0.101	5049
f_{69}	5489	0.096	5049	6672	0.094	5049	335976	0.099	5049
f_{70}	5354	0.094	5049	2929	0.095	5049	318738	0.097	5049
f_{71}	5835	0.134	5049	7627	0.137	5049	460166	0.137	5049
f_{72}	5500	0.131	5049	7304	0.13	5049	432785	0.137	5049
f73	5802	0.134	5049	7362	0.13	5049	451055	0.139	5049
f74	2966	0.133	5049	7599	0.133	5049	462018	0.136	5049
f_{75}	2637	0.135	5049	7373	0.132	5049	450673	0.133	5049
f76	5391	0.134	5049	7199	0.132	5049	423947	0.136	5049
f_{77}	5735	0.129	5049	7294	0.134	5049	443647	0.137	5049
f_{78}	5723	0.131	5049	7437	0.134	5049	443329	0.136	5049
f79	6051	0.134	5049	7632	0.132	5049	451817	0.135	5049
f_{80}	5915	0.132	5049	7508	0.129	5049	467223	0.145	5049
f_{81}	6613	0.207	5049	8378	0.211	5049	607717	0.22	5049
f_{82}	6565	0.212	5049	8327	0.212	5049	604330	0.217	5049
f_{83}	6595	0.211	5049	8276	0.212	5049	612867	0.218	5049
f_{84}	6649	0.207	5049	8345	0.21	5049	611044	0.224	5049
f_{85}	6653	0.216	5049	8303	0.212	5049	595347	0.215	5049
f_{86}	6713	0.21	5049	8331	0.211	5049	602323	0.219	5049
f_{87}	6595	0.207	5049	8519	0.211	5049	616825	0.219	5049
f_{88}	6785	0.213	5049	8567	0.215	5049	621720	0.217	5049
f_{89}	8999	0.212	5049	8411	0.209	5049	604596	0.217	5049
f_{90}	6728	0.208	5049	8512	0.211	5049	630701	0.218	5049

 $^{\rm 1}$, 3.4 GHz Intel core i5-3570K, 8 GB RAM

Table 3.4: Computation NEH Problems 91-120

Problem		FFS			FFSB			FFSNW	
	makespan	time	Evaluations	makespan	time	Evaluations	makespan	time	Evaluations
f_{91}	10942	0.514	20099	14425	0.515	20099	1.63079e+06	0.538	20099
f_{92}	10651	0.511	20099	14429	0.504	20099	1.62148e+06	0.53	20099
f_{93}	11061	0.503	20099	14568	0.5	20099	1.62579e+06	0.537	20099
f_{94}	11057	0.506	20099	14496	0.494	20099	1.63502e+06	0.539	20099
f_{95}	10615	0.506	20099	14402	0.504	20099	1.63788e+06	0.526	20099
f_{96}	10491	0.51	20099	14255	0.501	20099	1.65436e+06	0.522	20099
f_{97}	11001	0.508	20099	14633	0.497	20099	1.72748e+06	0.528	20099
f_{98}	10823	0.502	20099	14642	0.497	20099	1.6848e+06	0.532	20099
f_{99}	10617	0.503	20099	14232	0.495	20099	1.64083e+06	0.528	20099
f_{100}	10791	0.511	20099	14387	0.501	20099	1.63722e+06	0.522	20099
f_{101}	11588	0.861	20099	15649	0.924	20099	2.18707e+06	0.941	20099
f_{102}	11740	0.858	20099	15838	0.924	20099	2.23527e+06	0.915	20099
f_{103}	11825	0.866	20099	15840	0.927	20099	2.24087e+06	0.919	20099
f_{104}	11804	0.857	20099	15931	0.929	20099	2.23525e+06	0.923	20099
f_{105}	11657	0.864	20099	15710	0.935	20099	2.17681e+06	0.912	20099
f_{106}	11689	0.859	20099	16010	0.921	20099	2.19759e+06	0.944	20099
f_{107}	11894	0.899	20099	16003	0.956	20099	2.21672e+06	0.954	20099
f_{108}	11870	0.86	20099	15906	0.951	20099	2.23052e+06	0.91	20099
f_{109}	11631	0.87	20099	15991	0.923	20099	2.18026e+06	0.926	20099
f_{110}	11800	0.853	20099	15943	0.93	20099	2.20513e+06	0.912	20099
f_{111}	26693	7.259	125249	38247	9.555	125249	1.27043e+07	8.411	125249
f_{112}	27197	7.242	125249	38699	9.519	125249	1.29825e+07	8.455	125249
f_{113}	26875	7.362	125249	38081	9.721	125249	1.27635e+07	8.455	125249
f_{114}	27125	7.26	125249	38669	9.487	125249	1.29629e+07	8.41	125249
f_{115}	26837	7.235	125249	38311	9.576	125249	1.2766e+07	8.609	125249
f_{116}	27010	7.201	125249	38528	9.593	125249	1.27253e+07	8.437	125249
f_{117}	26806	7.258	125249	38000	9.611	125249	1.27854e+07	8.427	125249
f_{118}	27144	7.245	125249	38254	9.829	125249	1.27445e+07	8.329	125249
f_{119}	26653	7.219	125249	38252	609.6	125249	1.27319e+07	8.464	125249
f_{120}	27054	7.228	125249	38623	9.625	125249	1.287e+07	8.394	125249

 $^{\rm 1}$, 3.4 GHz Intel core i5-3570K, 8 GB RAM