RESULT AND DISCUSSION

Analysis of output

The program is then tested with a set of 6 months data from a can manufacturing company. There exists an average of 300 jobs to be scheduled in each month. Each job consists of an order of product which is classified into 6 product class as mentioned earlier with associate due dates. Actual production time of each job is converted into $C_{max, act}$ as shown in Appendix A. A summary of the number of jobs in each month and total number of production are shown in the following tables.

Table 14 Number of Jobs and Number of Production in pieces within 6 months.

	No. of Job						
	Month 1	**Month 2**	**Month 3**	**Month 4**	**Month 5**	**Month 6**	Total
Class 1	70	56	69	72	74	55	396
Class 2	62	66	71	68	71	78	416
Class 3	72	51	75	72	83	89	442
Class 4	12	16	18	19	19	26	110
Class 5	105	87	58	59	77	62	448
Class 6	71	56	59	60	62	65	373
Total	392	332	350	350	386	375	**2185**

	No. of Production(pieces)						
	Month 1	**Month 2**	**Month 3**	**Month 4**	**Month 5**	**Month 6**	**Total**
Class 1	89283	96581	94381	96390	118281	64779	559695
Class 2	109416	102296	102252	105020	97868	99917	616769
Class 3	179931	224157	227650	279767	257450	175189	1344144
Class 4	47000	40468	38340	37384	34670	41675	239537
Class 5	144921	134588	126557	106180	141677	102346	756269
Class 6	176922	115133	110790	117210	89470	121557	731082
Total	747473	713223	699970	741951	739416	605463	**4247496**

The output data from the program is show in appendix B.

Result from heuristic algorithm can be discussed 3 steps as follow;

1. Comparison of C_{max} from simple dispatching rule.
2. Consider $C_{max,heuristic}$ when there is skill differentiation among workers and apply heuristic rules to assigning workers to each machine.
3. Comparison of $C_{max,heuristic}$ to those of the actual assign schedules of the company and conclusion of the best heuristic methods.

1. Comparison C_{max} from simple dispatching rule

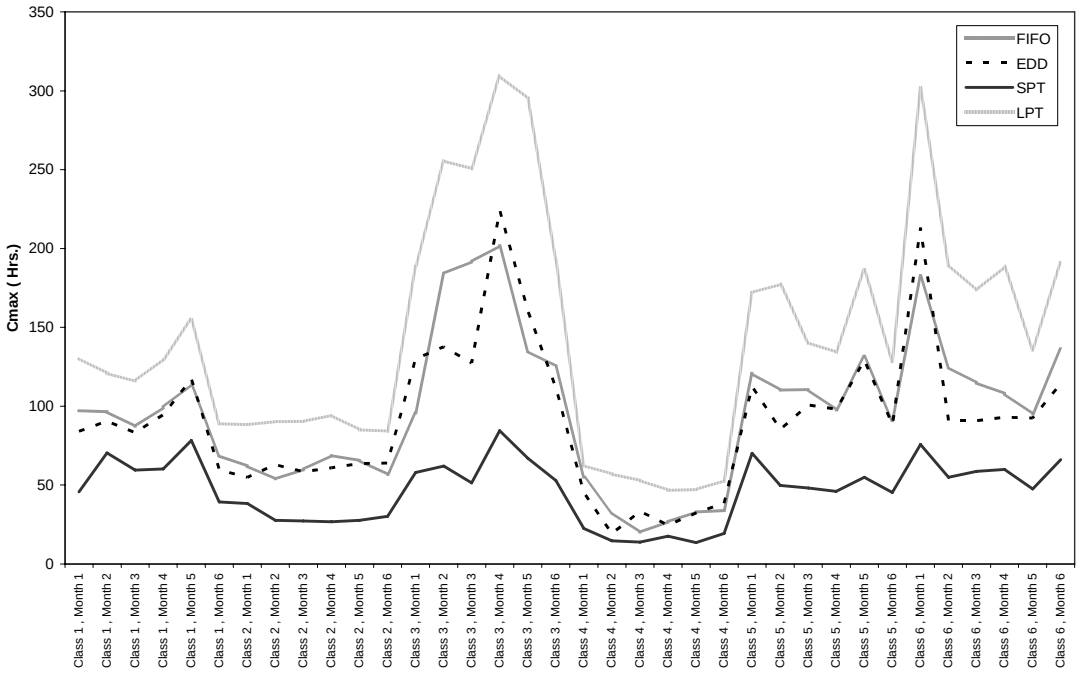

Figure 20 The completion time from the simple dispatching rule.

The result from the simple dispatching rule shown clearly indicates that in all situations shortest processing time (SPT) is the best dispatching rule for simple one or two stage parallel sequencing jobs. However in such situation, it is assumed that all operators are of the skillful and there is no differentiation in the skill of workers and the effects on the operation.

Therefore in condition 1,

$$C_{max} = C_{max,1}$$

2. Consider $C_{max,heuristic}$ when there is skill differentiation

In step two, assigning workers to each job where there is a skill differentiation. The ratio of multi-skill operators ranging from 0 to 80 (100 is omitted because this would be the same as considering a simple scheduling problem where there is no differentiation in the skill levels. A penalty is allocated where the worker skill does not match with that of the assigned machine, using a penalty rate of 25%, 50% and 100%.

Step2: Skill differentiation in the group ranging from 0 – 80.
Heuristic rule for workers allocation;

Rule 1 – Single skill workers first
Rule 2 – Multiple skill workers first
Rule 3 – Random skill allocation

Where skill does not match with those of assigned jobs , a penalty is applied. The penalty rate varies from 25%, 50% and 100% on the standard time is added to each unmatched job assignment.

When skill matches,

$$C_{max,2} = C_{max}$$

However if not match , $C_{max,2} > C_{max}$,

$$C_{max,2} - C_{max} = \Delta t$$

Calculate $\Sigma \Delta t$ of all products in each month. Results of the calculation are shown.

Table 15 Penalty rate 25%

Skill		heuristic rules	Month					
			1	2	3	4	5	6
80	S	Processing	0.005	0.003	0.005	0.005	0.005	0.005
80	S	Continuous	0.004	0.002	0.003	0.004	0.004	0.003
80	S	Maximum M/C	0.005	0.003	0.005	0.005	0.005	0.005
50	S	Processing	0.545	0.312	0.454	0.518	0.508	0.445
50	S	Continuous	0.404	0.231	0.337	0.384	0.376	0.329
50	S	Maximum M/C	0.562	0.322	0.469	0.535	0.524	0.459
20	S	Processing	0.648	0.371	0.540	0.616	0.603	0.529
20	S	Continuous	0.480	0.275	0.400	0.456	0.447	0.392
20	S	Maximum M/C	0.669	0.383	0.557	0.635	0.623	0.545
0	S	Processing	1.409	0.807	1.174	1.339	1.312	1.149
0	S	Continuous	1.043	0.598	0.870	0.992	0.972	0.851
0	S	Maximum M/C	1.453	0.832	1.212	1.381	1.353	1.186
80	M	Processing	0.230	0.132	0.192	0.218	0.214	0.188
80	M	Continuous	0.170	0.097	0.142	0.162	0.159	0.139
80	M	Maximum M/C	0.237	0.136	0.198	0.225	0.221	0.194
50	M	Processing	22.806	13.060	19.011	21.675	21.236	18.601
50	M	Continuous	16.893	9.674	14.082	16.055	15.730	13.778
50	M	Maximum M/C	23.530	13.475	19.614	22.363	21.910	19.191
20	M	Processing	27.108	15.524	22.597	25.763	25.242	22.109
20	M	Continuous	20.080	11.499	16.738	19.084	18.698	16.377
20	M	Maximum M/C	27.968	16.016	23.314	26.581	26.043	22.811
80	R	Processing	0.326	0.186	0.271	0.309	0.303	0.266
80	R	Continuous	0.241	0.138	0.201	0.229	0.225	0.197
80	R	Maximum M/C	0.336	0.192	0.280	0.319	0.313	0.274
50	R	Processing	32.301	18.498	26.926	30.699	30.077	26.345
50	R	Continuous	23.926	13.702	19.945	22.740	22.280	19.515
50	R	Maximum M/C	33.326	19.085	27.781	31.673	31.032	27.181
20	R	Processing	38.394	21.987	32.005	36.489	35.751	31.314
20	R	Continuous	28.440	16.286	23.707	27.029	26.482	23.196
20	R	Maximum M/C	39.612	22.685	33.021	37.648	36.886	32.308
0	R	Processing	83.464	47.797	69.575	79.325	77.719	68.074
0	R	Continuous	61.825	35.405	51.537	58.759	57.570	50.425
0	R	Maximum M/C	86.114	49.315	71.784	81.843	80.186	70.235

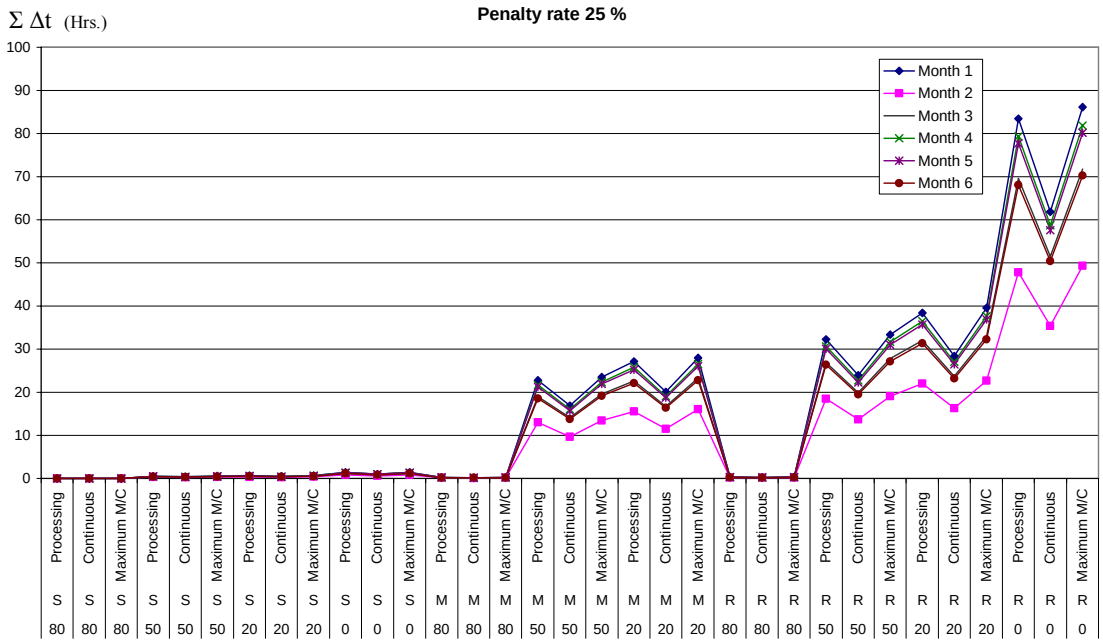

Figure 21 Skill effects at 25% penalty rate.

Table 16 Penalty rate 50%

Skill		heuristic rules	Month					
			1	2	3	4	5	6
80	S	Processing	0.006	0.003	0.005	0.005	0.005	0.005
80	S	Continuous	0.005	0.002	0.004	0.004	0.004	0.004
80	S	Maximum M/C	0.006	0.003	0.005	0.006	0.005	0.005
50	S	Processing	0.603	0.345	0.503	0.573	0.561	0.492
50	S	Continuous	0.462	0.264	0.385	0.439	0.430	0.377
50	S	Maximum M/C	0.620	0.355	0.517	0.589	0.577	0.506
20	S	Processing	0.768	0.440	0.640	0.730	0.715	0.626
20	S	Continuous	0.600	0.344	0.500	0.570	0.559	0.489
20	S	Maximum M/C	0.789	0.452	0.657	0.749	0.734	0.643
0	S	Processing	1.707	0.977	1.423	1.622	1.589	1.392
0	S	Continuous	1.342	0.768	1.118	1.275	1.249	1.094
0	S	Maximum M/C	1.752	1.003	1.460	1.665	1.631	1.429
80	M	Processing	0.242	0.139	0.202	0.230	0.225	0.197
80	M	Continuous	0.182	0.104	0.152	0.173	0.170	0.149
80	M	Maximum M/C	0.249	0.143	0.208	0.237	0.232	0.203
50	M	Processing	25.219	14.442	21.023	23.968	23.483	20.569
50	M	Continuous	19.307	11.056	16.094	18.349	17.978	15.747
50	M	Maximum M/C	25.943	14.857	21.626	24.657	24.157	21.159
20	M	Processing	32.128	18.398	26.781	30.534	29.916	26.204
20	M	Continuous	25.100	14.374	20.923	23.855	23.372	20.472
20	M	Maximum M/C	32.988	18.891	27.499	31.352	30.718	26.905
80	R	Processing	0.343	0.196	0.286	0.326	0.319	0.280
80	R	Continuous	0.258	0.148	0.215	0.246	0.241	0.211
80	R	Maximum M/C	0.353	0.202	0.294	0.336	0.329	0.288
50	R	Processing	35.719	20.455	29.775	33.947	33.260	29.132

Table 16 (Cont'd)

Skill		heuristic rules	Month					
			1	2	3	4	5	6
50	R	Continuous	27.344	15.659	22.794	25.988	25.462	22.302
50	R	Maximum M/C	36.744	21.042	30.630	34.922	34.215	29.969
20	R	Processing	45.503	26.058	37.932	43.247	42.371	37.113
20	R	Continuous	35.550	20.358	29.634	33.787	33.103	28.994
20	R	Maximum M/C	46.722	26.756	38.948	44.405	43.506	38.107
0	R	Processing	101.129	57.913	84.300	96.113	94.168	82.481
0	R	Continuous	79.490	45.521	66.262	75.548	74.018	64.832
0	R	Maximum M/C	103.778	59.430	86.509	98.632	96.635	84.642

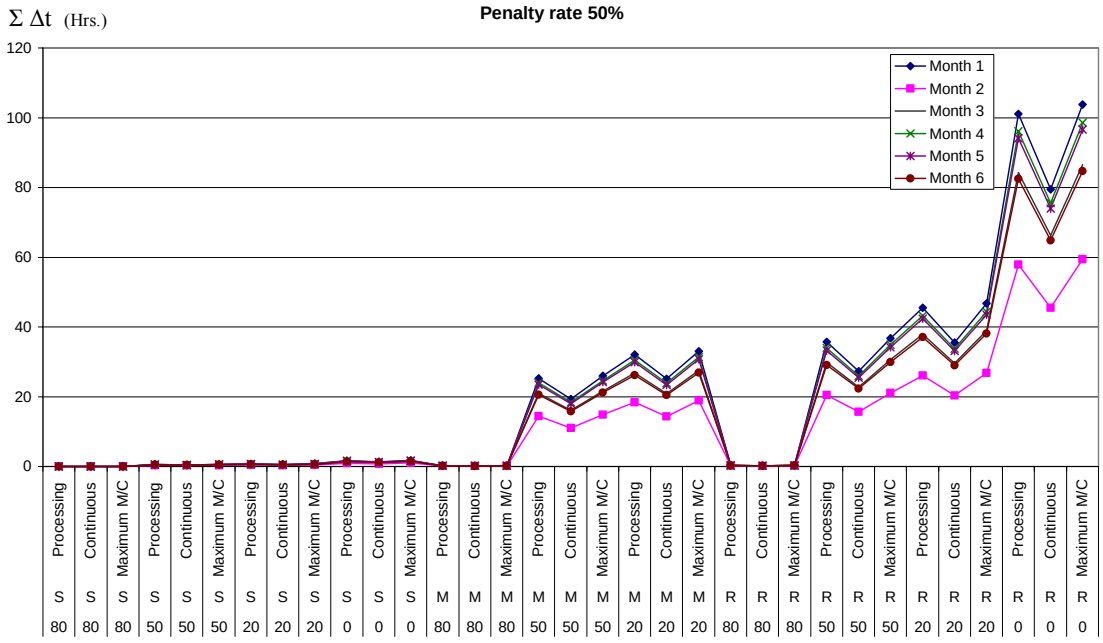

Figure 22 Skill effects at 50% penalty rate.

Table 17 Penalty rate 100%

Skill		heuristic rules	Month					
			1	2	3	4	5	6
80	S	Processing	0.008	0.005	0.007	0.008	0.007	0.007
80	S	Continuous	0.007	0.004	0.006	0.006	0.006	0.006
80	S	Maximum M/C	0.008	0.005	0.007	0.008	0.007	0.007
50	S	Processing	0.805	0.461	0.671	0.765	0.749	0.656
50	S	Continuous	0.663	0.380	0.553	0.631	0.618	0.541
50	S	Maximum M/C	0.822	0.471	0.685	0.781	0.765	0.671
20	S	Processing	0.974	0.558	0.812	0.925	0.907	0.794
20	S	Continuous	0.806	0.461	0.672	0.766	0.750	0.657
20	S	Maximum M/C	0.994	0.569	0.829	0.945	0.926	0.811
0	S	Processing	2.139	1.225	1.783	2.033	1.992	1.745
0	S	Continuous	1.774	1.016	1.479	1.686	1.652	1.447
0	S	Maximum M/C	2.184	1.251	1.820	2.076	2.034	1.781
80	M	Processing	0.337	0.193	0.281	0.320	0.314	0.275
80	M	Continuous	0.277	0.159	0.231	0.264	0.258	0.226
80	M	Maximum M/C	0.344	0.197	0.287	0.327	0.320	0.281
50	M	Processing	33.666	19.279	28.064	31.996	31.348	27.458
50	M	Continuous	27.753	15.893	23.135	26.377	25.843	22.636
50	M	Maximum M/C	34.390	19.694	28.667	32.684	32.023	28.048
20	M	Processing	40.733	23.327	33.955	38.713	37.929	33.222
20	M	Continuous	33.705	19.302	28.097	32.034	31.385	27.490
20	M	Maximum M/C	41.594	23.819	34.672	39.531	38.731	33.924
80	R	Processing	0.477	0.273	0.398	0.453	0.444	0.389
80	R	Continuous	0.393	0.225	0.327	0.373	0.366	0.320
80	R	Maximum M/C	0.487	0.279	0.406	0.463	0.454	0.398
50	R	Processing	47.682	27.306	39.747	45.317	44.400	38.890
50	R	Continuous	39.308	22.510	32.767	37.358	36.602	32.060
50	R	Maximum M/C	48.707	27.893	40.602	46.292	45.355	39.726
20	R	Processing	57.692	33.038	48.092	54.831	53.721	47.054
20	R	Continuous	47.738	27.338	39.794	45.371	44.452	38.935
20	R	Maximum M/C	58.911	33.736	49.108	55.989	54.856	48.048
0	R	Processing	126.742	72.581	105.652	120.456	118.018	103.371
0	R	Continuous	105.103	60.189	87.614	99.891	97.869	85.723
0	R	Maximum M/C	129.392	74.098	107.860	122.975	120.485	105.532

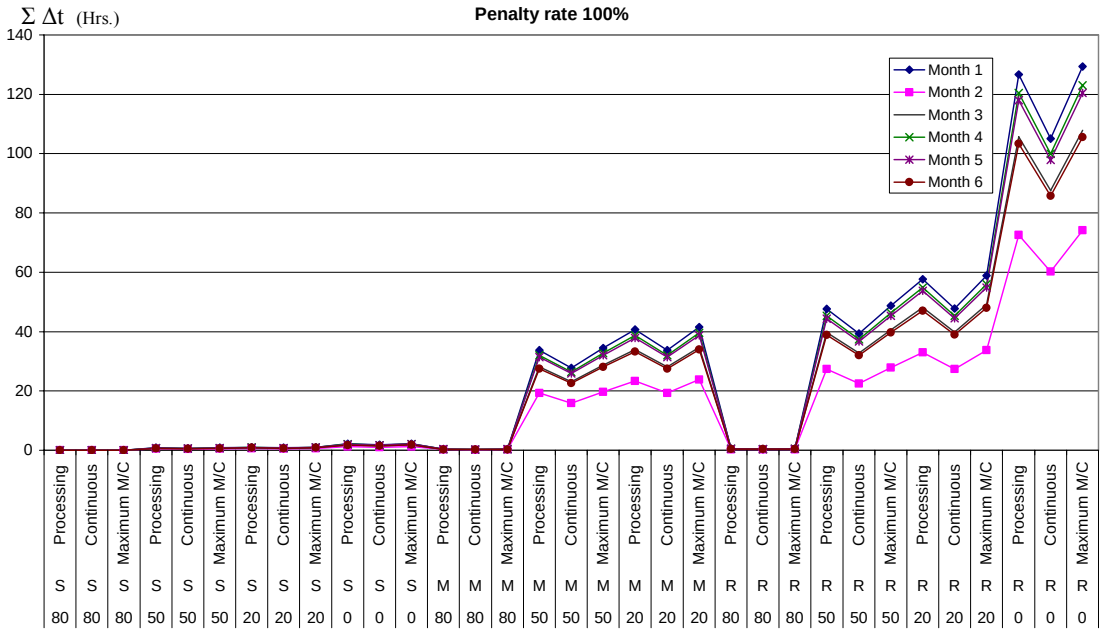

Figure 23 Skill effects at 100% penalty rate.

From results shown in figure 21, 22, 23, it is shown that skill has effects highly in the case where using heuristic of multiple skill and random skill allocation. The impact is higher with the diminishing of ratio of multiple skill workers in the group. Such effects to the completion time (C_{max}) take place even when penalty rate is as low as 25%. The cumulative of delay time is worsening with the higher number of jobs in each month.

Machine priority rule has little or no impact on the completion time where there is a high ratio of skill workforce and allocate single skill workers first. However with other skill allocation rules, multiple and random, machine priority rule has effects on the completion time at the low ratio of skill workforce.

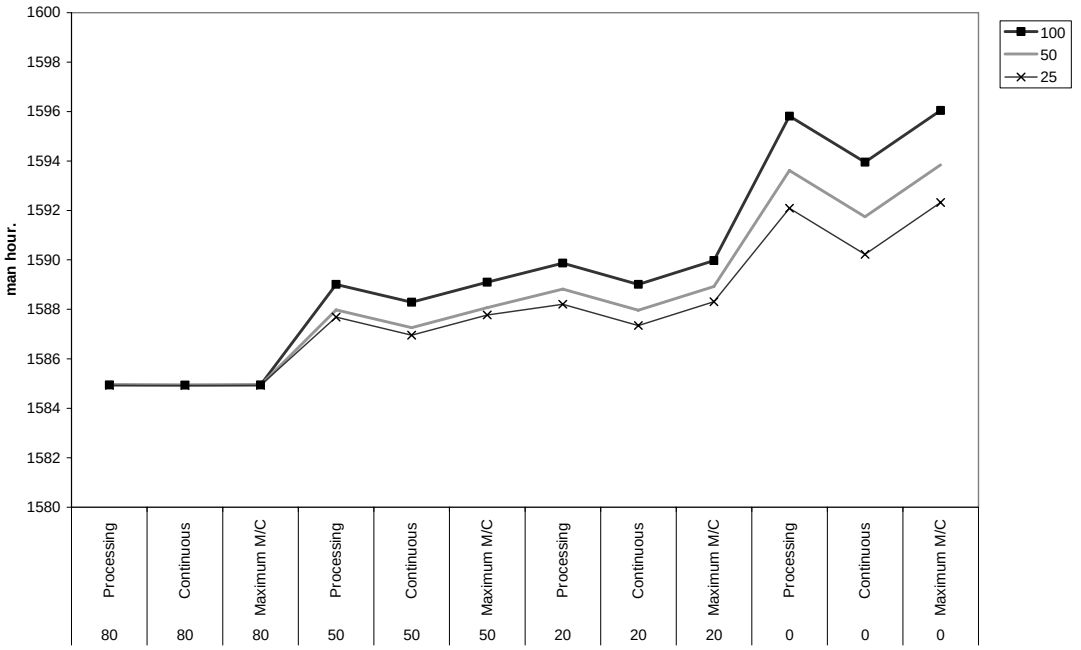

Figure 24 Skill effects at different penalty rates using heuristic rule 1 Single skill first.

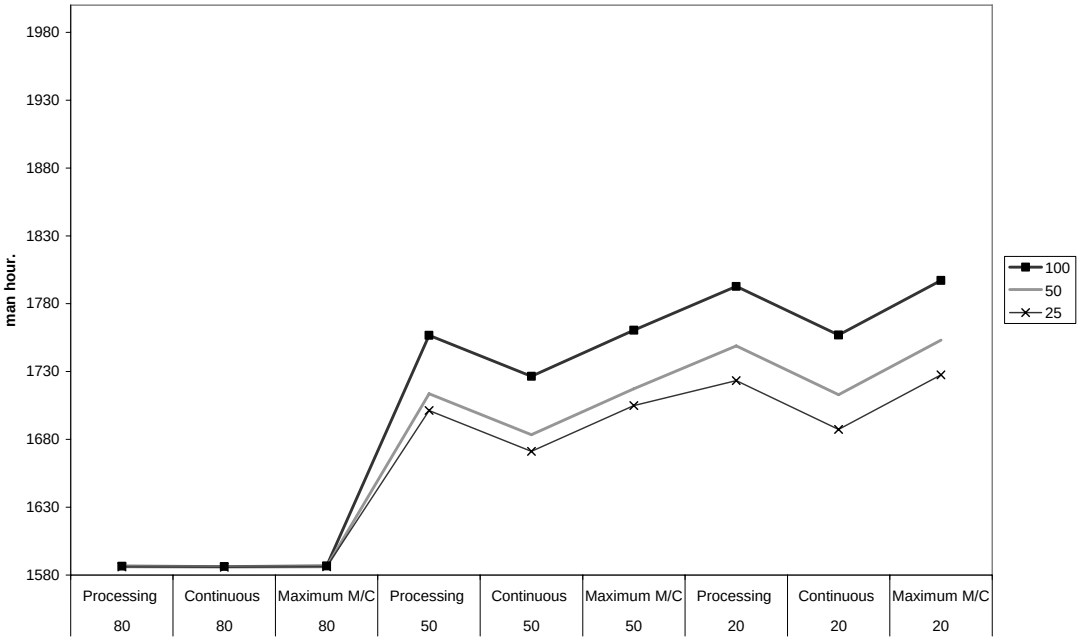

Figure 25 Skill effects at different penalty rates using heuristic rule 2 Multiple skill first.

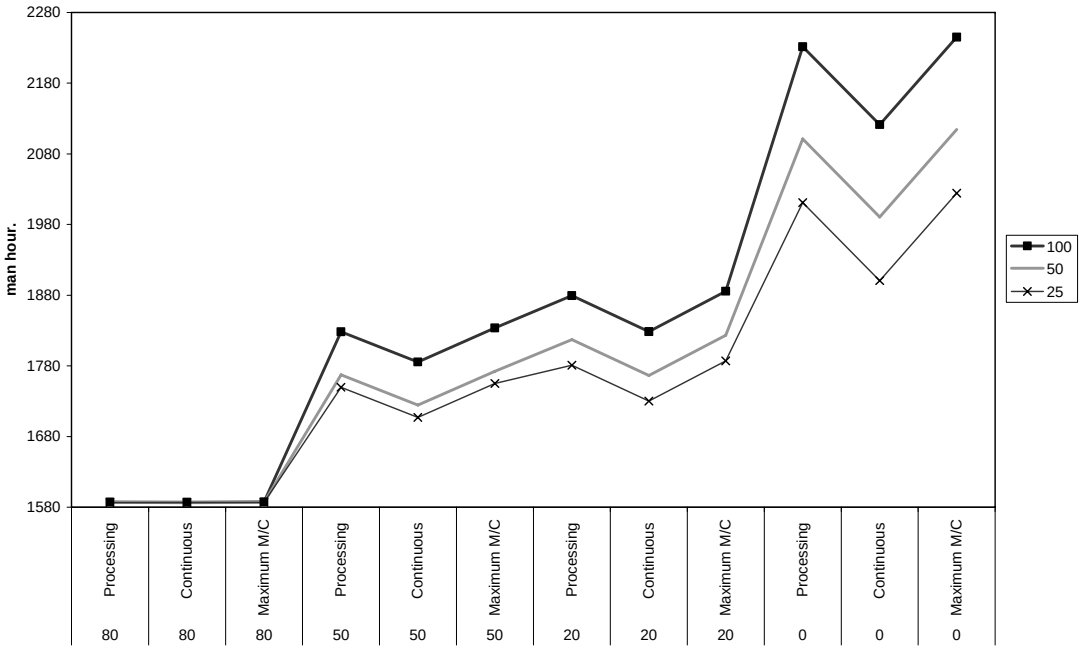

Figure 26 Skill effects at different penalty rates using heuristic rule 3- Random skill

When considering the effects of different penalty rates using different heuristic rules of workers allocation. From figure 24, 25, and 26, it can be seen clearly that the effects of skill differentiation will have impact on the total completion time when the ratio of skill workers in the group is less than 80%. The effects remain high even when the penalty rate is only 25%. When using the single skill allocation rule, this will reduce the impact of penalty. However in the worst case situation, the penalty increases with lower ratio of skill operators and maximum machines priority.

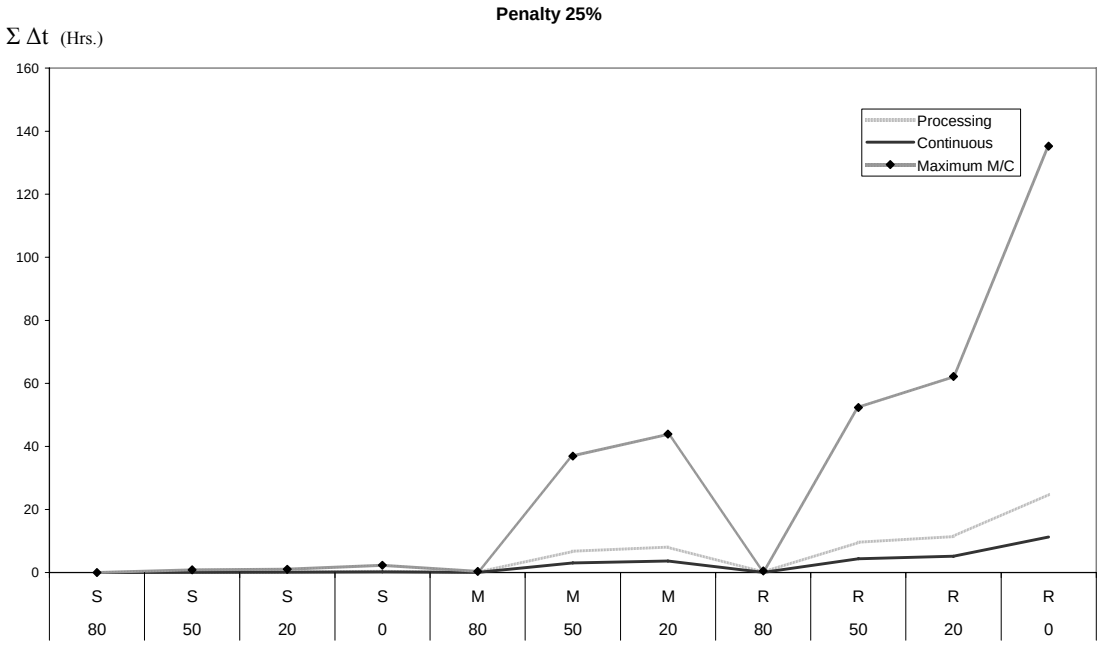

Figure 27 Effects of different machine priority rules at 25% penalty rates

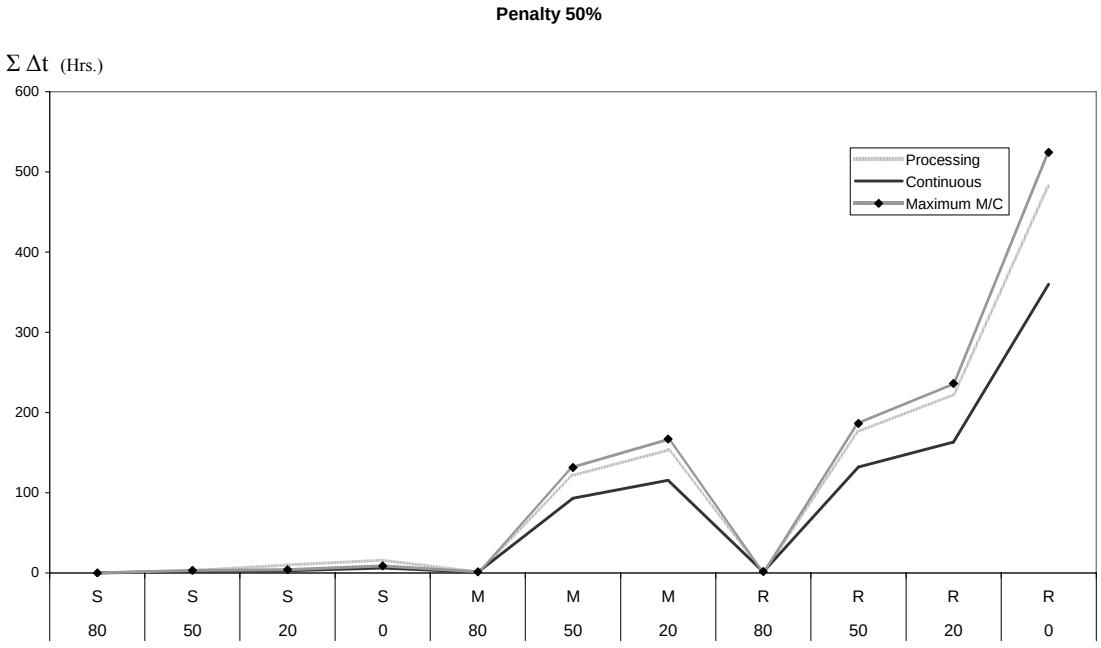

Figure 28 Effects of different machine priority rules at 50% penalty rates

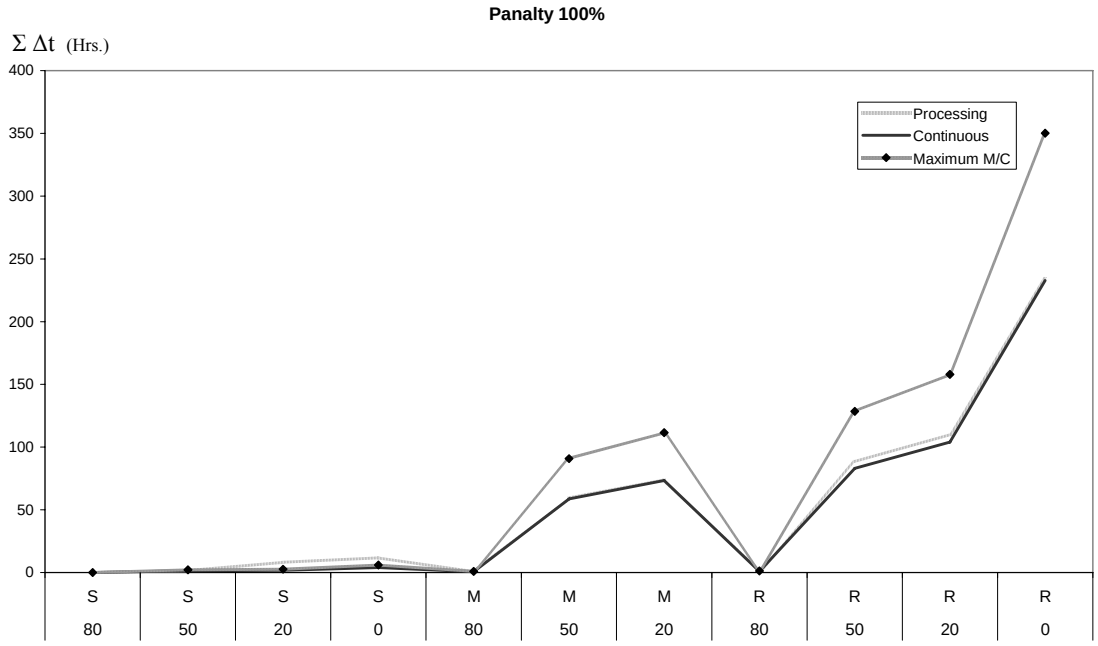

Figure 29 Effects of different machine priority rules at 100% penalty rates

From figure 27, 28, and 29, it can be seen clearly that machine priority rules will have more impact in the worst case situation where there are low ratio of skill work force and higher penalty rates.

3. Comparison of $C_{max,heuristic}$ to those of the company

With the tested heuristic rules, the results are then compared with those from the company. Using the following heuristic rules;

1) Assigning jobs to machines by using SPT
2) Assigning operators to tasks using skill allocation rules as follows;
    - Single skill workers first
    - Continuous machine has priority first

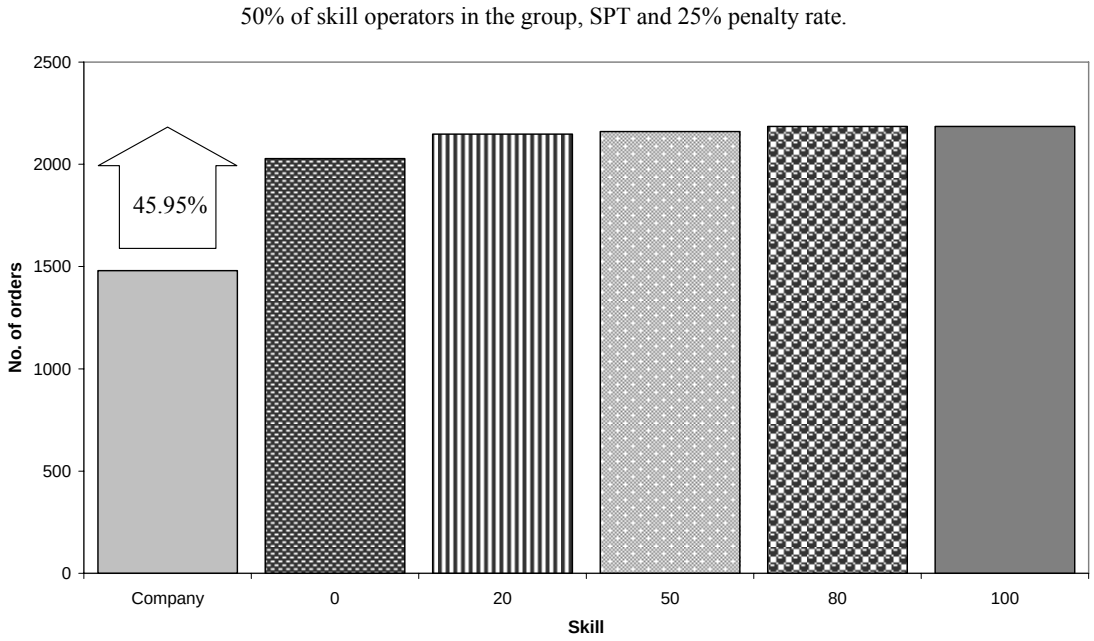

Figure 30 The number of orders meet due date.

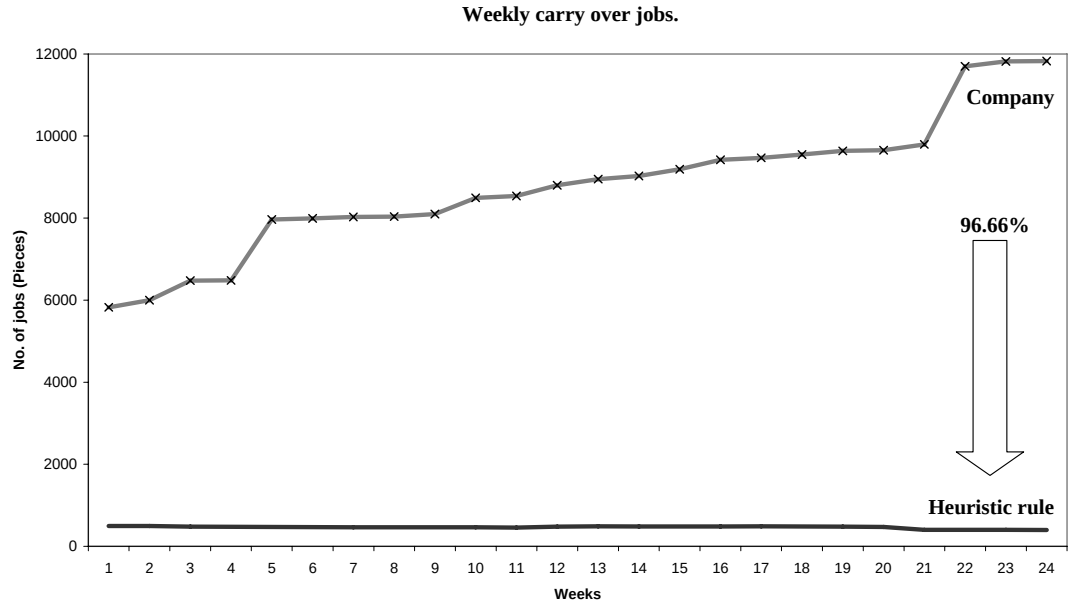

Figure 31 Weekly carry over jobs.

At the minimum penalty rate of 25%, it can be seen from Figure 30 that the new heuristic rule can improve the number of orders meeting due dates from 35% to 46%. In the mean time it also reduces throughput time and reduces number of weekly carry over jobs by 96.66 %.

From the comparison of results, it is obvious that the company is using a random skill allocation with first-come-first-serve rule for their job scheduling. The total number of orders meeting due date over the last 6 months period is only 1480 orders which is only 67.7% of the total order of 2185. By using a two-step heuristic scheduling method as proposed in this study, the optimal solution is using a skill ratio of 50%, and a minimum 25% penalty rate will give the result of 2160 orders meeting the target due dates. This is 98.85% achievement. comparing to 67.7% of the original result.

DISCUSSION

With no proper guidance, the method which is commonly employed by any scheduling jobs is FIFO and random assignment of workers. As can be seen from the comparison of heuristic rules in this study that such case yields the worst result of overall completion time and hence the cumulative of carry over unfulfilled orders (Appendix C).

The best heuristic rules derived from the study can be concluded as follows;

1) Scheduling jobs to machines first using simple SPT rule
2) Assigning single skill workers to tasks first before multiple skill workers.
3) Where there are uneven number of machines in the two stage flow shop, assign job to the longer sequential machine first before single machines.

CONCLUSION AND RECOMMENDATION

Conclusion

The study is to develop a heuristic set of rules for scheduling of a two-step flow shop assignment. The objectives is to minimize the maximum completion time of jobs by consider worker skills. Previously, there are no algorithms available for the scheduling in this case. Using a two-step approach and simple heuristic rules for the assignment of jobs in a can manufacturing, it can improve the overall completion time of the jobs, reduce tardiness and hence meeting delivery due dates.

From this thesis, it can be concluded that

1) The worker skills have influence over completion time especially where there is more than one skill needed for the operation. The company has to maintain the multiple skill workers at least 50 % in the work group in order to get the best results.

2) SPT rule gives the best solution for simple jobs scheduling. On the other hand, other rules as EDD, FIFO and LPT can also give better results when combined with right skill allocations.

3) Machine priority rules such as sequential machines, maximum processing time and higher number of machines will be considered only with low ratio of skill operators in the work group.

4) Effects of skill differentiation remain high even when there is a low learning curve, in this case represented by low penalty rate.

5) The new heuristic not only decrease the completion time but can improve the productivity, reduce throughput time and reduce number of weekly carry over jobs by 96.66%

Recommendation

Recommendation for application to real world situation;

1. Classification of worker skill according to each type of work.
2. Training of workers to the standard skill level using standard time as a milestone.
3. Allocate each worker to the appropriate task.
4. Scheduling jobs to machines and workers to task using heuristic rules of single skill first.
5. Where there are multiple tasks and skills in operation, a minimum ratio of 50% of multi-skill in the work group is suggested.
6. Follow up on standard time for improve and managing production plan.

Recommendation for future study

This study is based on the objective function of minimize the maximum completion time using a two-step schedule approach in a two stage parallel flow shop. For future study, addition situations might be included, such as;

- multiple stages hybrid flow shop,
- differentiation in the skill preference of operators,
- incentive effects on the assignment of skill operators.