CHAPTER 8: RESULTS AND CONCLUSIONS

The research results presented here provide a way to evaluate the overall performance of the scheduling algorithms under analysis. Prior to presenting the results, a brief discussion of how the data was collected to ensure a 95% confidence level is given. Following that, all the results are summarized in tables and a brief discussion of the results is given. In conclusion, the three scheduling algorithms and their results will be summarized and compared. Also, potential future research will be discussed.

8.1 Determining the Number of Replications

The simulation model is a random experiment with an uncertain outcome; different runs give different results. A point estimate is a single value used to estimate a quantity. Such an estimate does not indicate the amount of uncertainty or variability associated with the quantity being estimated. Therefore, it is more appropriate to use an interval estimate referred to as a confidence interval. A confidence interval is an "interval that will have a [given] probability of including the [true] value (Duncan 1986)." The desired confidence level determines the confidence interval. For this project, the desired confidence level is 95%; i.e., we want to be 95% confident that the true value lies within our defined confidence interval.

To determine the necessary number of replications to meet the desired confidence level, first collect 50 replications of data for analysis. Calculate the average, variance, and confidence interval values of all the replications for the schedule completion time using the following formulas:

Average Value $$\overline{X} = \frac{\sum_{j=1}^{J} X_j}{J},$$

Variance $$S_0^2 = \frac{\sum_{j=1}^{J} \left(X_j - \overline{X}\right)^2}{J-1},$$

95% Confidence Interval $$CI = \pm 1.96 \frac{S_0}{\sqrt{J}}.$$

Next, calculate the estimated number of replications required to obtain the desired confidence level using the following:

$$R_{est} \geq \left(\frac{Z_{\alpha/2} S_0}{\varepsilon} \right)^2$$

where: R_{est} = *estimated number of replications required to obtain confidence interval within confidence level,*
$Z_{\alpha/2}$ = *the critical value for a normal distribution with tail probability* $\alpha/2$,
S_0 = *standard deviation,*
α =*1- confidence level,*
ε =*desired confidence interval of observed value.*

Finally, test the integer values greater than or equal to R_{est} to determine the smallest integer, R_{tot}, satisfying the following inequality:

$$R_{tot} \geq \left(\frac{t_{\alpha/2, R_{tot}-1} S_0}{\varepsilon} \right)^2$$

where: R_{tot} = *integer value for number of replications required*
$t_{\alpha/2,Rtot-1}$ = *the critical value for a t-test with tail probability* $\alpha/2$, *and* R_{tot-1} *degrees of freedom.*

Since R_0 replications have already been run, only $R_{tot} - R_0$ additional replications are needed to generate the confidence interval.

A sample calculation of the total number of replications required is shown in Table 11. First, 50 replications were generated, then the R_{est}, 87, was determined using the formulas given above, with $\alpha = 0.05$, $\varepsilon = 0.5$, and $S_0 = 2.37$. The desired confidence interval was set for half and hour because it is an appropriate indifference value. The R_{tot}, 89, was then determined using the t-statistical values; this is shown also in Table 11. As a result, 39 more replications were generated.

α=	**0.05**		
ε=	**0.5**		
$Z_{\alpha/2}$=	**1.96**		

R_{tot}	87	88	89
$t_{\alpha/2,Rtot-1}$	1.991	1.991	1.99
$t_{\alpha/2,Rtot-1}^2$*Variance / ε^2	88.871	88.871	88.781

R_{tot}	92	93	94
$t_{\alpha/2,Rtot-1}$	1.9896	1.9893	1.989
$t_{\alpha/2,Rtot-1}^2$*Variance / ε^2	93.628	93.600	93.572

Replic	ST	ST	
1	209.93	208.6	
2	207.71	207.87	
3	214.11	208.54	
4	210	208.72	
5	206.61	208.37	
6	214.2	209.03	
7	208.81	209.79	
8	209.8	207.27	
9	209.42	207.19	
10	210.03	215.29	
11	211.79	208.04	
12	208.3	206.5	
13	211.57	210.28	
14	207.44	206.76	
15	209.11	213.9	
16	214.01	214.29	
17	207.81	208.2	
18	209.88	207.81	
19	207.8	214.57	
20	206.85	207.23	
21	208.92	206.72	
22	208.31	205.38	
23	208.14	207.52	
24	209.29	208.55	
25	207.62	207.99	
26	206.36	209.65	
27	208.53	213.44	
28	212.45	206.92	
29	208.04	209.53	
30	208.16	206.95	
31	211.44	211.38	
32	213.98	207.79	
33	209.18	207.83	
34	211.23	206.36	
35	207.24	209.13	
36	209.71	212.9	
37	207.16	212.29	
38	209.01	206.86	Additional
39	212.92	212.16	Replications
40	213.99		206.29
41	208.39		207.03
42	209.63		211.29
43	207.81		208.17
44	207.08		210.38
45	208.26		
46	209.12		
47	214.99		
48	209.29		
49	205.85		
50	213.38		
Average	**209.6132**	**209.4187**	**209.38**
STD	**2.367433**	**2.466126**	**2.4462199**
Variance	**5.604741**	**6.081778**	**5.9839919**
CI	**0.656206**	**0.512351**	**0.4945145**
Rest	**86.12469**	**93.45503**	**91.952412**

Table 11: Calculation for Number of Replications

Unfortunately, the newly calculated R_{est} value, 94, was greater than 89. So 5 more replications were collected and then the new R_{est} value, 92, was checked again to determine if enough replications have been performed. It is less than the previous R_{est} value, so the R_{tot} was determined to see if enough replications have been performed. It was determined that 94 replications were sufficient to generate a 95 % confidence level.

8.2 Objective Function and Performance Results

The objective function value is the total tardiness of the schedules. The total tardiness for the deterministic case is based on the final processing times developed using queueing theory. The stochastic objective function is the average total tardiness of multiple replications of the simulation model needed to obtain a 95% confidence interval.

Two sets of customer orders were analyzed. The first set consists of 7 customer orders and the second set consists of 20 customer orders to be scheduled. Customer 0 is used to schedule the changeovers. Product Type 4 is the changeover time for Product Type 1 and 2 and Product Type 5 is the changeover time for Product Type 3. The deterministic objective function value was calculated using the system times presented in Table 9. The resulting objective function values for both sets of customer orders are presented in Sections 8.3.1 and Section 8.3.2.

8.2.1 Set 1: Customer Orders

The first set of customer orders consists of 7 customer orders, with a total of 256 dehy-batches, and is shown in Table 12. The results for each of the scheduling algorithms are shown and discussed in the following subsections.

Customer #	Product Type	Due Date	Total Dehy Batches
1	1	16	20
2	3	20	4
3	1	13	24
4	2	56	56
5	2	68	80
6	3	55	4
7	1	150	68

Table 12: First Set of Customer Orders

8.2.1.1 Musier and Evans Scheduling Algorithm Results

The Musier and Evans Scheduling Algorithm schedules customer orders by first assigning a random number to each of the customer orders and then determining if the order can be processed on time. Customer orders that cannot be processed on-time, are then scheduled by earliest-due-date. Since this scheduling algorithm has a random component, it was necessary to perform multiple runs to increase the probability of finding the best schedule. Therefore, seven schedules were developed using the Musier and Evans Algorithm and the best solution, the schedule with the minimum total tardiness, was simulated. The best solution is shown in Table 13, the remaining schedules may be found in Appendix 2.

The total tardiness using the deterministic method is 159.28 hours; whereas the real world total tardiness for the given schedule may be anywhere between 156.25 and 159.07 hours. This shows that the deterministic method is slightly overestimating the total tardiness. The throughput for this schedule is on average approximately 256 batches / 91.31 hours = 2.80 dehy-batches/hour.

The standard deviation for the original schedule is 1.57 hours. Therefore, the robustness of the schedule is 100 - 100 * (1.57/159.28) = 99.01% and the performance is (157.66 / 159.28) * 100 = 95.56%.

CPU Time 0 sec	Seed = 19		Musier and Evans (Dehy Time)		Simulation (50 Replications)	
Customer #	Product Type	Due Date	Finish Process Time (Hours)	Tardy (Hours)	Finish Process Time (Hours)	Tardy (Hours)
0	4	1000	3.25	0.00		
3	1	13	11.28	0.00	12.46 +/- 0.03	0.00 +/- 0.03
0	4	1000	14.53	0.00		+/- 0.00
5	2	68	37.32	0.00	38.09 +/- 0.12	0.00 +/- 0.12
0	4	1000	40.57	0.00		
7	1	150	59.88	0.00	60.69 +/- 0.19	0.00 +/- 0.19
1	1	16	65.01	49.01	65.85 +/- 0.33	49.85 +/- 0.33
0	5	1000	69.07	0.00		
2	3	20	73.11	53.11	73.66 +/- 0.23	53.66 +/- 0.23
6	3	55	74.14	19.14	74.91 +/- 0.22	19.91 +/- 0.22
0	4	1000	77.39	0.00		
4	2	56	94.02	38.02	91.31 +/- 0.29	35.31 +/- 0.29
Total				159.28		157.66 +/- 1.41

Table 13: Objective Function Results for Musier and Evans Algorithm for 7 Orders

8.2.1.2 Ku and Karimi Algorithm, Greedy Heuristic and Musier and Evans HIM Results

The results shown in this section are for the remaining three scheduling algorithms: Ku and Karimi Sequence Building, Greedy Heuristic, and Musier and Evans Heuristic Improvement Method (HIM), because all three algorithms produced the same schedule. Ku and Karimi Sequence Building scheduling algorithm first sorts the customer orders by earliest-due-date. Each order is then checked to determine if it can be processed on-time. If not, then it is placed at the bottom of the scheduling sequence. The Greedy Heuristic simply schedules all the orders by earliest-due-date. Finally, HIM takes the existing schedule and performs a 1-optimal and 2-optimal method to make a new schedule that is either better than or the same as the original schedule. The schedule that was obtained by these three scheduling algorithms is shown in Table 14. It should be noted that the schedule obtained by these scheduling algorithms is the optimal schedule for 7 orders, this was checked with the program in Appendix 8.

The total tardiness using the deterministic method is 4.93 hours; whereas the simulation model provided total tardiness of 4.98 ± 1.38 hours. This means that the deterministic method provides a good estimate of the schedule's total tardiness. The standard deviation for the original and the improved schedule is 3.78 hours. Therefore, the robustness of the schedule is 23.33% and the performance 101.01%. The throughput for this schedule is on average approximately 2.99 dehy-batches/hour.

Customer #	Product Type	Due Date	Finish Process Time (Hours)	Tardy (Hours)	Finish Process Time (Hours)	Tardy (Hours)	Finish Process Time (Hours)	Tardy (Hours)
0	4	1000	3.25	0.00			3.25	0.00
3	1	13	11.28	0.00	11.98 +/- 0.05	0.00 +/- 0.05	7.99	0.00
1	1	16	16.41	0.41	16.72 +/- 0.09	0.63 +/- 0.09	10.25	0.00
0	5	1000	20.47	0.00			14.31	0.00
2	3	20	24.52	4.52	24.45 +/- 0.10	4.35 +/- 0.10	17.92	0.00
6	3	55	25.54	0.00	25.78 +/- 0.10	0.00 +/- 0.10	18.38	0.00
0	4	1000	28.79	0.00			21.63	0.00
4	2	56	45.42	0.00	44.84 +/- 0.19	0.00 +/- 0.19	30.37	0.00
5	2	68	65.93	0.00	64.29 +/- 0.35	0.00 +/- 0.35	39.41	0.00
0	4	1000	69.18	0.00			42.66	0.00
7	1	150	88.49	0.00	85.65 +/- 0.50	0.00 +/- 0.50	52.37	0.00
Total				4.93		4.98 +/- 1.38		0.00

Table 14: Objective Function Results for Ku and Karimi SB, Greedy Heuristic, and Musier and Evans HIM for 7 Orders

A deterministic processing time based on queueing theory using the cutter time instead of the dehy time was also analyzed to determine which gives better results. The total tardiness estimate using the cutter time provides worse results than that of the dehy time. Therefore the dehy time was used in the total processing time for the rest of the schedule analysis.

8.2.2 Set 2: Customer Orders

The second set of customer orders consists of 20 customer orders, with a total of 528 dehy-batches, and is shown in Table 15. The results for each of the scheduling algorithms are shown and discussed in the following subsections. For this section, the improved schedule results will be presented immediately after the original schedule results.

8.2.2.1 Musier and Evans Algorithm Results

Similar to the Set 1: Customer Orders, multiple runs (9) of this scheduling algorithm were applied to the 20 customer orders to be scheduled. The schedule with the minimum total tardiness was simulated. The result for this algorithm is shown in Table 16. The remaining schedules may be found in Appendix 3.

Customer #	Product Type	Due Date	Total Dehy Batches
1	1	1	4
2	2	12	24
3	3	48	8
4	2	34	16
5	1	8	32
6	1	52	8
7	2	79	60
8	3	155	12
9	3	85	4
10	1	61	12
11	2	12	36
12	3	201	48
13	3	37	20
14	1	8	44
15	3	96	32
16	1	92	40
17	2	66	8
18	1	73	12
19	2	49	48
20	1	18	60

Table 15: Second Set of Customer Orders

The deterministic total tardiness is 1227.63 hours and the stochastic result is 1265.06 ± 4.61 hours. This means that the deterministic method is significantly underestimating the schedule's tardiness. The throughput for this schedule is on average approximately 528 batches / 209.4 hours = 2.52 dehy-batches/hour.

When HIM is applied to the Musier and Evans Algorithm, the resulting schedule is very different than the original. There was significant improvement in the tardy time. The deterministic total tardiness after HIM was applied is 479.32. The simulation indicated that the improved schedule's tardiness is 453.21 ± 5.82 hours. Table 17 shows the results of the improved Musier and Evans schedule. The throughput for this schedule is, on average, approximately 3.06 dehy-batches/hour.

The standard deviation for the original schedule is 98.51 hours. Therefore, the robustness of the schedule is 98.51% and the performance is 103.05%. The reason for the high robustness value is because the standard deviation value is significantly small compared to the deterministic function value, 1227.63. The high performance value is also contributed to the large objective function values. The standard deviation of the improved schedule is 19.93 hours; hence the robustness is 95.84% and the performance is 94.55%. The reason the standard deviation of the improved schedule is less than the standard deviation of the original schedule is because the improved schedule is closer to the optimal schedule and therefore there is less variation.

CPU Time 0 sec	Seed: 1		**Musier and Evans (Dehy Time)**		**Simulation (95 Replications)**					
Customer #	Product Type	Due Date	Finish Process Time (Hours)	Tardy (Hours)	Finish Process Time (Hours)			Tardy (Hours)		
0	4	1000	3.25	0.00						
4	2	34	9.63	0.00	10.10	+/-	0.07	0.00	+/-	0.07
0	4	1000	12.88	0.00						
6	1	52	16.81	0.00	17.11	+/-	0.03	0.00	+/-	0.03
0	4	1000	20.06	0.00						
19	2	49	34.64	0.00	33.86	+/-	0.17	0.00	+/-	0.17
0	5	1000	38.70	0.00						
3	3	48	43.77	0.00	42.73	+/-	0.08	0.00	+/-	0.08
0	4	1000	47.02	0.00						
18	1	73	51.98	0.00	50.71	+/-	0.15	0.00	+/-	0.15
0	5	1000	56.04	0.00						
12	3	201	71.37	0.00	73.45	+/-	0.12	0.00	+/-	0.12
8	3	155	74.44	0.00	77.66	+/-	0.12	0.00	+/-	0.12
15	3	96	82.65	0.00	88.66	+/-	0.12	0.00	+/-	0.12
9	3	85	83.67	0.00	90.22	+/-	0.12	5.22	+/-	0.12
0	4	1000	86.92	0.00						
1	1	1	89.83	88.83	96.2	+/-	0.12	95.20	+/-	0.12
14	1	8	101.11	93.11	106.44	+/-	0.19	98.44	+/-	0.19
5	1	8	109.31	101.31	113.83	+/-	0.25	105.83	+/-	0.25
0	4	1000	112.56	0.00						
11	2	12	124.06	112.06	127.54	+/-	0.26	115.54	+/-	0.26
2	2	12	130.22	118.22	133.37	+/-	0.31	121.37	+/-	0.31
0	4	1000	133.47	0.00						
20	1	18	150.73	132.73	152.46	+/-	0.44	134.46	+/-	0.44
0	5	1000	154.79	0.00						
13	3	37	162.94	125.94	165.4	+/-	0.36	128.40	+/-	0.36
0	4	1000	166.19	0.00						
10	1	61	171.14	110.14	173.53	+/-	0.37	112.53	+/-	0.37
0	4	1000	174.39	0.00						
17	2	66	178.72	112.72	180.72	+/-	0.38	114.72	+/-	0.38
7	2	79	194.10	115.10	194.95	+/-	0.47	115.95	+/-	0.47
0	4	1000	197.35	0.00						
16	1	92	209.4848	117.48	209.4	+/-	0.48	117.40	+/-	0.48
				1227.63				1265.06	+/-	4.61

Table 16: Objective Function Results for Musier and Evans Algorithm for 20 Orders

CPU Time 0.06 sec	Seed: 1		HIM for Musier and Evans (Dehy Time)		Simulation (119 Replications)	
Customer #	Product Type	Due Date	Finish Process Time (Hours)	Tardy (Hours)	Finish Process Time (Hours)	Tardy (Hours)
0	4	1000	3.25	0.00		
1	1	1	6.16	5.16	7.20 +/- 0.02	6.20 +/- 0.02
5	1	8	14.36	6.36	14.71 +/- 0.05	6.71 +/- 0.05
14	1	8	25.64	17.64	24.86 +/- 0.11	16.86 +/- 0.11
20	1	18	41.02	23.02	38.84 +/- 0.20	20.84 +/- 0.20
10	1	61	44.09	0.00	41.62 +/- 0.22	0.00 +/- 0.22
6	1	52	46.14	0.00	43.52 +/- 0.22	0.00 +/- 0.22
18	1	73	49.22	0.00	46.29 +/- 0.27	0.00 +/- 0.27
0	4	1000	52.47	0.00		
4	2	34	58.85	24.85	55.26 +/- 0.26	21.26 +/- 0.26
2	2	12	65.00	53.00	60.98 +/- 0.28	48.98 +/- 0.28
17	2	66	67.05	1.05	62.88 +/- 0.32	0.00 +/- 0.32
0	5	1000	71.11	0.00		
3	3	48	76.18	28.18	71.78 +/- 0.30	23.78 +/- 0.30
13	3	37	81.31	44.31	78.79 +/- 0.30	41.79 +/- 0.30
9	3	85	82.34	0.00	80.05 +/- 0.30	0.00 +/- 0.30
15	3	96	90.54	0.00	91.19 +/- 0.31	0.00 +/- 0.31
0	4	1000	93.79	0.00		
11	2	12	105.29	93.29	105.15 +/- 0.33	93.15 +/- 0.33
19	2	49	117.60	68.60	116.54 +/- 0.38	67.54 +/- 0.38
7	2	79	132.98	53.98	130.84 +/- 0.44	51.84 +/- 0.44
0	4	1000	136.23	0.00		
16	1	92	148.36	56.36	145.52 +/- 0.55	53.52 +/- 0.55
0	5	1000	152.43	0.00		
8	3	155	158.52	3.52	155.73 +/- 0.48	0.73 +/- 0.48
12	3	201	170.82	0.00	172.73 +/- 0.48	0.00 +/- 0.48
				479.32		453.21 +/- 5.82

Table 17: Objective Function Results for HIM: Musier and Evans Algorithm for 20 Orders

8.2.2.2 Ku and Karimi Sequence Building Algorithm Results

The result for this algorithm is shown in Table 18. The deterministic total tardiness is 436.22 hours and the stochastic result is 428.76 ± 5.22 hours. This means that the deterministic method is within the range where the schedule's true tardiness may fall. The throughput for this schedule is on average approximately 3.02 dehy-batches/hour.

When HIM is applied to Ku and Karimi SB, the resulting schedule is very similar to the original. Only 3 customer orders were interchanged, all of which remained in the same cluster of jobs. Therefore, the deterministic total tardiness, 436.22 hours, remained the same as before.

The simulation indicated that the improved schedule's tardiness is 423.63 ± 5.16 hours. Table 19 shows the results of the improved Ku and Karimi SB schedule. The throughput for this schedule is on average approximately 3.02 dehy-batches/hour.

CPU Time 0 sec			**Ku and Karimi (Dehy Time)**		**Simulation (316 Replications)**	
Customer #	Product Type	Due Date	Finish Process Time (Hours)	Tardy (Hours)	Finish Process Time (Hours)	Tardy (Hours)
0	4	1000	3.25	0.00		
1	1	1	6.16	5.16	7.21 +/- 0.01	6.21 +/- 0.01
5	1	8	14.36	6.36	14.84 +/- 0.05	6.84 +/- 0.05
14	1	8	25.64	17.64	25.25 +/- 0.11	17.25 +/- 0.11
18	1	73	28.71	0.00	28.14 +/- 0.12	0.00 +/- 0.12
10	1	61	31.79	0.00	31.02 +/- 0.14	0.00 +/- 0.14
6	1	52	33.84	0.00	32.98 +/- 0.18	0.00 +/- 0.18
0	4	1000	37.09	0.00		
4	2	34	43.47	9.47	42.06 +/- 0.17	8.06 +/- 0.17
2	2	12	49.62	37.62	47.94 +/- 0.19	35.94 +/- 0.19
11	2	12	58.85	46.85	56.64 +/- 0.23	44.64 +/- 0.23
17	2	66	60.90	0.00	58.52 +/- 0.24	0.00 +/- 0.24
19	2	49	73.20	24.20	70.21 +/- 0.32	21.21 +/- 0.32
0	5	1000	77.27	0.00		0.00
3	3	48	82.34	34.34	79.20 +/- 0.29	31.20 +/- 0.29
9	3	85	83.36	0.00	80.53 +/- 0.29	0.00 +/- 0.29
13	3	37	88.49	51.49	87.75 +/- 0.30	50.75 +/- 0.30
15	3	96	96.69	0.69	98.98 +/- 0.29	2.98 +/- 0.29
0	4	1000	99.94	0.00		
16	1	92	112.08	20.08	113.62 +/- 0.35	21.62 +/- 0.35
20	1	18	127.46	109.46	128.02 +/- 0.44	110.02 +/- 0.44
0	4	1000	130.71	0.00		0.00
7	2	79	148.36	69.36	147.88 +/- 0.52	68.88 +/- 0.52
0	5	1000	152.43	0.00		
8	3	155	158.52	3.52	158.16 +/- 0.49	3.16 +/- 0.49
12	3	201	170.82	0.00	175.02 +/- 0.50	0.00 +/- 0.50
Total				436.22		428.76 +/- 5.22

Table 18: Objective Function Results for Ku and Karimi SB for 20 Orders

The standard deviation for the original schedule is 34.00 hours. Therefore, the robustness of the schedule is 92.21% and the performance is 98.29%. The standard deviation of the improved schedule is 5.16 hours; hence the robustness is 93.43% and the performance is 97.11%.

CPU Time 0.021 sec			HIM for Ku and Karimi (Dehy Time)		Simulation (233 Replications)	
Customer #	Product Type	Due Date	Finish Process Time (Hours)	Tardy (Hours)	Finish Process Time (Hours)	Tardy (Hours)
0	4	1000	3.25	0.00		
1	1	1	6.16	5.16	7.22 +/- 0.01	6.22 +/- 0.01
5	1	8	14.36	6.36	14.80 +/- 0.05	6.80 +/- 0.05
14	1	8	25.64	17.64	25.10 +/- 0.11	17.10 +/- 0.11
6	1	52	27.69	0.00	27.11 +/- 0.12	0.00 +/- 0.12
18	1	73	30.76	0.00	29.85 +/- 0.14	0.00 +/- 0.14
10	1	61	33.84	0.00	32.77 +/- 0.18	0.00 +/- 0.18
0	4	1000	37.09	0.00		
4	2	34	43.47	9.47	41.78 +/- 0.17	7.78 +/- 0.17
2	2	12	49.62	37.62	47.60 +/- 0.19	35.60 +/- 0.19
11	2	12	58.85	46.85	56.28 +/- 0.22	44.28 +/- 0.22
17	2	66	60.90	0.00	58.18 +/- 0.23	0.00 +/- 0.23
19	2	49	73.20	24.20	69.95 +/- 0.32	20.95 +/- 0.32
0	5	1000	77.27	0.00		
3	3	48	82.34	34.34	78.81 +/- 0.28	30.81 +/- 0.28
9	3	85	83.36	0.00	80.15 +/- 0.28	0.00 +/- 0.28
13	3	37	88.49	51.49	87.33 +/- 0.28	50.33 +/- 0.28
15	3	96	96.69	0.69	98.53 +/- 0.29	2.53 +/- 0.29
0	4	1000	99.94	0.00		
16	1	92	112.08	20.08	113.16 +/- 0.35	21.16 +/- 0.35
20	1	18	127.46	109.46	127.39 +/- 0.46	109.39 +/- 0.46
0	4	1000	130.71	0.00		
7	2	79	148.36	69.36	147.07 +/- 0.51	68.07 +/- 0.51
0	5	1000	152.43	0.00		
8	3	155	158.52	3.52	157.59 +/- 0.49	2.59 +/- 0.49
12	3	201	170.82	0.00	174.55 +/- 0.49	0.00 +/- 0.49
Total				436.22		423.63 +/- 5.16

Table 19: Objective Function Results for HIM: Ku and Karimi SB for 20 Orders

8.2.2.3 Greedy Heuristic Results

The deterministic total tardiness is 978.67 hours and the stochastic result is 935.25 $\pm$ 7.05 hours. This means that the deterministic method is not within the range where the schedule's true tardiness may fall. The result for the initial Greedy Heuristic schedule is shown in Table 20. The throughput for this schedule is on average approximately 2.49 dehy-batches/hour.

CPU Time 0 sec			Greedy Heuristic (Dehy Time)		Simulation (237 Replications)					
Customer #	Product Type	Due Date	Finish Process Time (Hours)	Tardy (Hours)	Finish Process Time (Hours)			Tardy (Hours)		
0	4	1000	3.25	0.00						
1	1	1	6.16	5.16	7.16	+/-	0.01	6.16	+/-	0.01
14	1	8	17.44	9.44	17.52	+/-	0.07	9.52	+/-	0.07
5	1	8	25.64	17.64	25.06	+/-	0.14	17.06	+/-	0.14
0	4	1000	28.89	0.00						
11	2	12	40.39	28.39	39.33	+/-	0.20	27.33	+/-	0.20
2	2	12	46.55	34.55	45.12	+/-	0.22	33.12	+/-	0.22
0	4	1000	49.80	0.00						
20	1	18	67.06	49.06	64.42	+/-	0.31	46.42	+/-	0.31
0	4	1000	70.31	0.00			0.32			0.32
4	2	34	76.69	42.69	73.56	+/-	0.29	39.56	+/-	0.29
0	5	1000	80.75	0.00						
13	3	37	88.89	51.89	86.79	+/-	0.29	49.79	+/-	0.29
3	3	48	90.94	42.94	89.62	+/-	0.36	41.62	+/-	0.36
0	4	1000	94.19	0.00						
19	2	49	108.78	59.78	106.57	+/-	0.35	57.57	+/-	0.35
0	4	1000	112.03	0.00						
6	1	52	115.96	63.96	113.56	+/-	0.39	61.56	+/-	0.39
10	1	61	119.03	58.03	116.49	+/-	0.38	55.49	+/-	0.38
0	4	1000	122.28	0.00						
17	2	66	126.61	60.61	123.54	+/-	0.41	57.54	+/-	0.41
0	4	1000	129.86	0.00						
18	1	73	134.82	61.82	131.58	+/-	0.45	58.58	+/-	0.45
0	4		138.07	0.00						
7	2	79	155.73	76.73	151.27	+/-	0.44	72.27	+/-	0.44
0	5	1000	159.79	0.00						
9	3	85	163.83	78.83	158.9	+/-	0.44	73.90	+/-	0.44
0	4		167.08	0.00						
16	1	92	179.22	87.22	173.51	+/-	0.51	81.51	+/-	0.51
0	5	1000	183.28	0.00						
15	3	96	194.50	98.50	190.92	+/-	0.49	94.92	+/-	0.49
8	3	155	197.58	42.58	195.15	+/-	0.49	40.15	+/-	0.49
12	3	201	209.88	8.88	212.18	+/-	0.49	11.18	+/-	0.49
Total				978.67				935.25	+/-	7.05

Table 20: Objective Function Results for Greedy Heuristic for 20 Orders

When HIM is applied to the Greedy Heuristic, the resulting schedule's tardiness is half as much as the original schedule's tardiness. The deterministic total tardiness is 453.81 hours. The simulation indicated that the improved schedule's tardiness is 452.63 ± 4.74 hours. Table 21 shows the results of the improved Greedy Heuristic schedule. The throughput for this schedule is on average approximately 2.92 dehy-batches/hour.

The standard deviation for the original schedule is 7.05 hours. Therefore, the robustness of the schedule is 94.78% and the performance is 95.56%. The standard deviation of the improved schedule is 4.74 hours; hence the robustness is 94.63% and the performance is 99.74%.

CPU Time 0.06 sec			HIM for Greedy Heuristic (Dehy Time)		Simulation (315 Replications)					
Customer #	Product Type	Due Date	Finish Process Time (Hours)	Tardy (Hours)	Finish Process Time (Hours)			Tardy (Hours)		
0	4	1000	3.25	0.00						
2	2	12	11.68	0.00	12.16	+/-	0.30	0.16	+/-	0.30
11	2	12	20.91	8.91	20.92	+/-	0.06	8.92	+/-	0.06
4	2	34	25.01	0.00	24.80	+/-	0.08	0.00	+/-	0.08
17	2	66	27.06	0.00	26.92	+/-	0.15	0.00	+/-	0.15
0	5	1000	31.12	0.00						
13	3	37	39.27	2.27	40.03	+/-	0.09	3.03	+/-	0.09
9	3	85	40.29	0.00	41.54	+/-	0.10	0.00	+/-	0.10
3	3	48	42.34	0.00	44.30	+/-	0.09	0.00	+/-	0.09
0	4	1000	45.59	0.00						
1	1	1	48.50	47.50	50.42	+/-	0.10	49.42	+/-	0.10
6	1	52	50.55	0.00	52.34	+/-	0.11	0.34	+/-	0.11
5	1	8	58.75	50.75	59.94	+/-	0.15	51.94	+/-	0.15
10	1	61	61.83	0.83	62.77	+/-	0.17	1.77	+/-	0.17
18	1	73	64.91	0.00	65.57	+/-	0.18	0.00	+/-	0.18
14	1	8	76.18	68.18	75.98	+/-	0.24	67.98	+/-	0.24
16	1	92	86.44	0.00	85.51	+/-	0.31	0.00	+/-	0.31
0	4	1000	89.69	0.00						
19	2	49	104.27	55.27	102.23	+/-	0.34	53.23	+/-	0.34
7	2	79	119.65	40.65	116.8	+/-	0.44	37.80	+/-	0.44
0	5	1000	123.71	0.00						
15	3	96	134.93	38.93	134.14	+/-	0.41	38.14	+/-	0.41
8	3	155	138.01	0.00	138.35	+/-	0.41	0.00	+/-	0.41
0	4	1000	141.26	0.00						
20	1	18	158.52	140.52	157.9	+/-	0.52	139.90	+/-	0.52
0	5	1000	162.58	0.00						
12	3	201	177.91	0.00	180.87	+/-	0.49	0.00	+/-	0.49
Total				453.81				452.63	+/-	4.74

Table 21: Objective Function Results for HIM: Greedy Heuristic for 20 Orders

8.3 Comparison and Analysis

This section will summarize the results. First, all the data will be compared based on face value. Then Multiple Comparison with the Best will be applied to help determine which of the scheduling algorithms provides the overall best results for the objective function value, robustness, performance, required computing time, required simulation time, and throughput.

8.3.1 Comparison

Table 22 summarizes the results for the first set of customer orders. It should be noted that although the Musier and Evans Algorithm is more robust than the other algorithms and requires significantly fewer replications, it has a lower throughput rate and significantly higher number of tardy hours. The required CPU time, based on the throughput rate and the number of replications, required to generate enough simulation replications is not a very significant factor for such a small number customer orders. However it is more significant in the second set of customer orders.

	Total Tardy Hours						
Algorithm	Deterministic	Stochastic	Standard Deviation	# Reps	Scheduling CPU Time (sec)	Robustness (%)	Performance (%)
Musier & Evans (Schedule w/ minimum tardiness)	159.28	157.66 +/- 1.41	1.57	50	0	99.01	98.98
Ku and Karimi, Greedy, and HIM	4.93	4.98 +/- 1.38	3.78	134	0	23.33	101.01

Table 22: Summary of Results for Set 1: Customer Orders

Table 23 summarizes the results for the second set of customer orders. This set of customer orders has approximately three times as many orders as the first set of customer orders and therefore requires more time to schedule and simulate. Musier and Evans Algorithm once again is the most robust and requires the fewest number of replications, however it has the highest number of tardy hours, 1227.63 hours. In all cases, the HIM was able to improve the original schedules. The better the initial schedule, the less time it took to generate the improved schedule. The comparison of the robustness and performance will be discussed in the next section.

	Total Tardy Hours						
Algorithm	Deterministic	Stochastic	Standard Deviation	# Reps	Scheduling CPU Time (sec)	Robustness (%)	Performance (%)
Musier & Evans	1227.63	1265.06 +/- 4.61	18.26	95	0	98.51	103.05
Ku & Karimi	436.22	428.76 +/- 5.22	34.00	316	0	92.21	98.29
Greedy	978.67	935.25 +/- 7.05	51.05	237	0	94.78	95.56
HIM-Musier & Evans	479.32	453.21 +/- 5.82	19.93	119	0.06	95.84	94.55
HIM-Ku & Karimi	436.22	423.63 +/- 5.16	28.64	233	0.021	93.43	97.11
HIM-Greedy	453.81	452.63 +/- 4.74	24.38	315	0.06	94.63	99.74

Table 23: Summary of Results for Set 2: Customer Orders

Set	Schedule	Original Schedule Throughput	Improved Schedule Throughput	% Improved
1	Musier and Evans	2.8	2.99	0.068
	Ku and Karimi, Greedy, HIM	2.99	2.99	0.000
2	Musier and Evans	2.52	3.06	0.214
	Ku and Karimi	3.02	3.02	0.000
	Greedy Heuristic	2.49	2.92	0.173

Table 24: Summary of Throughput

The algorithm with the most improvement when HIM is applied to it is the Musier and Evans Algorithm. This is because it has the worse initial results; it should be noted that the throughput for the improved Musier and Evans Algorithm is the greatest value.

8.3.2 Multiple Comparison with the Best Results

Five techniques, Quantile-Quantile Plot, Histogram Plot, Chi-square Test, Kolmogorov-Smirnov Test, and Anderson-Darling Test were used to test the simulation results for normality. The majority of the tests for normality indicated that the results for each of the schedules were normally distributed, i.e., the p-values were all greater than 0.65. Therefore, MCB may be applied to determine the best scenario.

Table 25 summarizes the final overall sample average of total schedule processing time for each set of customer orders for each scheduling algorithm. The best scheduling algorithm is the one with the lowest overall average. Therefore MCB indicates that, for Set 1, Ku and Karimi Sequence Building Algorithm, Greedy Heuristic and Musier and Evans HIM are better than Musier and Evans Algorithm and Musier and Evans Algorithm is the best for Set 2. Therefore the CI for Set 1 is ±(85.6 – 94.63 – 1) = ±10.03 and ±39.57 for Set 2.

Set	Schedule	Original Schedule Overall Average	Improved Schedule Overall Average
1	Musier and Evans	94.63	85.6
	Ku and Karimi, Greedy, HIM	85.6	85.6
2	Musier and Evans	209.42	172.18
	Ku and Karimi	175.42	173.77
	Greedy Heuristic	210.75	181.07

Table 25: Multiple Comparison with the Best of Schedule Processing Time Results

8.4 Conclusion

The research presented in this paper focused on three heuristic scheduling algorithms, and one improvement method. The Musier and Evans Scheduling Algorithm schedules customer orders by first assigning a random number to each of the customer orders and then determining if the order can be processed on time. Customer orders that cannot be processed on-time are then scheduled by earliest-due-date. For this scheduling algorithm, it was necessary to perform multiple runs to increase the probability of finding the best schedule. The Ku and Karimi Sequence Building scheduling algorithm first sorts the customer orders by earliest-due-date and then determines if the orders can be processed on-time. If an order cannot be processed on time, then it is placed at the bottom of the scheduling sequence. The Greedy Heuristic simply schedules all the orders by earliest-due-date. Finally, Musier and Evans' Heuristic Improvement Method (HIM) takes the existing schedule and performs a 1-optimal and 2-optimal method to make a new schedule that is either better than or the same as the original schedule. The schedules' performances were tested using a discrete-event simulation model. The simulation model accounted for product type dependent processing and changeover times. It models an ideal work environment, i.e., breakdown and breaks were not considered.

Based on the MCB results, the best scheduling algorithms are Musier and Evans Algorithm for Set 1 and the improved Musier and Evans Algorithm for Set 2. Unfortunately MCB does not consider the other comparison factors; it only compares the overall schedule processing times. When considering just the objective function value, total tardiness, all schedules developed with the Musier and Evans Algorithm, including the improved schedules, should be rejected as being the best because it has the highest number of tardy hours. The Musier and Evans Algorithm also requires multiple runs in order to increase the probability of finding a good schedule.

By eliminating all the schedules related to Musier and Evans Algorithm, Set 1 does not provide any useful information as to which of the remaining schedules should be selected as the best, since they all provided the optimal schedule in the same amount of time. Therefore, by referring to Table 25: Set 2, the second best schedule is the improved Ku and Karimi SB Algorithm. The Ku and Karimi SB schedules, both the original and the improved, have the fewest tardy hours. But, the Greedy Heuristic is the most robust (precise) and has the best performance (most accurate). However, it takes slightly longer to develop the improved Greedy Heuristic schedule. The Ku and Karimi schedule has the best throughput rate. In conclusion, for a small set of customer orders, it does not make much difference which of the scheduling algorithms is used. However for larger numbers of customer orders, the best of the scheduling algorithm is Ku and Karimi SB Algorithm with Musier and Evans HIM applied to it.

8.5 Future Research

The research presented in this paper has focused on the modification of several theoretical scheduling algorithms to fit a production line generalized serial network and has applied these modified theoretical algorithms to a real world plant to evaluate their performances. Future research should compare other types of scheduling algorithms, such as mixed integer linear/nonlinear programming and simulated annealing, and to develop scheduling algorithms specifically for a generalized serial network. Schedules with more customer orders should be examined to further determine the benefits of Musier and Evans Heuristic Improvement Method.

Other research should examine the performance of these scheduling algorithms with a simulation model that accounts for machine breakdowns and worker breaks. The chemical plant used in this research allows for only one product to be produced at any given time. An interesting area for research is to investigate the scheduling method for a chemical plant where multiple products are simultaneously produced.

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APPENDIX

APPENDIX 1: RANDOM NUMBER GENERATORS

The built-in random number generators in Microsoft Visual C++ 5.0 and ProModel 4.1 were used in this research to generate the random numbers used by Musier and Evans' scheduling algorithm and in the simulation model for the machine and LUT times, respectively. The two random number generators were tested to see if they provide uniform and independent random numbers. The Chi-square Goodness-of-Fit Test was used to test for uniformity and the Runs Up and Down Test was used to test for independence. For the goodness-of-fit test, it is hypothesized that the random numbers are uniform. For the runs up and down test, it is hypothesized that the random numbers are independent. True random numbers have an expected value and variance values of $\frac{1}{2}$ and $\frac{1}{12}$, respectively (Banks, Carson, and Nelson 1996).

For both generators, 35 replications were collected and each replication consisted of 1000 random numbers. First the average and variance of each replication was determined and then the averages of both values were calculated. The calculated values were then compared to the expected values. The True Values fall within the 95% Confidence Intervals for both random number generators, so the tests for uniformity and independence were conducted. The results were as follows:

		Expected Value	Variance Value	Chi-square Goodness of Fit Test ($\chi^2_{24,0.025}$)	Runs Up and Down Test ($Z_{0.025}$)
True Values		$\frac{1}{2}$	$\frac{1}{12}$	39.4	1.96
95 % Confidence Interval	Microsoft Visual C++	0.400-0.591	0.082-0.084	26.43-32.28	0.78-1.54
	Promodel 4.1	0.397-0.588	0.082-0.084	25.57-30.35	0.52-1.26

Table 26: Results from Random Number Generator Tests

For both the uniformity and independence tests, the True Values (expected values) are greater than the 95% Confidence Intervals. This indicates that the goodness of fit test failed to reject the hypothesis that the random numbers are uniform and the runs up and down test fails to reject the hypothesis that the random numbers are independent. With 95% confidence the random number generators provide independent values.

APPENDIX 2: MUSIER AND EVANS SCHEDULING ALGORITHM RESULTS FOR SET 1: CUSTOMER ORDERS

CPU Time 0 sec — **seed = 1** — **Musier and Evans**

Customer #	Product Type	Due Date	Finish Process Time (Hours)	Tardy (Hours)
0	4	1000	3.25	0.00
4	2	56	19.88	0.00
0	5	1000	23.94	0.00
6	3	55	27.99	0.00
0	4	1000	31.24	0.00
5	2	68	54.02	0.00
0	4	1000	57.27	0.00
7	1	150	76.58	0.00
3	1	13	82.74	69.74
1	1	16	87.86	71.86
0	5	1000	91.93	0.00
2	3	20	95.97	75.97
Total				217.57

CPU Time 0 sec — **seed = 33** — **Musier and Evans**

Customer #	Product Type	Due Date	Finish Process Time (Hours)	Tardy (Hours)
0	5	1000	4.06	0.00
6	3	55	8.11	0.00
0	4	1000	11.36	0.00
5	2	68	34.14	0.00
0	4	1000	37.39	0.00
7	1	150	56.70	0.00
3	1	13	62.85	49.85
1	1	16	67.98	51.98
0	5	1000	72.04	0.00
2	3	20	76.09	56.09
0	4	1000	79.34	0.00
4	2	56	95.97	39.97
Total				197.89

CPU Time 0 sec — **seed = 15** — **Musier and Evans**

Customer #	Product Type	Due Date	Finish Process Time (Hours)	Tardy (Hours)
0	4	1000	3.25	0.00
5	2	68	26.03	0.00
4	2	56	40.39	0.00
0	5	1000	44.45	0.00
6	3	55	48.50	0.00
0	4	1000	51.75	0.00
7	1	150	71.06	0.00
3	1	13	77.21	64.21
1	1	16	82.34	66.34
0	5	1000	86.40	0.00
2	3	20	90.44	70.44
Total				200.99

CPU Time 0 sec — **seed = 78** — **Musier and Evans**

Customer #	Product Type	Due Date	Finish Process Time (Hours)	Tardy (Hours)
0	4	1000	3.25	0.00
3	1	13	11.28	0.00
0	4	1000	14.53	0.00
5	2	68	37.32	0.00
0	4	1000	40.57	0.00
7	1	150	59.88	0.00
1	1	16	65.01	49.01
0	5	1000	69.07	0.00
2	3	20	73.11	53.11
6	3	55	74.14	19.14
0	4	1000	77.39	0.00
4	2	56	94.02	38.02
Total				159.28

CPU Time 0 sec	**seed = 62**		**Musier and Evans**	
Customer #	Product Type	Due Date	Finish Process Time (Hours)	Tardy (Hours)
0	4	1000	3.25	0.00
4	2	56	19.88	0.00
0	4	1000	23.13	0.00
7	1	150	42.44	0.00
0	5	1000	46.51	0.00
6	3	55	50.55	0.00
0	4	1000	53.80	0.00
3	1	13	61.83	48.83
1	1	16	66.96	50.96
0	5	1000	71.02	0.00
2	3	20	75.07	55.07
0	4	1000	78.32	0.00
5	2	68	101.10	33.10
Total				187.96

CPU Time 0 sec	**seed = 8**		**Musier and Evans**	
Customer #	Product Type	Due Date	Finish Process Time (Hours)	Tardy (Hours)
0	4	1000	3.25	0.00
4	2	56	19.88	0.00
5	2	68	40.39	0.00
0	5	1000	44.45	0.00
6	3	55	48.50	0.00
0	4	1000	51.75	0.00
7	1	150	71.06	0.00
3	1	13	77.21	64.21
1	1	16	82.34	66.34
0	5	1000	86.40	0.00
2	3	20	90.44	70.44
Total				200.99

APPENDIX 3: MUSIER AND EVANS SCHEDULING ALGORITHM RESULTS FOR SET 2: CUSTOMER ORDERS

CPU Time 0 sec — Seed: 86

Customer #	Product Type	Due Date	Musier and Evans (Dehy Time) Finish Process Time (Hours)	Tardy (Hours)
0	4	1000	3.25	0.00
6	1	52	7.18	0.00
0	5	1000	11.24	0.00
8	3	155	17.34	0.00
15	3	96	25.54	0.00
0	4	1000	28.79	0.00
18	1	73	33.75	0.00
0	5	1000	37.81	0.00
9	3	85	41.86	0.00
0	4	1000	45.11	0.00
17	2	66	49.43	0.00
0	4	1000	52.68	0.00
16	1	92	64.82	0.00
0	5	1000	68.88	0.00
12	3	201	84.20	0.00
0	4	1000	87.45	0.00
1	1	1	90.36	89.36
14	1	8	101.64	93.64
5	1	8	109.84	101.84
0	4	1000	113.09	0.00
11	2	12	124.60	112.60
2	2	12	130.75	118.75
0	4	1000	134.00	0.00
20	1	18	151.26	133.26
0	4	1000	154.51	0.00
4	2	34	160.89	126.89
0	5	1000	164.95	0.00
13	3	37	173.10	136.10
3	3	48	175.15	127.15
0	4	1000	178.40	0.00
19	2	49	192.98	143.98
0	4	1000	196.23	0.00
10	1	61	201.19	140.19
0	4	1000	204.44	0.00
7	2	79	222.09	143.09
Total				1466.84

CPU Time 0 sec — Seed: 7

Customer #	Product Type	Due Date	Musier and Evans (Dehy Time) Finish Process Time (Hours)	Tardy (Hours)
0	5	1000	4.06	0.00
12	3	201	19.39	0.00
0	4	1000	22.64	0.00
19	2	49	37.22	0.00
0	5	1000	41.28	0.00
3	3	48	46.35	0.00
0	4	1000	49.60	0.00
16	1	92	61.73	0.00
0	5	1000	65.80	0.00
9	3	85	69.84	0.00
15	3	96	78.04	0.00
8	3	155	81.12	0.00
0	4	1000	84.37	0.00
1	1	1	87.28	86.28
14	1	8	98.55	90.55
5	1	8	106.76	98.76
0	4	1000	110.01	0.00
11	2	12	121.51	109.51
2	2	12	127.66	115.66
0	4	1000	130.91	0.00
20	1	18	148.18	130.18
0	4	1000	151.43	0.00
4	2	34	157.80	123.80
0	5	1000	161.87	0.00
13	3	37	170.01	133.01
0	4	1000	173.26	0.00
6	1	52	177.19	125.19
10	1	61	180.27	119.27
0	4	1000	183.52	0.00
17	2	66	187.85	121.85
0	4	1000	191.10	0.00
18	1	73	196.06	123.06
0	4	1000	199.31	0.00
7	2	79	216.9625	137.96
Total				1515.08

CPU Time 0 sec	Seed: 10		Musier and Evans (Dehy Time)	
Customer #	Product Type	Due Date	Finish Process Time (Hours)	Tardy (Hours)
0	4	1000	3.25	0.00
19	2	49	17.83	0.00
0	5	1000	21.89	0.00
8	3	155	27.99	0.00
0	4	1000	31.24	0.00
7	2	79	48.90	0.00
0	5	1000	52.96	0.00
9	3	85	57.00	0.00
0	4	1000	60.25	0.00
18	1	73	65.21	0.00
0	5	1000	69.27	0.00
12	3	201	84.60	0.00
15	3	96	92.80	0.00
0	4	1000	96.05	0.00
1	1	1	98.95	97.95
14	1	8	110.23	102.23
5	1	8	118.44	110.44
0	4	1000	121.69	0.00
11	2	12	133.19	121.19
2	2	12	139.34	127.34
0	4	1000	142.59	0.00
20	1	18	159.85	141.85
0	4	1000	163.10	0.00
4	2	34	169.48	135.48
0	5	1000	173.55	0.00
13	3	37	181.69	144.69
3	3	48	183.74	135.74
0	4	1000	186.99	0.00
6	1	52	190.92	138.92
10	1	61	194.00	133.00
0	4	1000	197.25	0.00
17	2	66	201.58	135.58
0	4	1000	204.83	0.00
16	1	92	216.9625	124.96
Total				1649.40

CPU Time 0 sec	Seed: 24		Musier and Evans (Dehy Time)	
Customer #	Product Type	Due Date	Finish Process Time (Hours)	Tardy (Hours)
0	4	1000	3.25	0.00
4	2	34	9.63	0.00
0	5	1000	13.69	0.00
9	3	85	17.74	0.00
0	4	1000	20.99	0.00
7	2	79	38.64	0.00
0	4	1000	41.89	0.00
10	1	61	46.85	0.00
6	1	52	48.90	0.00
18	1	73	51.98	0.00
16	1	92	62.23	0.00
0	5	1000	66.29	0.00
12	3	201	81.62	0.00
15	3	96	89.82	0.00
8	3	155	92.89	0.00
0	4	1000	96.14	0.00
1	1	1	99.05	98.05
5	1	8	107.25	99.25
14	1	8	118.53	110.53
0	4	1000	121.78	0.00
11	2	12	133.29	121.29
2	2	12	139.44	127.44
0	4	1000	142.69	0.00
20	1	18	159.95	141.95
0	5	1000	164.01	0.00
13	3	37	172.16	135.16
3	3	48	174.21	126.21
0	4	1000	177.46	0.00
19	2	49	192.04	143.04
17	2	66	194.09	128.09
Total				1231.01

CPU Time 0 sec	seed: 63		Musier and Evans (Dehy Time)	
Customer #	Product Type	Due Date	Finish Process Time (Hours)	Tardy (Hours)
0	5	1000	4.06	0.00
9	3	85	8.11	0.00
0	4	1000	11.36	0.00
6	1	52	15.29	0.00
0	5	1000	19.35	0.00
8	3	155	25.45	0.00
0	4	1000	28.70	0.00
17	2	66	33.02	0.00
0	5	1000	37.09	0.00
15	3	96	48.31	0.00
0	4	1000	51.56	0.00
18	1	73	56.52	0.00
10	1	61	59.59	0.00
0	5	1000	63.65	0.00
12	3	201	78.98	0.00
0	4	1000	82.23	0.00
1	1	1	85.13	84.13
5	1	8	93.34	85.34
14	1	8	104.61	96.61
0	4	1000	107.86	0.00
11	2	12	119.37	107.37
2	2	12	125.52	113.52
0	4	1000	128.77	0.00
20	1	18	146.03	128.03
0	4	1000	149.28	0.00
4	2	34	155.66	121.66
0	5	1000	159.72	0.00
13	3	37	167.87	130.87
3	3	48	169.92	121.92
0	4	1000	173.17	0.00
19	2	49	187.75	138.75
7	2	79	203.13	124.13
0	4	1000	206.38	0.00
16	1	92	218.5167	126.52
Total				1378.86

CPU Time 0 sec	Seed: 74		Musier and Evans (Dehy Time)	
Customer #	Product Type	Due Date	Finish Process Time (Hours)	Tardy (Hours)
0	4	1000	3.25	0.00
7	2	79	20.91	0.00
0	5	1000	24.97	0.00
13	3	37	33.12	0.00
0	4	1000	36.37	0.00
10	1	61	41.32	0.00
0	5	1000	45.39	0.00
15	3	96	56.61	0.00
12	3	201	68.91	0.00
8	3	155	71.99	0.00
0	4	1000	75.24	0.00
16	1	92	87.37	0.00
1	1	1	88.40	87.40
5	1	8	96.60	88.60
14	1	8	107.88	99.88
0	4	1000	111.13	0.00
2	2	12	119.56	107.56
11	2	12	128.79	116.79
0	4	1000	132.04	0.00
20	1	18	149.30	131.30
0	4	1000	152.55	0.00
4	2	34	158.93	124.93
0	5	1000	162.99	0.00
3	3	48	168.06	120.06
0	4	1000	171.31	0.00
19	2	49	185.89	136.89
0	4	1000	189.14	0.00
6	1	52	193.07	141.07
0	4	1000	196.32	0.00
17	2	66	200.65	134.65
0	4	1000	203.90	0.00
18	1	73	208.86	135.86
0	5	1000	212.92	0.00
9	3	85	216.96	131.96
Total				1556.92

CPU Time 0 sec — seed: 18

Customer #	Product Type	Due Date	Musier and Evans (Dehy Time) Finish Process Time (Hours)	Tardy (Hours)
0	5	1000	4.06	0.00
3	3	48	9.13	0.00
0	4	1000	12.38	0.00
7	2	79	30.04	0.00
0	4	1000	33.29	0.00
16	1	92	45.42	0.00
6	1	52	47.47	0.00
0	5	1000	51.54	0.00
9	3	85	55.58	0.00
0	4	1000	58.83	0.00
17	2	66	63.16	0.00
0	4	1000	66.41	0.00
18	1	73	71.37	0.00
0	5	1000	75.43	0.00
8	3	155	81.52	0.00
15	3	96	89.73	0.00
12	3	201	102.03	0.00
0	4	1000	105.28	0.00
1	1	1	108.19	107.19
14	1	8	119.47	111.47
5	1	8	127.67	119.67
0	4	1000	130.92	0.00
2	2	12	139.35	127.35
11	2	12	148.58	136.58
0	4	1000	151.83	0.00
20	1	18	169.09	151.09
0	4	1000	172.34	0.00
4	2	34	178.72	144.72
0	5	1000	182.78	0.00
13	3	37	190.92	153.92
0	4	1000	194.17	0.00
19	2	49	208.76	159.76
0	4	1000	212.01	0.00
10	1	61	216.96	155.96
Total				1367.69

CPU Time 0 sec — Seed: 97

Customer #	Product Type	Due Date	Musier and Evans (Dehy Time) Finish Process Time (Hours)	Tardy (Hours)
0	4	1000	3.25	0.00
17	2	66	7.58	0.00
19	2	49	19.88	0.00
0	4	1000	23.13	0.00
6	1	52	27.06	0.00
0	5	1000	31.13	0.00
9	3	85	35.17	0.00
0	4	1000	38.42	0.00
16	1	92	50.56	0.00
0	4	1000	53.81	0.00
7	2	79	71.46	0.00
0	5	1000	75.53	0.00
12	3	201	90.85	0.00
8	3	155	93.92	0.00
0	4	1000	97.17	0.00
1	1	1	100.08	99.08
14	1	8	111.36	103.36
5	1	8	119.56	111.56
0	4	1000	122.81	0.00
2	2	12	131.24	119.24
11	2	12	140.47	128.47
0	4	1000	143.72	0.00
20	1	18	160.98	142.98
0	4	1000	164.23	0.00
4	2	34	170.61	136.61
0	5	1000	174.67	0.00
13	3	37	182.82	145.82
3	3	48	184.87	136.87
0	4	1000	188.12	0.00
10	1	61	193.08	132.08
18	1	73	196.15	123.15
0	5	1000	200.21	0.00
15	3	96	211.44	115.44
Total				1494.65