Chapter 6 — Simulation Experiments

In this Chapter we compare several scheduling policies, *i.e.* release and dispatching schemes, on a number of wafer fab queueing networks. We limit ourselves to studying fabs with one process flow and a single bottleneck station. Mean delay/throughput tradeoff curves are generated for each policy-network pair under consideration. Simulations are carried out using FabSim on the Cray X-MP/14 supercomputer at U.C. - Berkeley.

Fab Network Name	Number of Stations	Bottleneck Station	Number of Recipe Steps
Small-Fab	5	S_2	12
Dayhoff-87	18	S_1	24
Bipolar	24	S_4	46
SSi-implant	41	S_{27}	182
SSi-aligner	41	S_5	182

Table 6.1 — Test Fab Queueing Networks

In Section 6.1 we discuss the experimental design. Table 6.1 summarizes the fab networks tested in this study. The first fab queueing network that we consider (in Section 6.2) is a small but representative hypothetical fab. This fab network consists of five work stations (one being the hub bottleneck) and a single product with a 29-step recipe. On this system we compare several dispatching and release strategies. In the remaining Sections we simulate larger queueing networks and compare Starvation Avoidance (release and dispatching) with UNIF release and either FIFO or SRPT dispatching. In Section 6.3 we adapt a fab network proposed by Dayhoff [Day87a].

In Section 6.4 we simulate a hypothetical 24 station, 49 step bipolar process fab suggested by Barry [Bar86a]. In Sections 6.5 and 6.6 we consider two 41 station, 182 step process fab networks adapted from data collected from a computer integrated manufacturing system at a Silicon Systems production fab. Both networks have one bottleneck station: the first has a bottleneck at ion implantation while the second has its bottleneck at the station of aligners.

6.1 – Experimental Design

To generate each average delay/throughput tradeoff curve we require the simulation of several levels of traffic intensities on the same wafer fab queueing network. One possible approach is be to run several *short* simulation experiments with different random seed sets for each configuration. We select a different approach, namely, to run a single *long* run for each traffic intensity with a single random seed set. We choose not to vary the random seed for the different traffic intensity levels as a measure of variance reduction, since this way scheduling policies are compared on the same sequence of machine up and down intervals. Within each run, statistics are collected in job batches of 50 jobs for the purpose of constructing a confidence interval. (See Law and Kelton [Law82a] for a discussion of confidence interval construction using this technique.)

For all runs, job statistics are collected for jobs that are released between simulation clock times $0.05H$ and H, where H is the given simulation horizon. H will vary according to the network being simulated to accommodate for the desired minimum sample size. Due to the large variability in uptimes and repair times introduced by the exponential distributions used in FabSim, it is necessary to collect statistics for a large number of jobs so as to generate acceptable confidence intervals. We collect statistics for at least 1000 jobs per run and in some cases for over 4000 jobs per run. Both axes of the delay/throughput tradeoff curves are scaled. The horizontal axis corresponds to the mean throughput. We scale throughput values such

that 1 corresponds to the maximum expected output of the fab. The vertical axis corresponds to mean delay. Entries there are divided by the total recipe processing time. All inter-station travel is assumed to be instantaneous.

6.2 – A Small Wafer Fab Queueing Network with Hub Station - Small-Fab

In this Section we compare several scheduling policies on a small hypothetical wafer fab queueing network (Small-Fab), whose topology is given in Fig. 6.2.1.

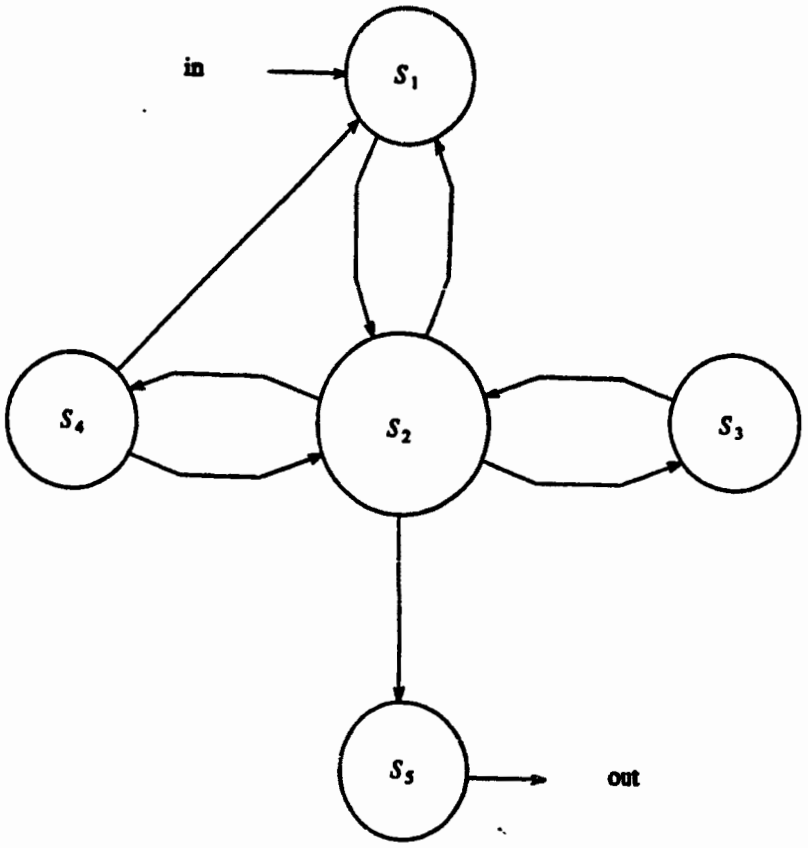

Fig. 6.2.1 – Network Topology - Small-Fab

This fab has five work stations that are summarized in Table 6.2.1. The bottleneck station is S_2. We assume all machines have identical values of mean time between failures (MTBF) of 12,240 minutes and mean time to repair (MTTR) of 1,440 minutes. The load size for all machines is one lot.

work station	number machines
1	5
2	2
3	6
4	6
5	10

Table 6.2.1 — Work Stations - Small-Fab

This fab network has one job type, whose 12 step process recipe is described in Table 6.2.2. The total duration of processing is 1,150 minutes.

step number	work station	step duration (mins)
1	1	60
2	2	120
3	3	60
4	2	90
5	3	90
6	2	120
7	4	60
8	2	60
9	4	90
10	1	60
11	2	100
12	5	240

Table 6.2.2 — Process Recipe - Small-Fab

No hot lots are allowed to start in this network. We also assume rework is never required. The nominal capacity of the network (*i.e.* assuming no equipment failures) is a production rate of one lot every 245 minutes (41.14 lots/week, assuming a 168-hour week). Its expected capacity (taking into account machine availability) is one lot every 277.67 minutes (36.30 lots/week).

We simulate 13 scheduling policies by making all possible combinations of release policies UNIF, SA, WR, and Fixed-WIP, with dispatching rules FIFO, SRPT, and SIPT. For SA release we also simulate the SA dispatching policy of Section 5.2. We use a simulation horizon of 500 thousand minutes (about 11 months and 13 days of a 24 hour/day, 7 days/week regime) requiring approximately 20 seconds of CPU time on the Cray X-MP/14 for each run. Tables 6.2.3 through 6.2.15 summarize the runs. The different system loads are controlled by start rates for UNIF, critical values for SA and WR, and WIP levels for Fixed-WIP.

start interval	mean delay	± 95% delay confidence interval	std. dev. delay	% delay/ cycle time	job starts
400	223.46	84.30	383.62	16.00	1188
390	254.69	93.60	451.22	17.96	1218
380	295.43	125.57	514.35	20.44	1250
370	351.79	145.33	591.21	23.05	1284
360	448.08	198.22	763.71	27.82	1319
350	506.25	265.31	932.87	30.47	1357
340	611.66	331.03	1161.00	34.08	1397
330	727.80	429.07	1412.19	38.16	1440
320	874.22	479.47	1656.17	42.65	1484
310	1152.57	596.14	2000.25	49.56	1532
300	1527.79	689.06	2375.52	56.57	1583
290	2350.49	850.64	2904.76	66.66	1638
280	5380.26	1191.82	4115.79	82.01	1696

Table 6.2.3.a. — UNIF/FIFO Scheduling (part a) – Small-Fab

start interval	mean departure interval	std. dev. departure interval	mean bottleneck queue	std. dev. bottleneck queue
400	399.97	139.64	0.55	1.06
390	389.89	140.60	0.65	1.25
380	379.95	150.44	0.78	1.44
370	369.85	157.40	0.93	1.67
360	359.87	123.85	1.23	2.19
350	349.83	127.78	1.44	2.72
340	339.78	125.15	1.75	3.45
330	329.58	133.58	2.15	4.31
320	319.67	139.46	2.68	5.20
310	309.48	145.61	3.65	6.47
300	299.45	148.56	4.99	7.92
290	289.37	150.86	7.94	10.02
280	279.26	138.07	18.73	14.68

Table 6.2.3.b. — UNIF/FIFO Scheduling (part b) – Small-Fab

start interval	mean delay	± 95% delay confidence interval	std. dev. delay	% delay/ cycle time	job starts
400	183.88	58.45	282.17	13.57	1188
390	209.05	69.13	331.20	15.25	1218
380	237.88	92.53	372.94	17.14	1250
370	278.13	100.46	411.67	19.16	1284
360	317.64	123.08	494.77	21.47	1319
350	366.71	164.56	588.73	24.10	1357
340	420.45	192.16	698.39	26.26	1397
330	494.27	254.29	853.60	29.54	1440
320	595.85	292.68	1023.89	33.65	1484
310	754.10	349.79	1187.33	39.15	1532
300	994.09	410.84	1423.35	45.88	1583
290	1495.27	495.16	1704.10	56.00	1638
280	3253.79	682.63	2356.20	73.40	1696
270	9867.40	1739.04	6012.92	89.58	1759

Table 6.2.4.a. — UNIF/SRPT Scheduling (part a) – Small-Fab

start interval	mean departure interval	std. dev. departure interval	mean bottleneck queue	std. dev. bottleneck queue
400	400.07	132.77	0.45	0.85
390	389.87	129.18	0.53	0.98
380	379.96	131.03	0.63	1.10
370	369.85	134.86	0.74	1.24
360	359.86	139.04	0.87	1.48
350	349.75	103.25	1.04	1.78
340	339.70	107.37	1.20	2.13
330	329.62	105.21	1.46	2.65
320	319.56	112.61	1.82	3.25
310	309.51	109.62	2.39	3.88
300	299.48	115.28	3.25	4.79
290	289.54	123.84	5.05	5.92
280	279.53	127.76	11.33	8.45
270	277.36	128.30	35.84	22.27

Table 6.2.4.b. — UNIF/SRPT Scheduling (part b) – Small-Fab

start interval	mean delay	± 95% delay confidence interval	std. dev. delay	% delay/ cycle time	job starts
400	202.11	67.07	324.42	14.70	1188
390	229.29	77.80	378.70	16.47	1218
380	259.47	97.99	414.86	18.41	1250
370	317.19	127.74	505.22	21.28	1284
360	375.50	159.88	628.73	24.40	1319
350	415.69	197.96	706.30	26.47	1357
340	495.61	249.07	885.16	29.54	1397
330	577.95	317.32	1054.76	32.90	1440
320	699.12	362.33	1261.65	37.30	1484
310	893.53	435.67	1474.45	43.25	1532
300	1180.70	509.68	1762.81	50.17	1583
290	1782.97	621.72	2132.83	60.27	1638
280	4001.17	869.37	3001.76	77.23	1696
270	12417.08	2210.58	7643.01	91.54	1759

Table 6.2.5.a. — UNIF/SIPT Scheduling (part a) – Small-Fab

start interval	mean departure interval	std. dev. departure interval	mean bottleneck queue	std. dev. bottleneck queue
400	399.98	163.76	0.50	0.92
390	389.88	152.95	0.58	1.08
380	379.94	157.49	0.68	1.20
370	369.83	169.41	0.84	1.46
360	359.76	158.14	1.03	1.82
350	349.83	137.78	1.18	2.09
340	339.76	141.85	1.42	2.65
330	329.69	139.47	1.71	3.24
320	319.61	141.86	2.14	3.98
310	309.49	149.96	2.83	4.79
300	299.44	155.34	3.86	5.90
290	289.43	164.43	6.02	7.34
280	279.36	180.97	13.93	10.73
270	279.31	174.41	44.31	28.31

Table 6.2.5.b. — UNIF/SIPT Scheduling (part b) – Small-Fab

work in process	mean delay	± 95% delay confidence interval	std. dev. delay	% delay/ cycle time	job starts
4	191.99	31.06	229.12	14.23	1414
5	346.52	46.70	312.81	22.97	1588
6	539.76	48.38	377.01	31.80	1688
7	789.61	58.28	423.35	40.65	1713
8	1063.61	67.68	469.53	47.99	1717
10	1616.94	84.58	541.05	58.39	1719
14	2723.52	118.05	656.05	70.27	1720
16	3276.68	132.76	698.41	73.98	1724
26	6038.26	206.87	946.30	84.00	1733

Table 6.2.6.a. — Fixed-WIP/FIFO Scheduling (part a) – Small-Fab

work in process	mean departure interval	std. dev. departure interval	mean bottleneck queue	std. dev. bottleneck queue
4	335.10	306.47	0.58	0.86
5	298.70	324.42	1.16	1.14
6	281.14	262.11	1.92	1.33
7	276.83	297.46	2.85	1.42
8	276.45	241.32	3.84	1.37
10	276.36	248.19	5.84	1.35
14	276.31	292.02	9.84	1.37
16	275.57	344.24	11.84	1.41
26	275.30	509.04	21.83	1.66

Table 6.2.6.b. — Fixed-WIP/FIFO Scheduling (part b) – Small-Fab

work in process	mean delay	± 95% delay confidence interval	std. dev. delay	% delay/ cycle time	job starts
4	169.12	33.48	233.78	12.62	1441
5	328.27	37.44	312.55	22.19	1602
6	522.78	49.84	366.40	31.25	1701
7	787.54	60.01	420.55	40.58	1716
8	1063.69	68.75	459.02	47.99	1717
12	2168.67	103.90	593.49	65.31	1721
16	3271.54	138.52	715.32	73.96	1725

Table 6.2.7.a. — Fixed-WIP/SRPT Scheduling (part a) – Small-Fab

work in process	mean departure interval	std. dev. departure interval	mean bottleneck queue	std. dev. bottleneck queue
4	328.91	142.78	0.51	0.81
5	295.34	146.02	1.11	1.08
6	278.70	125.57	1.88	1.23
7	276.44	128.98	2.84	1.25
8	276.37	131.40	3.84	1.25
12	276.28	131.33	7.84	1.25
16	276.23	131.26	11.84	1.26

Table 6.2.7.b. — Fixed-WIP/SRPT Scheduling (part b) – Small-Fab

work in process	mean delay	± 95% delay confidence interval	std. dev. delay	% delay/ cycle time	job starts
4	186.05	29.06	233.84	13.90	1419
5	311.39	41.79	324.12	21.24	1624
6	519.03	50.65	390.38	31.07	1706
7	787.61	60.27	466.20	40.59	1716
8	1063.59	67.84	484.07	47.99	1716
10	1616.86	84.97	560.08	58.38	1719
16	3274.69	136.21	724.00	73.98	1723
20	3827.18	153.33	784.88	76.86	1726

Table 6.2.8.a. — Fixed-WIP/SIPT Scheduling (part a) – Small-Fab

work in process	mean departure interval	std. dev. departure interval	mean bottleneck queue	std. dev. bottleneck queue
4	333.65	258.14	0.56	0.82
5	292.10	216.41	1.07	1.09
6	278.06	252.37	1.87	1.28
7	276.60	242.96	2.84	1.31
8	276.32	209.14	3.84	1.30
10	276.29	225.92	5.84	1.30
16	276.26	230.90	11.84	1.33
20	275.98	235.03	13.84	1.33

Table 6.2.8.b. — Fixed-WIP/SIPT Scheduling (part b) – Small-Fab

critical work content	mean delay	± 95% delay confidence interval	std. dev. delay	% delay/ cycle time	job starts
200	40.68	8.93	80.66	3.40	1056
400	90.32	19.07	146.50	7.21	1402
600	198.33	23.27	200.48	14.59	1590
800	335.36	32.63	239.49	22.47	1639
1000	519.86	37.36	297.66	31.09	1713
1400	944.28	52.52	369.92	45.04	1717
1800	1309.07	63.59	429.92	53.19	1717
2600	2119.87	88.63	538.29	64.79	1719
3000	2546.18	96.33	568.13	68.85	1720
3400	2898.46	109.62	616.50	71.56	1721

Table 6.2.9.a. — WR/FIFO Scheduling (part a) – Small-Fab

critical work content	mean departure interval	std. dev. departure interval	mean bottleneck queue	std. dev. bottleneck queue
200	448.77	57.11	0.10	0.39
400	338.15	65.61	0.28	0.56
600	298.09	103.06	0.67	0.81
800	289.23	108.07	1.16	0.99
1000	276.82	183.36	1.88	1.07
1400	276.45	94.57	3.41	0.96
1800	276.42	88.02	4.73	0.97
2600	276.38	81.18	7.66	1.03
3000	276.37	116.80	9.19	1.06
3400	276.25	97.61	10.47	0.98

Table 6.2.9.b. — WR/FIFO Scheduling (part b) – Small-Fab

critical work content	mean delay	± 95% delay confidence interval	std. dev. delay	% delay/ cycle time	job starts
200	40.07	8.82	80.15	3.35	1056
400	87.47	17.76	135.88	6.97	1393
600	162.49	21.97	169.35	12.26	1496
800	284.23	23.04	194.62	19.79	1610
1400	644.05	31.16	259.44	35.86	1716
3400	1797.45	65.53	440.87	60.95	1720
5800	3127.76	109.79	612.45	73.09	1725

Table 6.2.10.a. — WR/SRPT Scheduling (part a) - Small-Fab

critical work content	mean departure interval	std. dev. departure interval	mean bottleneck queue	std. dev. bottleneck queue
200	448.59	53.32	0.09	0.33
400	340.18	78.64	0.26	0.54
600	316.76	86.07	0.51	0.75
800	294.36	111.89	0.97	0.85
1400	276.32	131.44	2.33	0.96
3400	276.26	131.37	6.50	0.96
5800	276.23	131.26	11.32	0.96

Table 6.2.10.b. — WR/SRPT Scheduling (part b) - Small-Fab

critical work content	mean delay	± 95% delay confidence interval	std. dev. delay	% delay/ cycle time	job starts
200	40.42	8.73	80.57	3.38	1056
400	88.59	17.73	148.94	7.85	1389
600	177.68	24.63	197.45	13.36	1504
800	301.88	28.72	221.56	20.78	1656
1000	440.35	30.53	255.30	27.67	1707
1400	731.84	38.07	311.39	38.85	1716
2200	1336.06	54.84	397.19	53.70	1718
2600	1619.52	65.61	445.95	58.44	1719
3400	2181.50	83.67	520.42	65.45	1720
4200	2751.78	101.44	585.17	70.49	1722
5000	3334.95	118.66	641.44	74.33	1724

Table 6.2.11.a. — WR/SIPT Scheduling (part a) - Small-Fab

critical work content	mean departure interval	std. dev. departure interval	mean bottleneck queue	std. dev. bottleneck queue
200	448.59	56.89	0.10	0.35
400	341.09	134.48	0.26	0.56
600	315.17	113.43	0.57	0.80
800	286.35	135.18	1.06	0.90
1000	277.72	177.70	1.59	0.95
1400	276.43	162.43	2.64	1.02
2200	276.40	141.07	4.83	0.99
2600	276.34	175.32	5.85	1.01
3400	276.30	180.97	7.89	0.97
4200	276.27	163.39	9.95	1.05
5000	276.13	170.21	12.06	1.01

Table 6.2.11.b. — WR/SIPT Scheduling (part b) - Small-Fab

safety factor × m	mean delay	± 95% delay confidence interval	std. dev. delay	% delay/ cycle time	job starts
1.0	323.09	21.59	164.30	21.92	1628
1.3	459.24	16.48	189.45	28.48	1684
1.6	470.89	19.16	179.80	29.03	1688
1.9	500.15	23.19	182.04	30.25	1693
2.2	657.47	27.71	227.49	36.37	1709
2.8	682.50	26.34	229.46	37.20	1715
3.1	758.74	33.65	258.87	39.70	1717
3.4	760.74	32.42	245.24	39.76	1718
4.9	1048.27	36.11	285.60	47.66	1721
5.2	1102.40	43.63	316.35	48.91	1718

Table 6.2.12.a. — SA/FIFO Scheduling (part a) - Small-Fab

Note: m = 2 is the number of machines at the bottleneck.

safety factor × m	mean departure interval	std. dev. departure interval	mean bottleneck queue	std. dev. bottleneck queue
1.0	291.65	208.69	1.11	1.05
1.3	282.22	178.93	1.62	1.14
1.6	281.81	185.83	1.67	1.13
1.9	280.59	186.23	1.78	1.16
2.2	277.72	235.01	2.37	1.32
2.8	276.97	203.97	2.46	1.23
3.1	276.85	224.06	2.74	1.25
3.4	276.44	218.51	2.74	1.22
4.9	276.41	264.63	3.79	1.37
5.2	276.32	251.85	3.99	1.39

Table 6.2.12.b. — SA/FIFO Scheduling (part b) - Small-Fab

Note: m = 2 is the number of machines at the bottleneck.

safety factor × m	mean delay	± 95% delay confidence interval	std. dev. delay	% delay/ cycle time	job starts
1.3	250.18	21.19	166.76	17.84	1640
2.2	480.25	27.25	238.04	29.41	1716
2.8	532.19	27.09	235.78	31.62	1718
3.1	541.72	27.32	240.66	31.99	1718
3.7	640.21	29.71	255.77	35.74	1719
4.3	741.47	36.52	282.34	39.18	1718

Table 6.2.13.a. – SA/SRPT Scheduling (part a) – Small-Fab

Note: m = 2 is the number of machines at the bottleneck.

safety factor × m	mean departure interval	std. dev. departure interval	mean bottleneck queue	std. dev. bottleneck queue
1.3	293.46	121.34	0.85	0.86
2.2	276.61	137.61	1.73	0.95
2.8	276.40	130.88	1.92	0.98
3.1	276.39	127.95	1.96	0.97
3.7	276.31	125.72	2.31	0.94
4.3	276.29	125.76	2.68	0.93

Table 6.2.13.b. – SA/SRPT Scheduling (part b) – Small-Fab

Note: m = 2 is the number of machines at the bottleneck.

safety factor x m	mean delay	± 95% delay confidence interval	std. dev. delay	% delay/ cycle time	job starts
1.3	243.55	16.79	168.94	17.43	1540
1.6	263.66	17.41	176.05	18.66	1597
2.2	467.53	22.23	246.43	28.90	1702
2.8	488.74	23.68	248.25	29.81	1705
3.4	532.80	22.55	256.70	31.65	1707
3.7	611.44	24.33	258.09	34.69	1714
4.3	712.36	34.46	317.31	38.18	1718
4.6	718.55	33.53	315.65	38.42	1718
5.2	802.06	33.60	315.81	41.06	1718
5.5	811.09	32.01	316.72	41.33	1718

Table 6.2.14.a. — SA/SIPT Scheduling (part a) – Small-Fab

Note: m = 2 is the number of machines at the bottleneck.

safety factor x m	mean departure interval	std. dev. departure interval	mean bottleneck queue	std. dev. bottleneck queue
1.3	308.38	255.07	0.79	0.86
1.6	297.31	231.29	0.89	0.86
2.2	278.94	235.56	1.68	1.02
2.8	278.49	250.42	1.75	1.05
3.4	278.12	236.80	1.92	1.02
3.7	276.96	221.18	2.20	1.07
4.3	276.57	225.26	2.57	1.07
4.6	276.54	222.53	2.59	1.06
5.2	276.44	219.78	2.89	1.07
5.5	276.32	228.12	2.93	1.09

Table 6.2.14.b. — SA/SIPT Scheduling (part b) – Small-Fab

Note: m = 2 is the number of machines at the bottleneck.

safety factor $\times m$	mean delay	± 95% delay confidence interval	std. dev. delay	% delay/ cycle time	job starts
1.3	250.18	21.19	166.76	17.84	1640
2.2	480.25	27.25	238.04	29.41	1716
2.8	532.19	27.09	235.78	31.62	1718
3.7	700.27	24.34	260.55	37.89	1719
4.3	746.50	37.79	311.90	39.34	1720
5.5	868.86	33.28	296.87	43.04	1719

Table 6.2.15.a. — SA/SA Scheduling (part a) - Small-Fab

Note: m = 2 is the number of machines at the bottleneck.

safety factor $\times m$	mean departure interval	std. dev. departure interval	mean bottleneck queue	std. dev. bottleneck queue
1.3	293.46	121.34	0.85	0.86
2.2	276.61	137.61	1.73	0.95
2.8	276.40	130.88	1.92	0.98
3.7	276.29	158.31	2.53	1.07
4.3	276.25	149.35	2.70	0.99
5.5	276.18	188.55	3.15	1.07

Table 6.2.15.b. — SA/SA Scheduling (part b) - Small-Fab

Note: m = 2 is the number of machines at the bottleneck.

6.2.1 — Interpretation of Simulation Experiment - Small-Fab

To interpret the results of our simulation experiment on Small-Fab let us consider first each release strategy separately and observe the effect of varying the dispatching rule within each release policy. Secondly, we consider a fixed dispatching rule with different release strategies.

For UNIF release, SRPT dispatching appears to outperform both SIPT and

FIFO dispatching (Fig. 6.2.2).

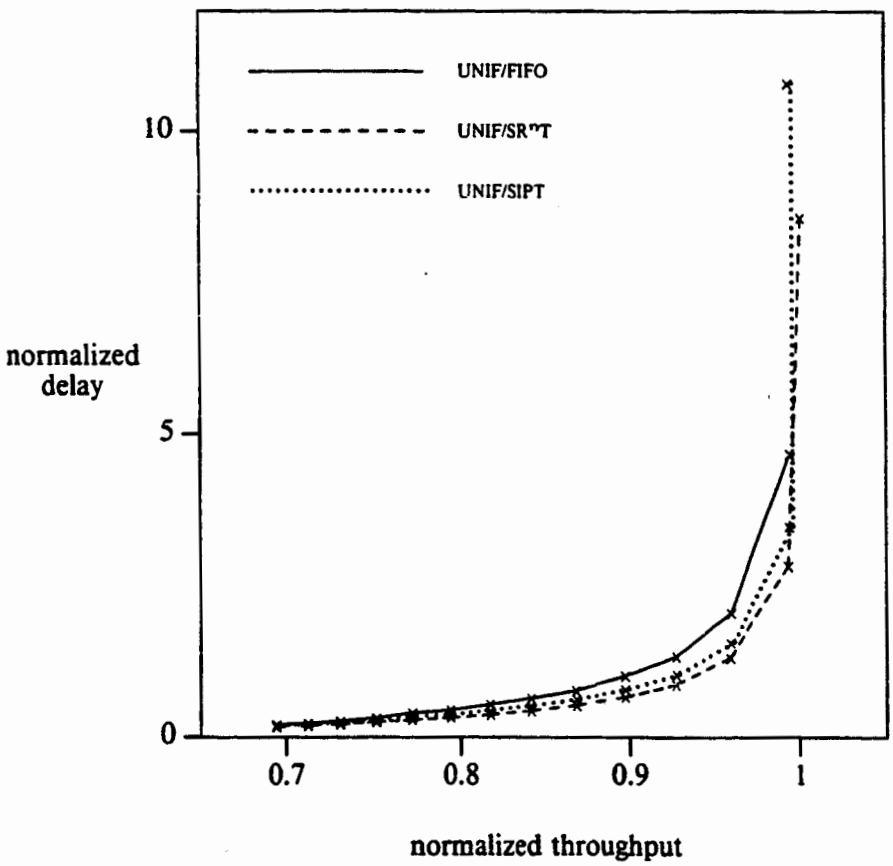

Fig. 6.2.2 — UNIF Release – Small-Fab

For all values of throughput rate SRPT produced schedules with less mean delay than both FIFO and SIPT, achieving reductions of approximately 40% and 19% (when compared to FIFO and SIPT, respectively) in mean delay at the throughput rate of about 1 lot per 280 minutes. At that throughput rate SIPT produced about 25% less delay than FIFO. With respect to the coefficient of variation of inter-departure times (CVID) SRPT and FIFO were about equal, while both produced schedules with less CVID than SIPT (see Tables 6.2.3.b, 6.2.4.b, and 6.2.5.b). CVID is a measure of the regularity of output.

Fixed-WIP release with SRPT, SIPT, and FIFO dispatching produced schedules with no noticeable mean delay differences (Fig. 6.2.3).

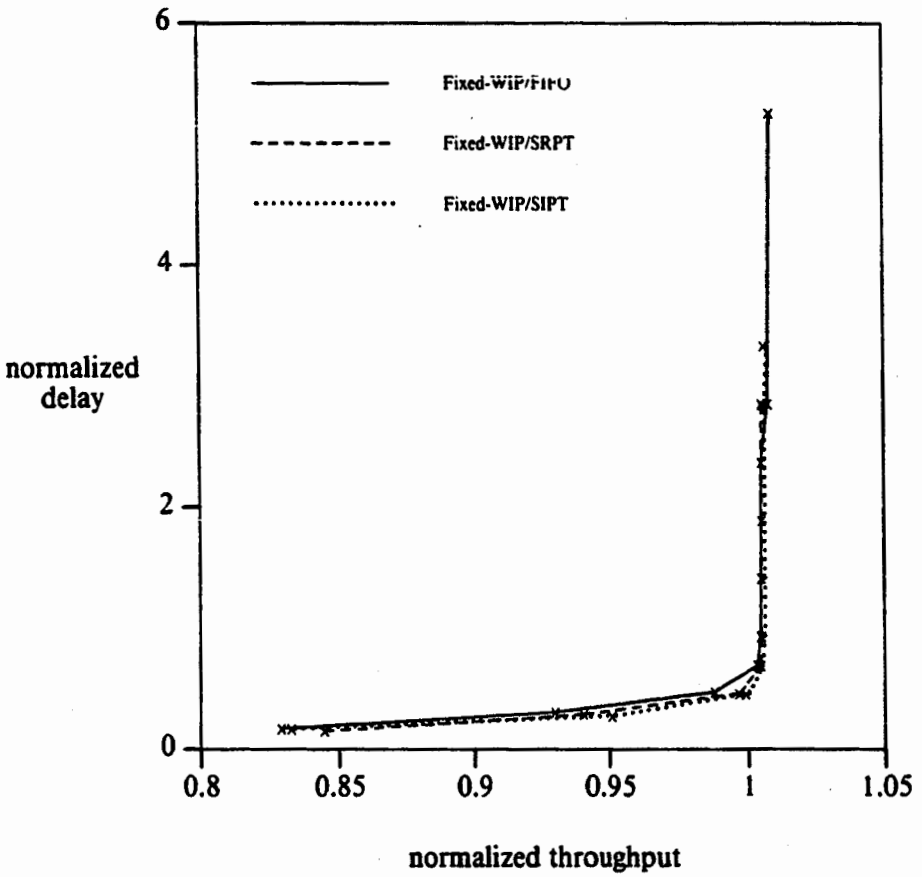

Fig. 6.2.3 — Fixed-WIP Release – Small-Fab

SRPT outperformed FIFO and SIPT dispatching in the sense that it produced schedules with less CVID (see Tables 6.2.6.b, 6.2.7.b, and 6.2.8.b).

With WR release, the relative dispatching rule performances were indifferent for the greater portion of the range of throughput rate values (Fig. 6.2.4).

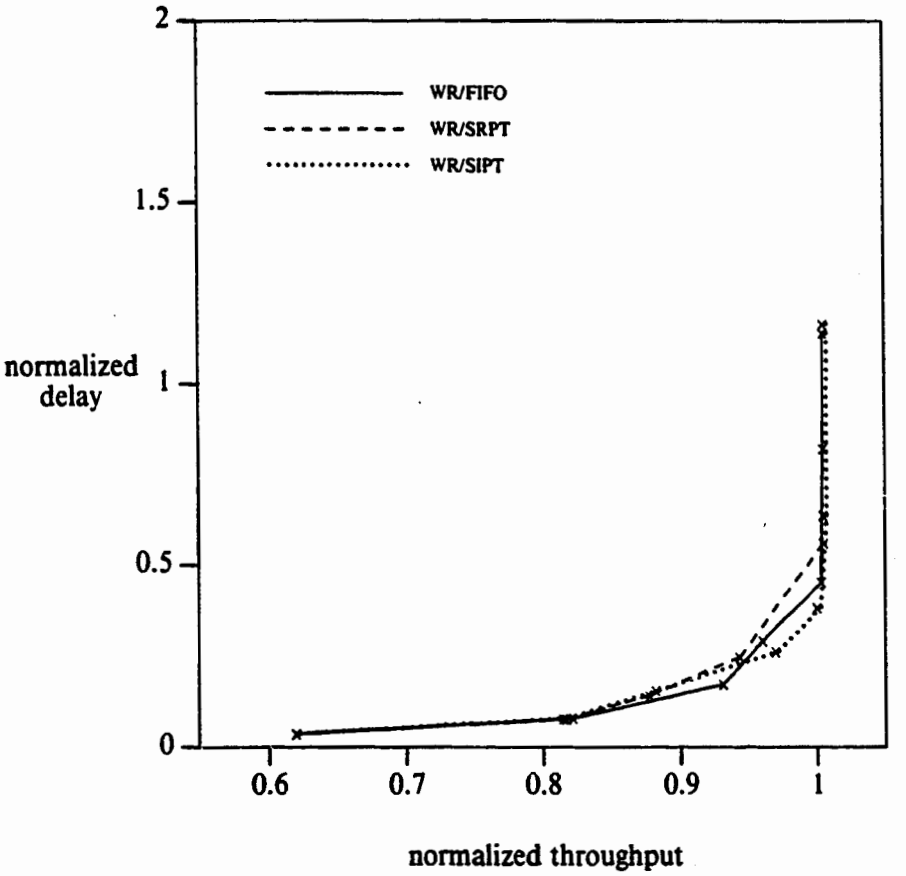

Fig. 6.2.4 — WR Release - Small-Fab

At the high end of the range, however, SRPT showed the least sensitivity to increases in throughput rate, while FIFO showed the highest, followed closely by SIPT. With respect to CVID (see Tables 6.2.9.b, 6.2.10.b, and 6.2.11.b) SIPT had the worst performance while SRPT and FIFO were better (SRPT was the most consistent in terms of inter-departure time variability).

With SA release, FIFO dispatching was clearly the worst rule of the four considered (Fig. 6.2.5).

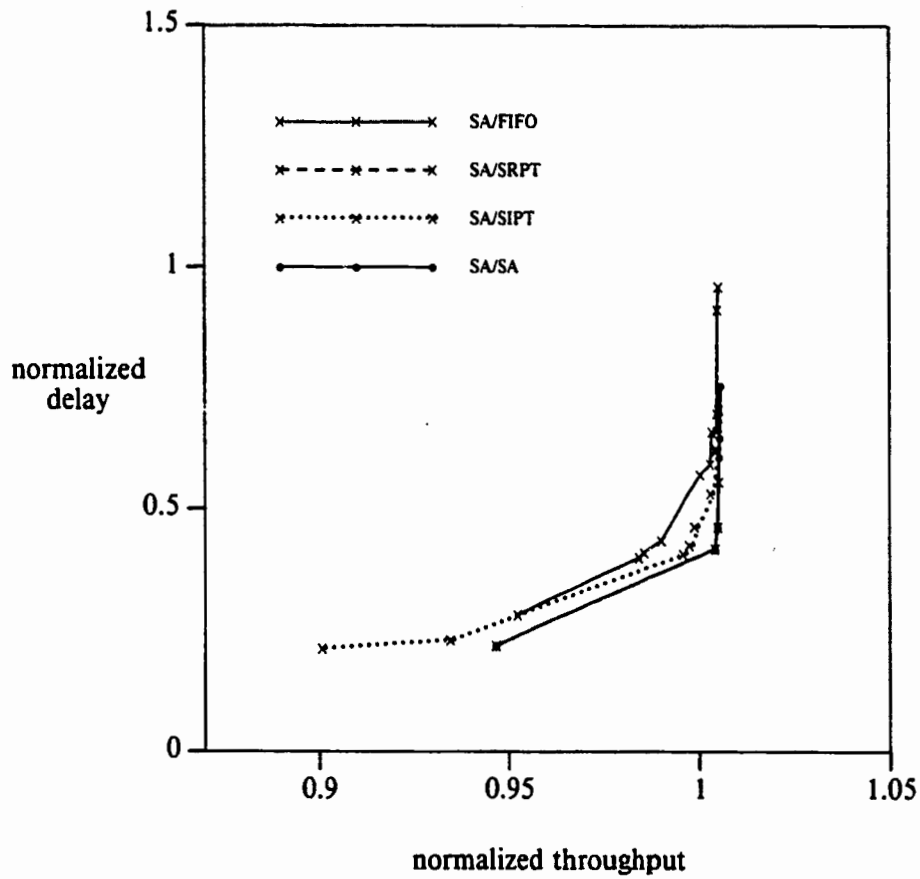

Fig. 6.2.5 — SA Release - Small-Fab

SA and SRPT dispatching were almost identical with respect to mean delay (note that their plots overlap in Fig. 6.2.5), but SRPT was slightly superior to SA with respect to CVID in the high end of the throughput range (see Tables 6.2.12.b, 6.2.13.b, 6.2.14.b, and 6.2.15.b). SIPT dispatching was better than FIFO with respect to mean delay and for a large portion of the throughput range it was superior to both SRPT and SA dispatching. For the highest throughput values, however, it could not outperform either SA or SRPT.

We now fix the dispatching strategy and compare the different release strategies. We choose for this analysis to fix the dispatching rule to SRPT, given its overall good performance. The scheduling policies we will consider are therefore - UNIF/SRPT,

Fixed-WIP/SRPT, WR/SRPT, and SA/SRPT. Within its domain of throughput values (from 95% to 100.5% of expected capacity) SA/SRPT clearly outperformed the other three scheduling policies. The improvement was most remarkable against UNIF/SRPT (Fig 6.2.6), where mean delay reductions varied from 80% to 92%.

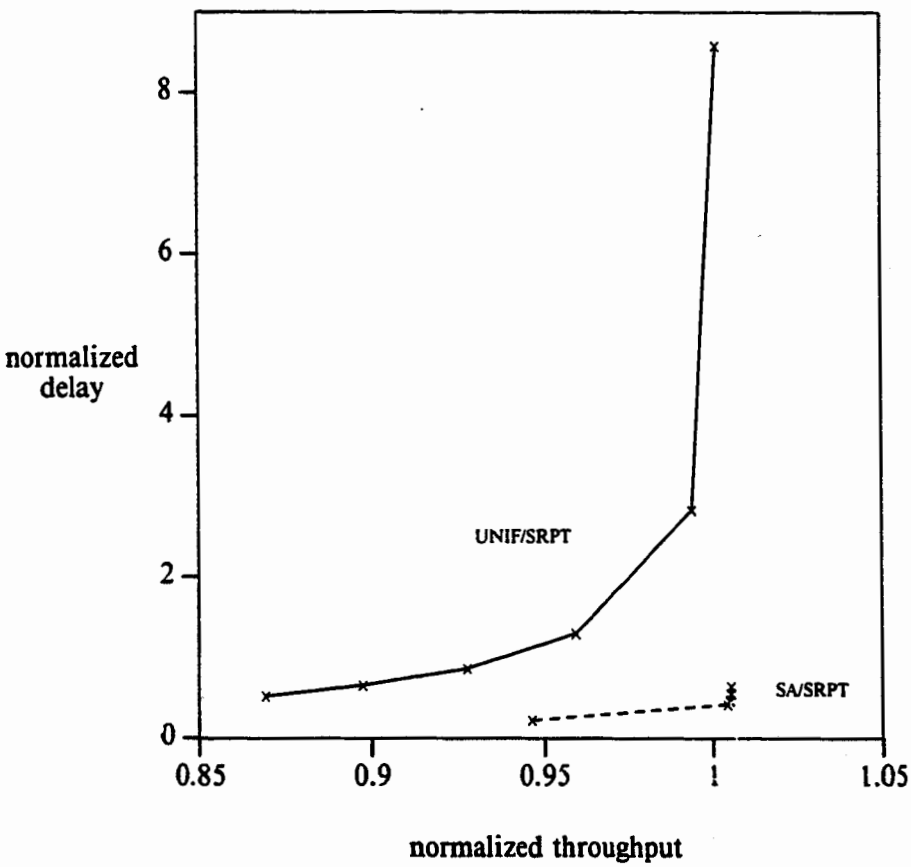

Fig. 6.2.6 – SA/SRPT vs UNIF/SRPT Release – Small-Fab

CVID values for SA/SRPT and UNIF/SRPT are similar (see Tables 6.2.4.b and 6.2.13.b). When compared to Fixed-WIP/SRPT (Fig. 6.2.7) and WR/SRPT (Fig. 6.2.8) improvements were not as marking, but SA/SRPT remained the best scheduling policy with 59% and 74% reductions in mean delay at the high end of throughput range, respectively.

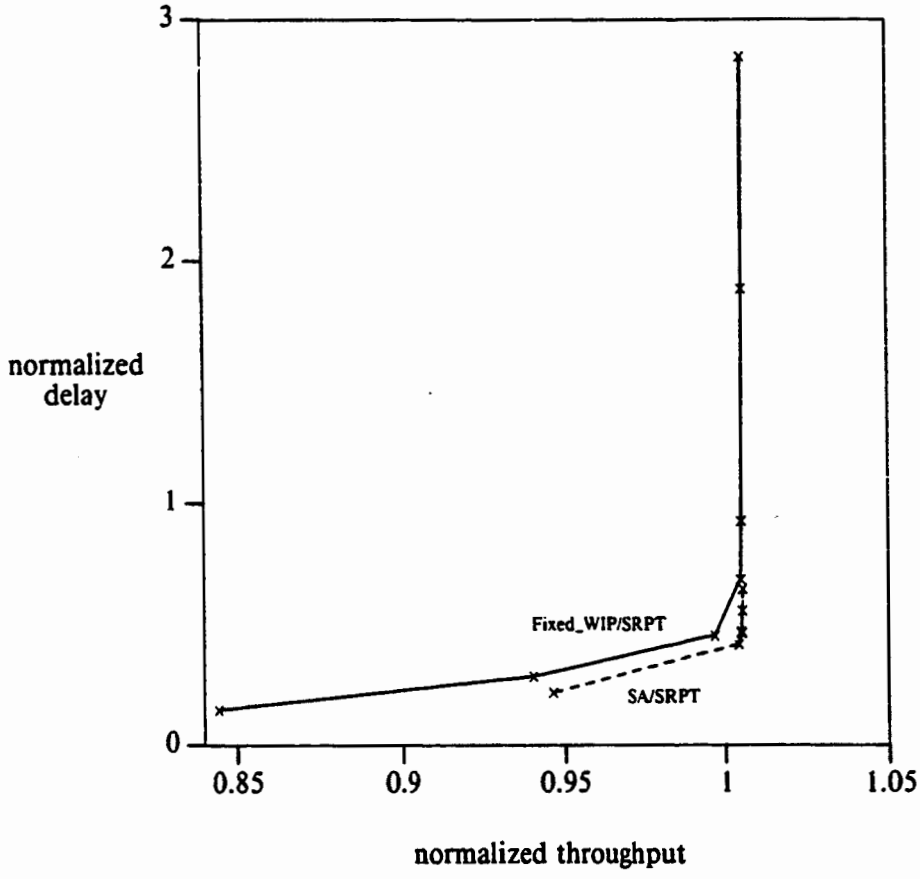

Fig. 6.2.7 — SA/SRPT vs Fixed-WIP/SRPT - Small-Fab

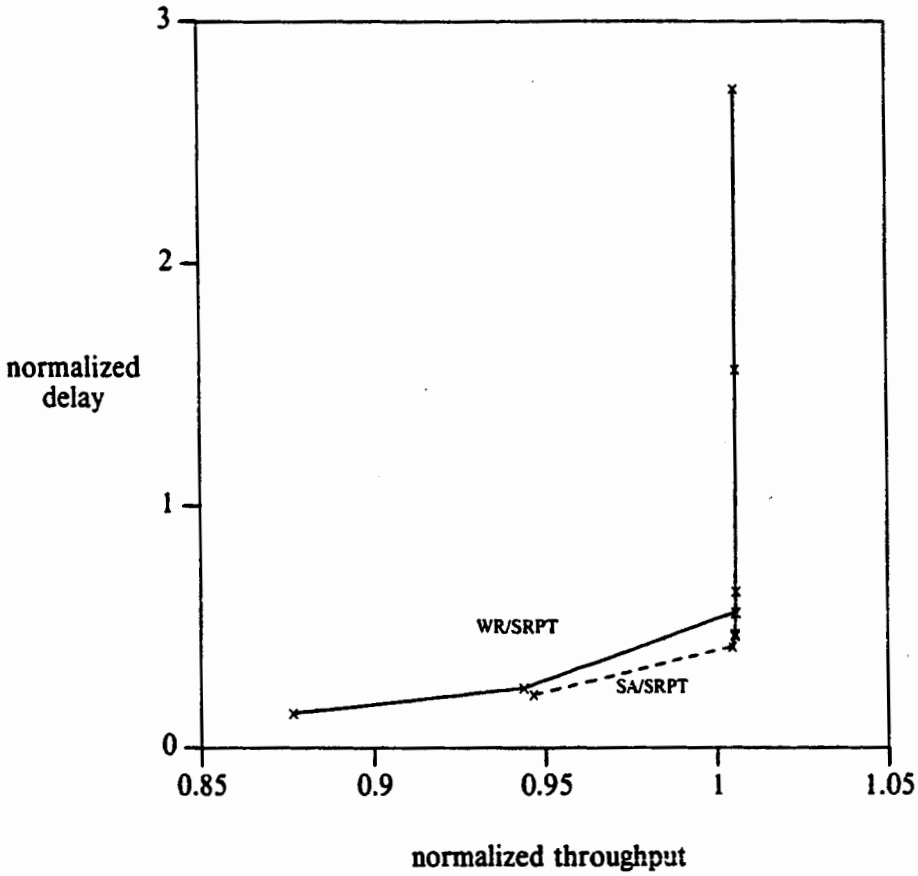

Fig. 6.2.8 — SA/SRPT vs WR/SRPT - Small-Fab

In summary, with respect to Small-Fab, varying the dispatching rule for a fixed release strategy did not show as much mean delay sensitivity as fixing the dispatching rule and varying the release strategy. SRPT was the best dispatching rule and SA the superior release strategy.

6.3 — A Single Bottleneck Fab Queueing Network - Dayhoff-87 [Day87a]

In this Section we compare SA scheduling with UNIF release and FIFO dispatching on a hypothetical single bottleneck wafer fab queueing network described by Dayhoff [Day87a], and whose topology is given in Fig. 6.3.1.

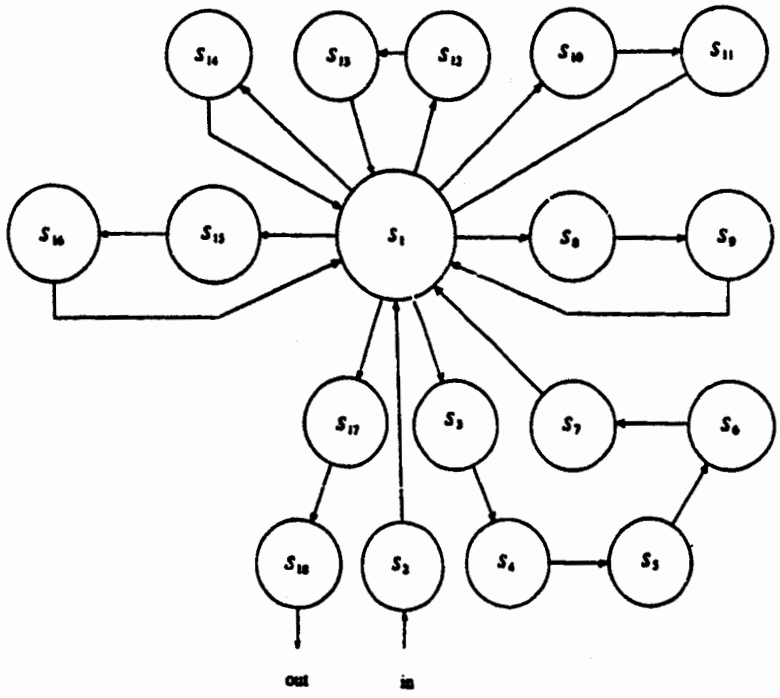

Fig. 6.3.1 — Network Topology – Dayhoff-87

This fab has 18 work stations (with one bottleneck) that are summarized in Table 6.3.1. Station S_1 is the bottleneck. Machine availability is not given in Dayhoff [Day87a] and is set so as to maintain station S_1 the bottleneck. Machine load sizes are also not provided by Dayhoff. We set load size to one for all machines.

work station	number machines	MTTR (mins)	MTBF (mins)
1	6	5440	16200
2	4	1440	12240
3	1	1440	12240
4	4	1440	12240
5	2	1440	12240
6	3	1440	12240
7	4	1440	12240
8	1	1440	12240
9	4	1440	12240
10	1	1440	12240
11	4	1440	12240
12	1	60	10860
13	4	1440	12240
14	1	40	10860
15	1	1440	12240
16	1	1440	12240
17	1	40	10840
18	1	40	10840

Table 6.3.1 — Work Stations - Dayhoff-87

Dayhoff-87 is a single product fab. The process recipe is given in Table 6.3.2. Dayhoff does not present processing times in her paper. The times given below, are again set so as to maintain S_1 the bottleneck. The total duration of processing is 2,600 minutes.

step number	work station	step duration (mins)
1	2	60
2	1	240
3	3	60
4	4	90
5	5	90
6	6	120
7	7	60
8	1	90
9	8	90
10	9	60
11	1	100
12	10	40
13	11	60
14	1	100
15	12	40
16	13	240
17	1	150
18	14	40
19	1	360
20	15	100
21	16	40
22	1	240
23	17	40
24	18	90

Table 6.3.2 — Process Recipe - Dayhoff-87

No hot lots are allowed to be started in this fab. Rework is assumed not to be required. The nominal capacity of this fab network is one lot every 213.33 minutes (47.25 lots/week). Its expected capacity is one lot every 320.79 minutes (31.42 lots/week). All simulations are run with H = 1.5 million minutes (about 34 months) and each requires approximately 200 seconds of CPU time on the Cray X-MP/14. Tables 6.3.3.a and 6.3.3.b summarize runs with UNIF/FIFO scheduling, while Tables 6.3.4.a and Table 6.3.4.b show results for SA/SA scheduling.

start interval	mean delay	± 95% delay confidence interval	std. dev. delay	% delay/ cycle time	job starts
500	1963.43	312.87	2332.84	43.03	2851
460	2329.18	365.28	2546.93	47.33	3097
420	3000.87	450.19	2981.88	53.84	3393
400	3732.59	601.24	3550.97	59.03	3563
390	4223.85	691.83	3996.93	61.91	3654
380	4727.87	781.72	4444.82	64.52	3750
360	6338.98	961.39	5478.52	70.94	3958
350	7550.22	1081.41	6149.94	74.46	4071
340	9404.08	1173.11	6680.99	78.47	4191
335	11077.32	1245.40	7119.31	81.00	4254
300	13889.32	1371.37	7823.17	84.25	4318
325	18328.45	1591.15	9087.56	87.54	4385
320	24878.26	2095.37	11997.52	90.54	4453

Table 6.3.3.a. — UNIF/FIFO Scheduling (part a) - Dayhoff-87

start interval	mean departure interval	std. dev. departure interval	mean bottleneck queue	std. dev. bottleneck queue
500	501.34	917.37	1.40	3.49
460	461.25	877.50	2.45	4.47
420	421.42	819.42	4.26	6.36
400	401.57	775.98	6.02	8.27
390	391.40	780.69	7.38	9.78
380	381.46	764.75	8.71	11.05
360	362.15	729.62	13.44	14.69
350	352.48	712.92	17.32	17.12
340	343.00	664.30	23.19	19.16
335	338.60	651.05	28.29	20.73
330	333.53	639.49	37.01	23.22
325	330.19	627.37	50.96	27.57
320	328.45	641.12	70.55	36.13

Table 6.3.3.b. — UNIF/FIFO Scheduling (part b) - Dayhoff-87

safety factor x m	mean delay	± 95% delay confidence interval	std. dev. delay	% delay/ cycle time	job starts
1.0	4674.58	835.14	5293.20	64.23	3890
1.9	5373.51	909.33	5739.34	67.17	4101
2.2	5580.97	912.70	5898.61	68.31	4145
2.5	5776.96	965.42	6290.10	69.03	4164
3.1	5943.97	987.92	6281.35	69.66	4165
3.4	6031.20	958.11	6226.32	69.92	4198
4.3	6078.34	972.44	6308.71	70.07	4255
4.9	6150.24	995.81	6520.29	70.29	4263
5.5	6273.13	1015.02	6665.39	70.80	4279
5.8	6422.19	1019.08	6663.96	71.25	4289
6.1	6440.08	948.31	6300.48	71.25	4296
6.4	6703.86	980.86	6413.36	72.11	4314

Table 6.3.4.a. — SA/SA Scheduling (part a) – Dayhoff-87

Note: m = 6 is the number of machines at the bottleneck.

safety factor x m	mean departure interval	std. dev. departure interval	mean bottleneck queue	std. dev. bottleneck queue
1.0	367.52	774.44	5.47	10.46
1.9	348.76	742.03	7.61	12.93
2.2	344.83	732.63	7.76	12.74
2.5	343.18	720.48	8.09	13.82
3.1	343.08	719.93	8.56	14.25
3.4	340.43	726.75	8.92	14.41
4.3	336.03	696.88	9.38	14.78
4.9	335.32	690.14	9.69	15.32
5.5	334.38	699.15	9.76	15.44
5.8	333.42	699.40	10.37	15.63
6.1	332.42	693.81	10.30	14.93
6.4	331.18	698.38	10.87	15.72

Table 6.3.4.b. — SA/SA Scheduling (part b) – Dayhoff-87

Note: m = 6 is the number of machines at the bottleneck.

6.3.1 — Interpretation of Simulation Experiment - Dayhoff-87

SA release coupled with the SA dispatching rule outperformed UNIF/FIFO with respect to mean delay (Fig. 6.3.2) producing schedules that had from 25% to 55% less mean delay.

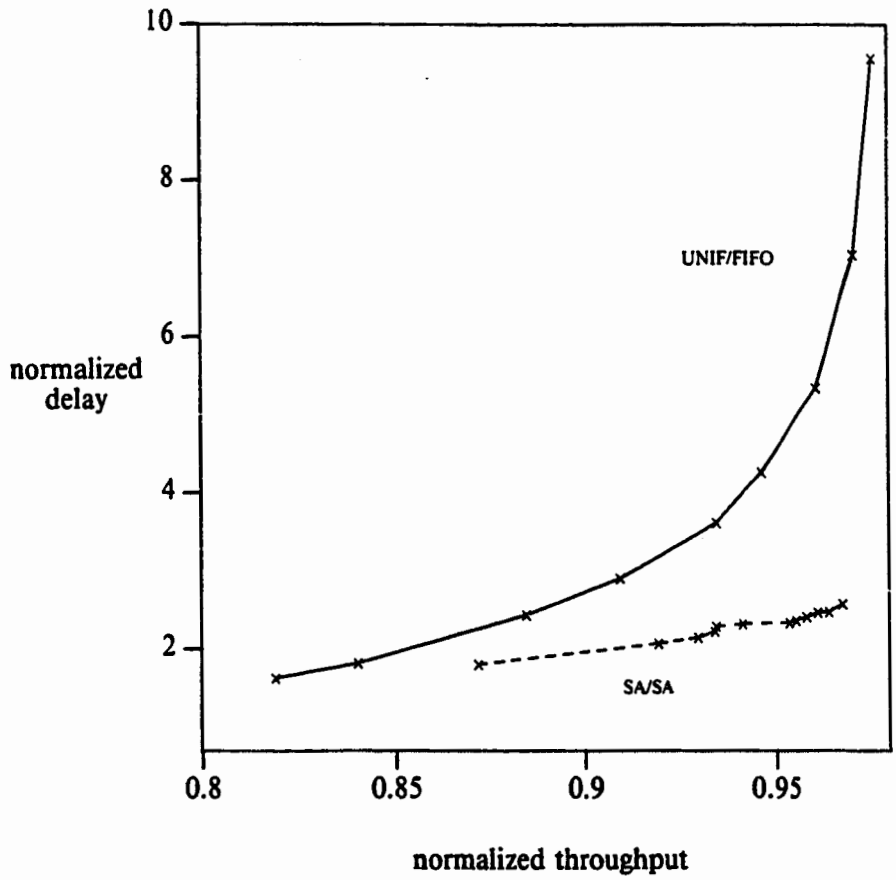

Fig. 6.3.2 — SA/SA vs UNIF/FIFO - Dayhoff-87

UNIF/FIFO did slightly better with respect to CVID (see Tables 6.3.1.b and 6.3.2.b).

6.4 — A Bipolar Process Fab Queueing Network - Bipolar [Bar86a]

We next compare SA scheduling with UNIF release and FIFO dispatching on a

hypothetical wafer fab queueing network suggested by Barry [Bar86a]. Its topology is given in Fig. 6.4.1. Photolithography, station S_4, is the bottleneck. In this example MTTR of the bottleneck machines is set to approximately 11.5 times the average step duration at the bottleneck. Bottleneck machine availability, however, is maintained relatively high, *i.e.* 82.4%.

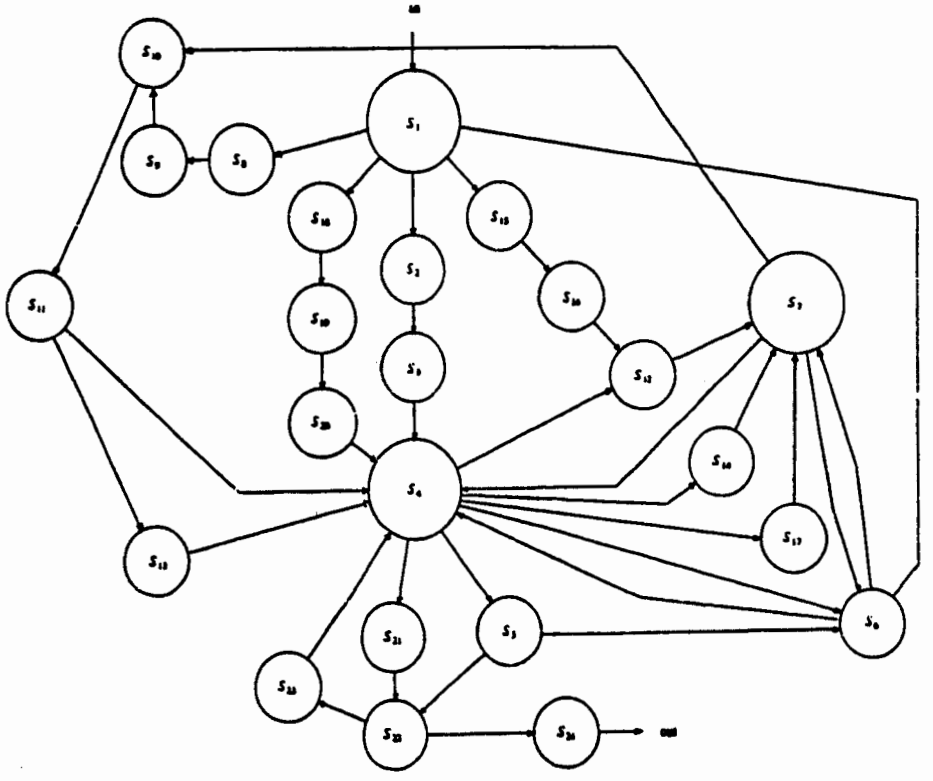

Fig. 6.4.1 — Network Topology – Bipolar

Table 6.4.1 summarizes the work stations of this fab. Load size is assumed to be a single lot for every machine.

work station	number machines	MTTR (mins)	MTBF (mins)
1	10	60	480
2	1	90	1200
3	2	90	1200
4	2	4000	22750
5	4	240	2400
6	8	360	1440
7	12	60	1440
8	10	120	3600
9	1	60	1440
10	10	90	1200
11	14	120	3600
12	4	240	2400
13	1	240	2400
14	4	240	2400
15	1	120	7200
16	2	90	1200
17	3	240	2400
18	1	120	7200
19	1	60	1440
20	2	240	2400
21	3	240	2400
22	4	60	1440
23	2	90	1200
24	4	120	1440

Table 6.4.1 — Work Stations - Bipolar

This fab processes a single product. Its total duration of processing is 8,100 minutes. The process recipe is given in Table 6.4.2.

step number	work station	step duration (mins)	rework probability
1	1	300	0.00
2	2	60	0.00
3	3	120	0.00
4	4	285	0.00
5	5	180	0.00
6	6	30	0.00
7	7	120	0.00
8	1	135	0.00
9	8	540	0.00
10	9	60	0.00
11	10	375	0.00
12	11	60	0.00
13	4	345	0.00
14	12	105	0.00
15	7	180	0.00
16	6	15	0.00
17	4	225	0.00
18	6	15	0.00
19	7	120	0.00
20	10	375	0.00
21	11	60	0.00
22	13	60	0.00
23	4	435	0.03
24	14	210	0.00
25	7	195	0.00
26	6	120	0.00
27	1	135	0.00
28	15	60	0.00
29	16	195	0.00
30	12	105	0.00
31	7	120	0.00
32	4	435	0.03
33	17	120	0.00
34	7	195	0.00
35	1	135	0.00
36	18	60	0.00
37	19	30	0.00
38	20	60	0.00
39	4	435	0.03
40	21	120	0.00

Table 6.4.2 — Process Recipe - Bipolar (continues)

step number	work station	step duration (mins)	rework probability
41	22	195	0.00
42	23	180	0.00
43	4	255	0.00
44	5	120	0.00
45	22	180	0.00
46	24	240	0.00

Table 6.4.2 — Process Recipe – Bipolar (continued)

Hot lots are not allowed to be started. The nominal capacity of the fab network is one lot every 1207.05 minutes (8.35 lots/week). Its expected capacity is one lot every 1465.10 minutes (6.88 lots/week). Simulations are run with a horizon H = 4 million minutes (about 91 months), each requiring approximately one half hour of CPU time on the Cray X-MP/14.

Tables 6.4.3.a and 6.4.3.b summarize runs with UNIF/FIFO scheduling, while Tables 6.4.4.a and Table 6.4.4.b show results for SA/SA scheduling.

start interval	mean delay	± 95% delay confidence interval	std. dev. delay	% delay/ cycle time	job starts
2000	1953.09	439.28	2599.02	19.45	1901
1940	2282.73	419.29	2863.91	21.97	1958
1880	2829.84	637.96	3490.65	25.89	2021
1820	3373.47	769.23	4033.26	29.47	2088
1760	3855.19	772.24	4578.91	32.27	2159
1700	4557.42	1050.90	5318.26	36.10	2235
1675	5003.10	1094.15	5727.34	38.26	2269
1655	5321.36	1219.39	6020.99	39.86	2296
1625	5796.61	1219.39	6519.97	41.88	2338
1595	6700.73	1443.41	7132.93	45.56	2382
1565	7563.06	1612.00	7501.18	48.53	2428
1535	10079.43	1734.84	8282.74	55.74	2475
1495	18757.37	2308.08	10481.37	70.33	2542

Table 6.4.3.a. — UNIF/FIFO Scheduling (part a) - Bipolar

start interval	mean departure interval	std. dev. departure interval	mean bottleneck queue	std. dev. bottleneck queue
2000	2000.50	890.55	0.93	1.55
1940	1939.98	876.56	1.13	1.73
1880	1880.34	972.30	1.44	2.10
1820	1819.65	1031.05	1.79	2.47
1760	1760.03	964.00	2.12	2.82
1700	1699.70	946.22	2.60	3.33
1675	1674.95	988.71	2.91	3.61
1655	1655.03	996.25	3.14	3.83
1625	1625.04	966.49	3.49	4.17
1595	1595.47	1025.47	NA	NA
1565	1565.48	986.79	4.73	4.93
1535	1535.18	998.67	6.44	5.53
1495	1498.75	982.78	12.31	7.14

Table 6.4.3.b. — UNIF/FIFO Scheduling (part b) - Bipolar

safety factor × m	mean delay	± 95% delay confidence interval	std. dev. delay	% delay/ cycle time	job starts
1.0	4267.15	165.99	2589.64	34.64	2499
1.3	5138.86	205.73	2868.91	38.89	2531
1.6	6126.85	248.31	3187.83	43.21	2549
1.9	7028.25	247.29	3262.89	46.52	2554
2.2	8228.79	260.96	3648.70	50.48	2558
2.5	9068.39	267.93	3649.97	52.87	2558
2.8	10310.02	283.63	3924.13	56.05	2558
3.4	12395.65	356.32	4110.73	60.55	2556
4.0	14448.73	391.87	4234.76	64.15	2558

Table 6.4.4.a. — SA/SA Scheduling (part a) – Bipolar

Note: m = 2 is the number of machines at the bottleneck.

safety factor × m	mean departure interval	std. dev. departure interval	mean bottleneck queue	std. dev. bottleneck queue
1.0	1520.41	1216.89	2.75	1.86
1.3	1498.84	1239.66	3.35	1.94
1.6	1488.94	1285.96	4.05	2.09
1.9	1487.69	1343.12	4.65	2.12
2.2	1486.12	1420.12	5.46	2.34
2.5	1485.41	1491.53	6.03	2.24
2.8	1485.32	1522.85	6.86	2.43
3.4	1485.13	1637.79	8.26	2.44
4.0	1483.46	1782.85	9.64	2.41

Table 6.4.4.b. — SA/SA Scheduling (part b) – Bipolar

Note: m = 2 is the number of machines at the bottleneck.

6.4.1 — Interpretation of Simulation Experiment - Bipolar

Once again SA/SA scheduling clearly outperformes UNIF/FIFO scheduling with regards to mean delay (Fig. 6.4.2) for the throughput range going from 96.4 to 98.8% of expected capacity.

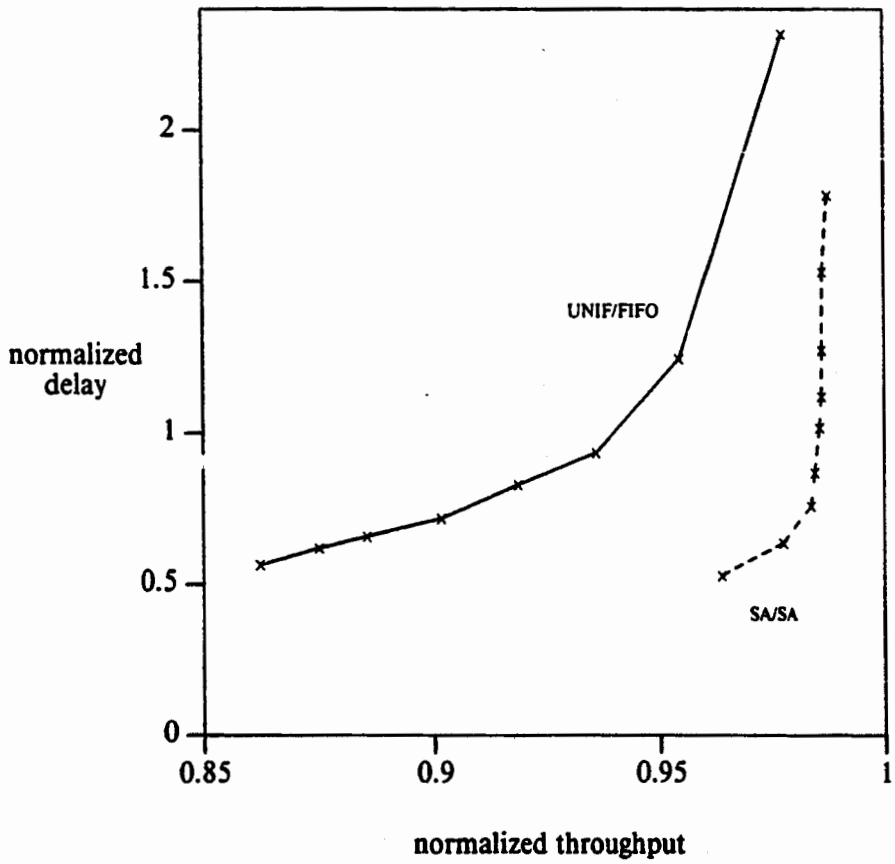

Fig. 6.4.2 — SA/SA vs UNIF/FIFO - Bipolar

In that range mean delay reductions of 50-73% were registered. UNIF/FIFO did produce schedules with less CVID (see Tables 6.4.3.b and 6.4.4.b).

6.5 — A Production Fab Queueing Network - SSi-Implant

We now compare SA scheduling with UNIF release and SRPT dispatching on a production wafer fab queueing network adapted from data gathered from a computer integrated manufacturing system at a Silicon Systems production fab. The topology of this network is given in Fig. 6.5.1. This fab has one bottleneck station, S_{17} (ion implantation).

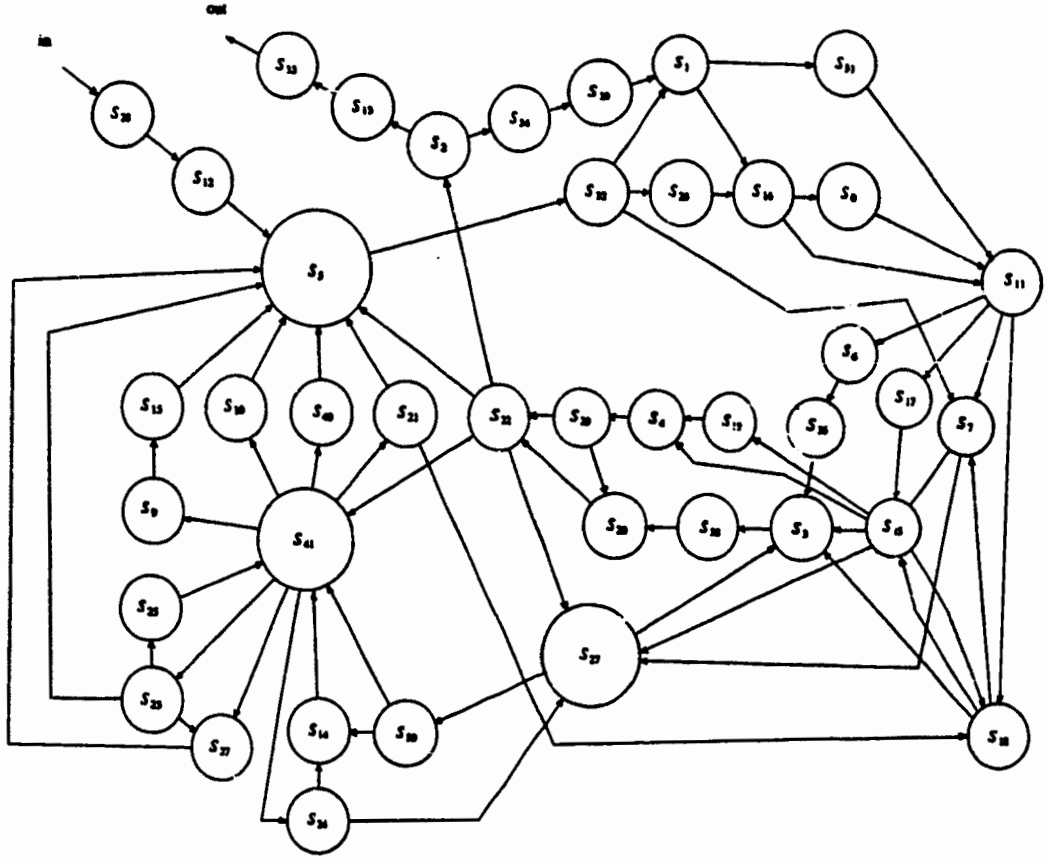

Fig. 6.5.1 — Network Topology - SSi-Implant

The network has 41 work stations and one process with a recipe length of 182 steps. Table 6.5.1 summarizes the work stations of this fab.

work station	number machines	load size	MTTR (mins)	MTBF (mins)
1	5	1	500.47	3022.27
2	1	4	460.50	4962.00
3	2	4	281.50	16637.50
4	2	4	281.50	16637.50
5	1	9	72.00	66852.00
6	1	9	42.00	111457.50
7	1	9	172.80	71592.30
8	1	1	15284.00	78228.00
9	2	4	850.15	6044.65
10	2	2	942.00	5668.50
11	3	1	0.00	113806.00
12	2	1	1792.36	32597.86
13	2	1	378.46	28305.46
14	1	4	1434.00	65833.50
15	1	4	913.00	71375.00
16	2	2	453.00	19522.50
17	1	2	10664.57	73076.57
18	2	4	4426.00	175978.00
19	1	2	1392.00	101055.00
20	1	1	13357.09	51441.09
21	2	4	715.38	4922.88
22	3	1	6748.50	114954.50
23	2	4	954.00	6427.50
24	2	4	1006.50	5320.50
25	1	2	372.00	2275.50
26	3	1	500.47	3022.27
27	1	1	264.75	1256.25
28	1	1	517.64	8661.14
29	1	2	23596.00	87832.00
30	4	1	824.77	7306.27
31	6	1	184.80	9867.30
32	5	1	698.40	8046.40
33	1	1	6748.50	114954.50
34	1	4	1512.00	5853.00
35	2	1	295.38	3193.38
36	1	1	1321.85	6502.85
37	2	4	1073.54	5078.54
38	2	4	114.00	35604.00
39	2	4	138.00	28021.50
40	3	1	2722.50	9895.50
41	1	6	167.54	1787.54

Table 6.5.1 — Work Stations – SSi-Implant

Machines in stations S_{11} are assumed to never fail. The single process recipe of

the fab is given in Table 6.5.2. The total duration of processing for this recipe is 11,695 minutes. Rework is assumed not to be required.

step number	work station	step duration (mins)
1	28	45
2	12	20
3	5	90
4	32	90
5	26	45
6	16	50
7	8	30
8	11	50
9	7	60
10	35	50
11	3	50
12	38	35
13	20	30
14	22	15
15	5	90
16	32	90
17	1	45
18	16	35
19	11	35
20	7	60
21	27	30
22	3	50
23	38	30
24	22	15
25	41	90
26	9	600
27	15	30
28	5	90
29	32	90
30	1	45
31	16	35
32	11	30
33	7	60
34	27	30
35	3	50
36	38	30
37	22	15
38	27	30
39	39	45
40	41	90

Table 6.5.2 — Process Recipe – SSi-Implant (continues)

step number	work station	step duration (mins)
41	21	600
42	5	90
43	32	90
44	1	30
45	16	35
46	11	30
47	18	45
48	7	60
49	35	45
50	27	90
51	3	50
52	38	30
53	22	15
54	41	90
55	21	300
56	18	30
57	35	90
58	39	45
59	14	30
60	41	90
61	24	120
62	14	30
63	41	90
64	24	180
65	27	30
66	39	45
67	41	75
68	37	270
69	27	90
70	39	45
71	5	90
72	32	90
73	26	50
74	16	35
75	8	20
76	11	30
77	7	60
78	35	60
79	3	50
80	38	30

Table 6.5.2 — Process Recipe - SSi-Implant (continued)

step number	work station	step duration (mins)
81	20	30
82	22	15
83	5	90
84	32	90
85	1	30
86	16	35
87	11	30
88	7	60
89	27	30
90	3	50
91	38	30
92	22	15
93	39	45
94	41	75
95	23	300
96	37	180
97	5	90
98	32	90
99	7	60
100	35	60
101	18	60
102	3	50
103	38	30
104	22	15
105	41	90
106	10	90
107	5	90
108	32	90
109	1	30
110	16	35
111	11	30
112	7	60
113	35	60
114	3	50
115	38	30
116	22	15
117	5	90
118	32	90
119	1	30
120	16	35

Table 6.5.2 — Process Recipe - SSi-Implant (continued)

step number	work station	step duration (mins)
121	11	30
122	18	30
123	7	60
124	27	90
125	3	50
126	38	30
127	22	15
128	5	90
129	32	90
130	1	30
131	16	35
132	11	30
133	7	60
134	27	90
135	3	50
136	38	30
137	22	15
138	41	75
139	23	120
140	25	90
141	41	75
142	23	180
143	5	90
144	32	90
145	26	50
146	16	35
147	8	20
148	11	30
149	6	60
150	36	45
151	3	50
152	38	30
153	20	30
154	22	30
155	41	75
156	40	60
157	5	90
158	32	90
159	26	50
160	16	35

Table 6.5.2 — Process Recipe - SSi-Implant (continued)

step number	work station	step duration (mins)
161	8	20
162	11	30
163	17	90
164	35	15
165	4	50
166	29	30
167	20	15
168	22	30
169	2	90
170	34	120
171	30	120
172	1	30
173	31	15
174	11	15
175	35	45
176	19	30
177	4	50
178	29	30
179	22	30
180	2	90
181	13	60
182	33	15

Table 6.5.2 — Process Recipe – SSi-Implant (continued)

Hot lots are not allowed to be started. The nominal capacity of the fab network is one lot every 510.00 minutes (19.8 lots/week). Its expected capacity is one lot every 646.18 minutes (15.6 lots/week). Simulations are run with a horizon H = 2.5 minutes (about 57 months), each requiring approximately one hour of CPU time on the Cray X-MP/14.

Tables 6.5.3.a and 6.5.3.b summarize runs with UNIF/SRPT scheduling, while Tables 6.5.4.a and Table 6.5.4.b show results for SA/SA scheduling.

start interval	mean delay	± 95% delay confidence interval	std. dev. delay	% delay/ cycle time	job starts
1000	34246.57	5395.83	25195.89	74.88	2376
950	36218.12	5379.75	24741.74	75.59	2500
850	41139.06	4897.90	24793.14	78.24	2794
750	55828.20	4622.96	24115.46	82.74	3167
700	67664.73	4219.06	23316.98	85.36	3393
675	77314.17	3847.52	21922.82	86.89	3518
650	98508.23	3165.40	18876.89	89.39	3654
630	126529.32	4685.71	26827.19	91.57	3770
615	154528.77	7672.96	41539.80	92.97	3862

Table 6.5.3.a. — UNIF/SRPT Scheduling (part a) - SSi-Implant

start interval	mean departure interval	std. dev. departure interval	mean bottleneck queue	std. dev. bottleneck queue
1000	1028.56	4390.98	8.02	12.51
950	969.42	4141.39	9.58	13.66
850	875.16	3920.89	15.12	18.17
750	769.45	3755.12	30.95	26.31
700	718.63	3561.14	46.28	31.69
675	694.41	3472.06	60.80	34.27
650	668.75	3413.29	90.52	39.19
630	673.59	3633.79	133.21	49.42
615	659.11	3585.00	175.56	67.30

Table 6.5.3.b. — UNIF/SRPT Scheduling (part b) - SSi-Implant

safety factor × m	mean delay	± 95% delay confidence interval	std. dev. delay	% delay/ cycle time	job starts
1.0	31683.88	3751.08	21410.49	73.20	2411
1.6	43999.04	4383.57	24274.41	79.17	2821
2.5	59222.63	4857.40	28137.22	83.72	3049
3.4	72361.52	5343.33	30392.46	86.17	3286
4.0	78184.96	5024.20	29717.42	87.09	3394
4.6	86022.43	4627.43	27423.92	88.06	3427
5.2	93432.15	5097.97	30741.34	88.95	3484
5.5	95096.49	5249.88	31499.02	89.07	3562

Table 6.5.4.a. — SA/SA Scheduling (part a) - SSi-Implant

Note: m = 1 is the number of machines at the bottleneck.

safety factor × m	mean departure interval	std. dev. departure interval	mean bottleneck queue	std. dev. bottleneck queue
1.0	1013.02	4525.48	8.59	10.52
1.6	865.94	4357.06	16.33	16.76
2.5	800.81	4043.40	28.37	24.73
3.4	719.94	3765.06	42.59	32.22
4.0	696.84	3776.32	52.09	36.17
4.6	672.58	3829.06	60.39	39.44
5.2	688.53	3981.23	67.81	42.96
5.5	654.24	3762.82	69.05	39.51

Table 6.5.4.b. — SA/SA Scheduling (part b) - SSi-Implant

Note: m = 1 is the number of machines at the bottleneck.

6.5.1 — Interpretation of Simulation Experiment - SSi-Implant

In SSi-implant, where, unlike the other examples, the first visit to the bottleneck only occurs at step number 21, SA scheduling only shows a clear improvement over UNIF/SRPT for throughput values greater than 94% of expected capacity. Because of sampling variability there were no statistically significant differences between the

two policies below that throughput rate. In the high end of this range (i.e. close to capacity) SA is able to produce schedules with approximately 40% less delay than those produced by UNIF/SRPT (Fig. 6.5.2).

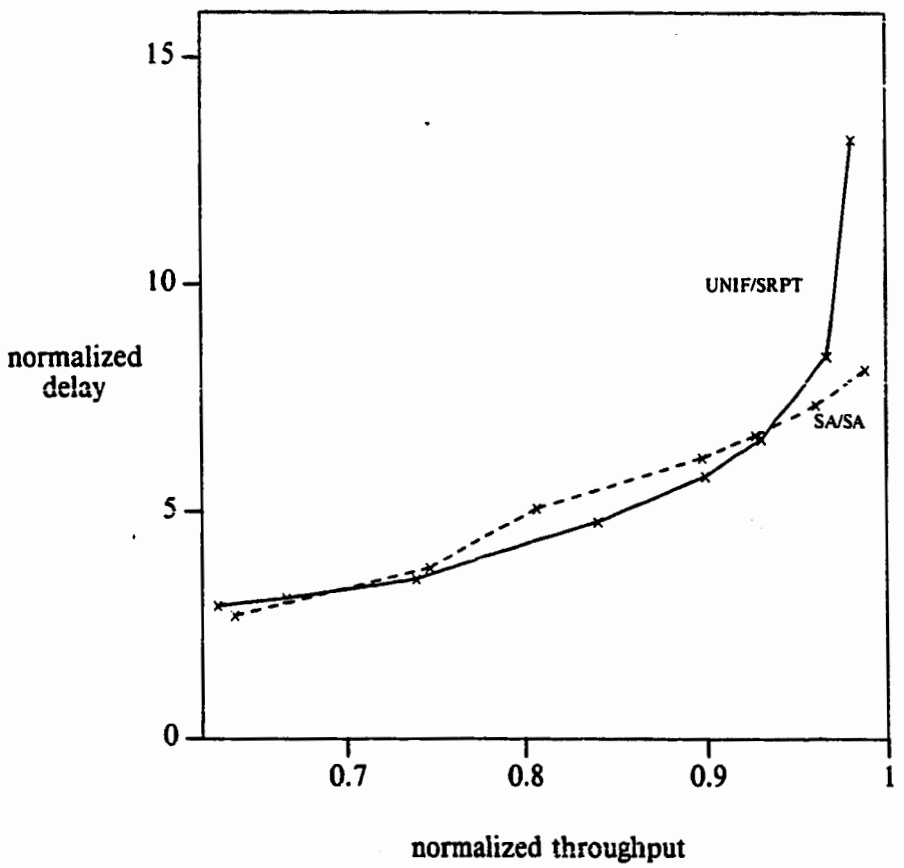

Fig. 6.5.2 – SA/SA vs UNIF/SRPT - SSi-Implant

CVID differences are negligible throughout (see Tables 6.5.3.b and 6.5.4.b).

6.6 – Another Production Fab Queueing Network - SSi-Aligner

In this Section we compare SA scheduling with UNIF release and SRPT dispatching on a production wafer fab queueing network generated with data obtained from the same computer integrated manufacturing system as in the last section. We modify the number of machines at some work stations so as to make the aligners, station S_5,

the single bottleneck station.

As stated earlier, the network has 41 work stations and one process with a recipe length of 182 steps. Table 6.6.1 summarizes the work stations of this fab.

work station	number machines	load size	MTTR (mins)	MTBF (mins)
1	5	1	500.47	3022.27
2	1	4	460.50	4962.00
3	2	4	281.50	16637.50
4	2	4	281.50	16637.50
5	2	1	1000.00	6000.00
6	1	9	42.00	111457.50
7	1	9	172.80	71592.30
8	5	1	15284.00	78228.00
9	2	4	850.15	6044.65
10	2	2	942.00	5668.50
11	3	1	0.00	113806.00
12	2	1	1792.36	32597.86
13	2	1	378.46	28305.46
14	1	4	1434.00	65833.50
15	1	4	913.00	71875.00
16	2	2	453.00	19522.50
17	5	2	10664.57	73076.57
18	2	4	4426.00	175978.00
19	1	2	1392.00	101055.00
20	5	1	13357.09	51441.09
21	2	4	715.38	4922.88
22	3	1	6748.50	114954.50
23	2	4	954.00	6427.50
24	2	4	1006.50	5320.50
25	1	2	372.00	2275.50
26	3	1	500.47	3022.27
27	5	1	264.75	1256.25
28	1	1	517.64	8661.14
29	1	2	23596.00	87832.00
30	4	1	824.77	7306.27
31	6	1	184.80	9867.30
32	10	1	698.40	8048.40
33	1	1	6748.50	114954.50
34	1	4	1512.00	5853.00
35	4	1	295.38	3193.38
36	1	1	1321.85	6502.85
37	2	4	1073.54	5078.54
38	2	4	114.00	35604.00
39	2	4	138.00	28021.50
40	3	1	2722.50	9895.50
41	1	6	167.54	1787.54

Table 6.6.1 — Work Stations – SSi-Aligner

Machines in stations S_{11} are assumed to never fail. The single process recipe of

the fab is the same as in Table 6.5.2.

As before, hot lots are not allowed to be started. The nominal capacity of the fab network is one lot every 540.00 minutes (18.67 lots/week). Its expected capacity is one lot every 630.00 minutes (16.1 lots/week). Simulations are run with a horizon H = 2 million minutes (about 46 months), each requiring approximately 50 minutes of CPU time on the Cray X-MP/14.

Tables 6.6.2.a and 6.6.2.b summarize runs with UNIF/SRPT scheduling, while Tables 6.6.3.a and Table 6.6.3.b show results for SA/SA scheduling.

start interval	mean delay	± 95% delay confidence interval	std. dev. delay	% delay/ cycle time	job starts
640	17204.50	2337.97	12228.57	59.49	2969
635	18304.03	2383.48	12503.37	60.99	2992
630	21171.77	2441.49	12446.01	64.41	3016
625	25418.44	2685.52	13721.05	68.53	3041
620	31464.80	3093.38	15609.13	72.93	3064

Table 6.6.2.a. — UNIF/SRPT Scheduling (part a) - SSi-Aligner

start interval	mean departure interval	std. dev. departure interval	mean bottleneck queue	std. dev. bottleneck queue
640	640.87	2350.92	12.25	7.03
635	636.58	2359.42	13.86	7.16
630	634.29	2322.03	18.54	7.61
625	630.77	2354.51	25.44	10.26
620	628.94	2313.16	34.96	15.34

Table 6.6.2.b. — UNIF/SRPT Scheduling (part b) - SSi-Aligner

safety factor × m	mean delay	± 95% delay confidence interval	std. dev. delay	% delay/ cycle time	job starts
1.2	15218.28	2213.99	12134.98	56.43	2945
1.4	15224.22	2200.99	11994.12	56.54	2950
1.6	16142.28	2219.82	11903.33	57.90	2991
1.8	16362.69	2249.93	12021.93	58.20	2993

Table 6.6.3.a. — SA/SA Scheduling (part a) – SSi-Aligner

Note: m = 1 is the number of machines at the bottleneck.

safety factor × m	mean departure interval	std. dev. departure interval	mean bottleneck queue	std. dev. bottleneck queue
1.2	643.53	2346.77	8.71	6.96
1.4	643.37	2353.50	8.92	7.12
1.6	632.44	2316.62	10.21	7.08
1.8	631.70	2340.79	10.47	7.26

Table 6.6.3.b. — SA/SA Scheduling (part b) – SSi-Aligner

Note: m = 1 is the number of machines at the bottleneck.

6.6.1 — Interpretation of Simulation Experiment - SSi-Aligner

For SSi-Aligner the range of throughput values generated went from 98-100.2% of expected capacity. In this range SA scheduling produced mean delays varying from 88% to 65% of those produced by UNIF/SRPT (Fig. 6.6.2).

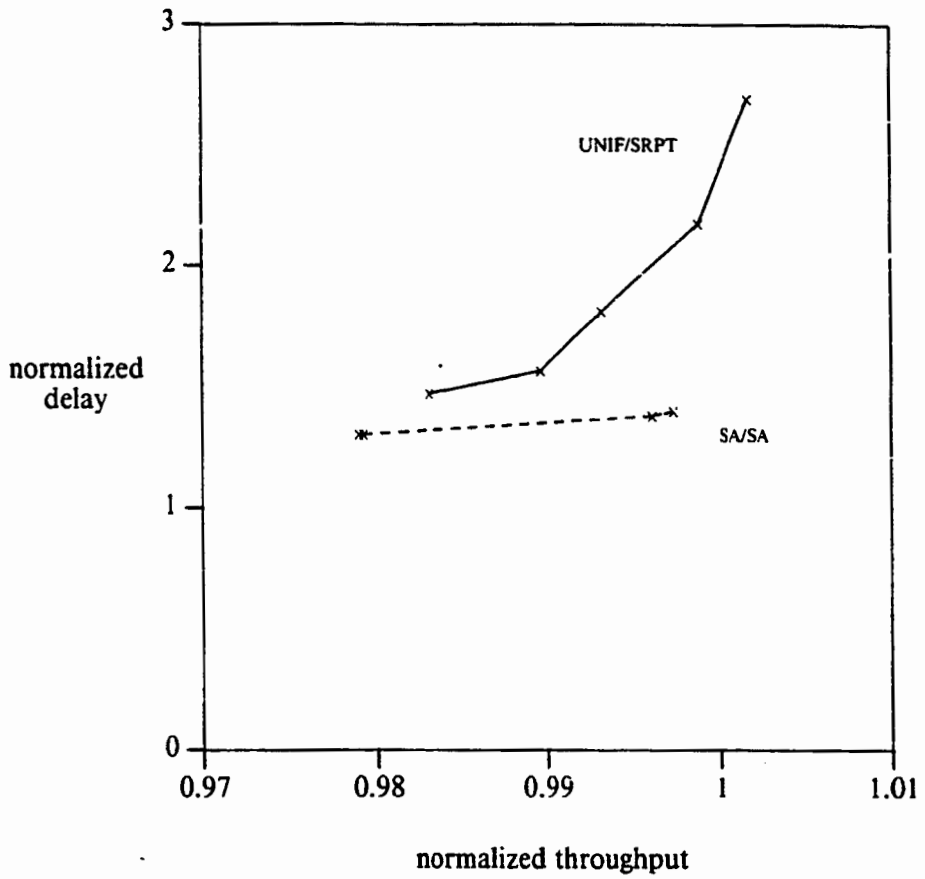

Fig. 6.6.2 — SA/SA vs UNIF/SRPT - SSi-Aligner

6.7 — Summary

In this Chapter we present results of testing many scheduling policies on several wafer fab queueing networks running FabSim on the Cray X-MP/14 at U.C.-Berkeley. Networks vary from small (5 stations) to large (41 stations) in size. Starvation Avoidance (SA) compares favorably against the scheduling policies tested, displaying increased improvement as the throughput approaches the network capacity.