STUDIA UNIVERSITATIS BABEȘ-BOLYAI
Engineering 65(1) 2020 doi:10.24193/subbeng.2020.1.1

Simulation of a waiting system

Olga-Ioana Amariei, Codruța-Oana Hamat

This paper analyzes an existing production system in an industrial hall, consisting of 11 machines (service stations) and 13 intermediate stocks (queues), where 4 types of parts are processed and assembled, with the aim of increasing production volume. The Queuing System Simulation module of the WinQSB software is used, which allows the simulation of waiting systems.

Keywords*: queues, serving stations, average processing time, average waiting time, average stationary time, standard deviation*

1. Introduction

Probability theory and mathematical statistics are inevitable in the analysis of simple or complex waiting systems, because there are constantly situations of uncertainty both in terms of time of arrival and duration of services [2].

Waiting, forming a "waiting line" or a "queue" is a common phenomenon in the activity of an organization [9].

The design of a “waiting” model implies the knowledge of some characteristics of the studied phenomenon regarding the average number of: units in the system, of the units about to be served, of units in the queue, of unoccupied stations, of units arriving in a given time as well as the average time: serving, waiting in the system and waiting in a line [8].

The basic process in models for waiting phenomena consists of units generated over time by an input source, which require to be served by one or more serving stations. Units that cannot be served immediately will form waiting lines or queues. The most commonly used serving discipline is FIFO (first come, first served) [1].

2. Illustrative example

The production system (fig.2) required to be analyzed consists of 11 machines (serving stations or servers) on which 4 types of parts are processed and assembled (R1 ÷ R4).

Part R1 is processed on machines M1 and M5, and part R2 on machines M2 and M6, then a piece of each part type is assembled on machine M8 (Subassembly 1). Parts R3 and R4 are processed on machines M3 and M4, and then a piece of each part is assembled on machine M7 (Subassembly 2). On the M9 machine, the two subassemblies are assembled, which are then processed on the M10 and M11 machines, both machines being identical.

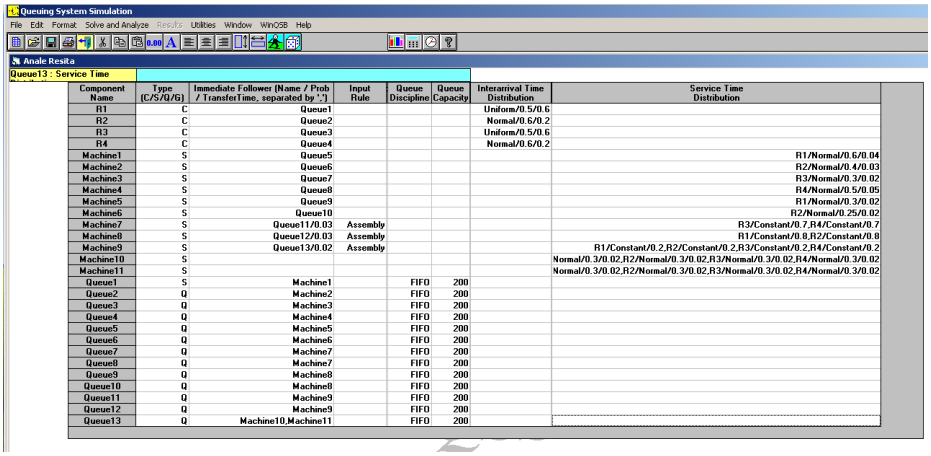
If a machine from the first six (M1 ÷ M6) is occupied, the parts wait for the release of that machine in the container corresponding to that machine, the so-called queues (intermediate stocks) between different jobs. There are also queues after the machines where the subassemblies are made and the assembly, more precisely, the M7, M8 and M9 machines. In the case of M10 and M11 machines, processing is carried out on any of them which are available.

It is considered that all parts are processed and assembled according to the FIFO serving discipline, and the storage space for the parts to be processed and assembled is limited and therefore the maximum capacity for each queue, which is equal to 200, is specified.

The duration of the time intervals between two consecutive arrivals of parts R1 to machine M1 is a uniformly distributed probabilistic quantity between 0.5 and 0.6 hours. The duration of the time intervals between two consecutive arrivals of parts R2 to the machine M2 is a probabilistic quantity with normal distribution with an average of 0.6 hours and the standard deviation 0.2 hours. The duration of the time intervals between two consecutive arrivals of parts R3 at machine M3 is a uniformly distributed probabilistic quantity between 0.5 and 0.6 hours. The duration of the time intervals between two consecutive arrivals of parts R4 to the machine M4 is a probabilistic quantity with normal distribution with an average of 0.6 hours and the standard deviation 0.2 hours.

The machining time on the M1 machine is a probabilistic quantity with normal distribution with an average of 0.6 hours/part and the standard deviation 0.04 hours/part, for the M2 machine it is a probabilistic quantity with a normal distribution with an average of 0.4 hours/part and standard deviation 0.03 hour/part, for the M3 machine is a probabilistic size with normal distribution with an average of 0.3 hours/part and standard deviation 0.02 hours/part, for the M4 machine is a probabilistic size with normal distribution with an average of 0.5 hours/part and standard deviation 0.05 hours part, for the M5 machine is a probabilistic quantity with normal distribution with an average of 0.3 hours/part and the standard deviation 0.02 hours/part and for the M6 machine is a

probabilistic quantity with normal distribution averaging 0.25 hours/part and standard deviation 0.02 hours/part. The assembly time on M7 for subassembly 1 is a constant of 0.7 hours, for subassembly 2 (machine M8) is a constant of 0.8 hours, and for the assembly (machine M9) is 0.2 hours. Finally, the assembly is processed on M10 and M11 machines, and the processing time is a probabilistic quantity with normal distribution, with an average of 0.3 hours/part and the standard deviation 0.02 hours/part. The transfer time of subassembly 1 from machine M7 to queue 11 and that of subassembly 2 from machine M8 to queue 12 is 0.03 hours, and that of assembly from M9 to queue 13 is 0.02 hours.



Component Name	Type (C/S/Q/G)	Immediate Follower (Name / Prob / TransferTime, separated by ",")	Input Rule	Queue Discipline	Queue Capacity	Interarrival Time Distribution	Service Time Distribution
R1	C	Queue1				Uniform/0.5/0.6	
R2	C	Queue2				Normal/0.6/0.2	
R3	C	Queue3				Uniform/0.5/0.6	
R4	C	Queue4				Normal/0.6/0.2	
Machine1	S	Queue5					R1/Normal/0.6/0.04
Machine2	S	Queue6					R2/Normal/0.4/0.03
Machine3	S	Queue7					R3/Normal/0.3/0.02
Machine4	S	Queue8					R4/Normal/0.5/0.05
Machine5	S	Queue9					R1/Normal/0.3/0.02
Machine6	S	Queue10					R2/Normal/0.25/0.02
Machine7	S	Queue11/0.03	Assembly				R3/Constant/0.7,R4/Constant/0.7
Machine8	S	Queue12/0.03	Assembly				R1/Constant/0.8,R2/Constant/0.8
Machine9	S	Queue13/0.02	Assembly				R1/Constant/0.2,R2/Constant/0.2,R3/Constant/0.2,R4/Constant/0.2
Machine10	S						Normal/0.3/0.02,R2/Normal/0.3/0.02,R3/Normal/0.3/0.02,R4/Normal/0.3/0.02
Machine11	S						Normal/0.3/0.02,R2/Normal/0.3/0.02,R3/Normal/0.3/0.02,R4/Normal/0.3/0.02
Queue1	S	Machine1		FIFO	200		
Queue2	Q	Machine2		FIFO	200		
Queue3	Q	Machine3		FIFO	200		
Queue4	Q	Machine4		FIFO	200		
Queue5	Q	Machine5		FIFO	200		
Queue6	Q	Machine6		FIFO	200		
Queue7	Q	Machine7		FIFO	200		
Queue8	Q	Machine8		FIFO	200		
Queue9	Q	Machine9		FIFO	200		
Queue10	Q	Machine8		FIFO	200		
Queue11	Q	Machine9		FIFO	200		
Queue12	Q	Machine9		FIFO	200		
Queue13	Q	Machine10,Machine11		FIFO	200		

Figure 1. Input data of the problem

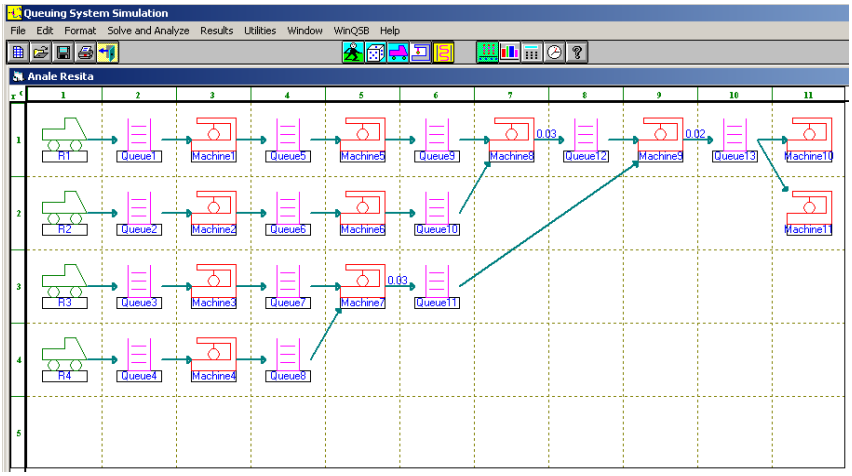


Figure 2. Graphic representation of the production system

After entering the problem data (fig.1) the simulation of 100 hours is specified. The results are collected starting with the 20th hour of operation, in order to remove the influence of the initial conditions, when the intermediate stocks are zero [2],[5].

2.1. Solving the problem

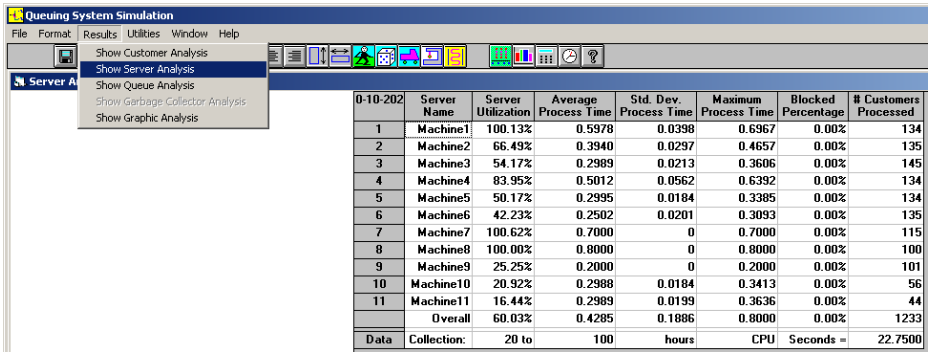
The program provides results for three types of analysis: analysis of customers who have entered the system (fig.3), analysis of the use of service stations (fig.4) and queue analysis (fig.5).

0-10-202	Result	R1	R2	R3	R4	Overall
1	Total Number of Arrival	146	134	146	134	560
2	Total Number of Balking	0	0	0	0	0
3	Average Number in the System (L)	36.7813	27.3391	35.1105	12.2735	111.5043
4	Maximum Number in the System	60	43	58	24	185
5	Current Number in the System	60	42	58	23	183
6	Number Finished	100	0	0	0	100
7	Average Process Time	4.3316	0	0	0	4.3316
8	Std. Dev. of Process Time	0.0766	0	0	0	0.0766
9	Average Waiting Time (Wq)	56.5872	0	0	0	56.5872
10	Std. Dev. of Waiting Time	23.4452	0	0	0	23.4452
11	Average Transfer Time	0	0	0	0	0
12	Std. Dev. of Transfer Time	0	0	0	0	0
13	Average Flow Time (W)	20.1584	0	0	0	20.1584
14	Std. Dev. of Flow Time	7.3957	0	0	0	7.3957
15	Maximum Flow Time	32.9214	0	0	0	32.9214
	Data Collection: 20 to	100 hours				
	CPU Seconds =	22.7500				

Figure 3. Show Customer Analysis. Current situation

After simulating the 100 hours, it is found that during the 80 hours taken into account, 146 parts R1 and R3 enter the system, and also 134 parts R2 and R4. On average per hour there are 36.78 R1 parts in the system; 27.34 - R2; 35.11 - R3 and 12.27 - R4. The total number of products obtained by processing and assembly is 100 finished products.

The average processing time of a finished product is 4.3316 hours, with a standard deviation of 0.0766 hours. The average waiting time for a finished product is 56.5872 hours, with a standard deviation of 23.4452 hours. The average time spent in the system by a finished product is 20.1584 hours, with a standard deviation of 7.3957 hours, and the total time spent in the system by a finished product is 32.9214 hours.

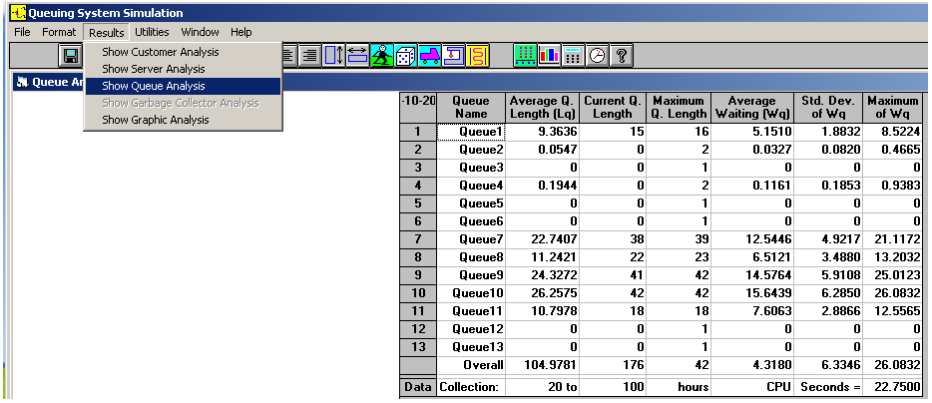


0-10-202	Server Name	Server Utilization	Average Process Time	Std. Dev. Process Time	Maximum Process Time	Blocked Percentage	# Customers Processed
1	Machine1	100.13%	0.5978	0.0398	0.6967	0.00%	134
2	Machine2	66.49%	0.3940	0.0297	0.4657	0.00%	135
3	Machine3	54.17%	0.2989	0.0213	0.3606	0.00%	145
4	Machine4	83.95%	0.5012	0.0562	0.6392	0.00%	134
5	Machine5	50.17%	0.2995	0.0184	0.3385	0.00%	134
6	Machine6	42.23%	0.2502	0.0201	0.3093	0.00%	135
7	Machine7	100.62%	0.7000	0	0.7000	0.00%	115
8	Machine8	100.00%	0.8000	0	0.8000	0.00%	100
9	Machine9	25.25%	0.2000	0	0.2000	0.00%	101
10	Machine10	20.92%	0.2988	0.0184	0.3413	0.00%	56
11	Machine11	16.44%	0.2989	0.0199	0.3636	0.00%	44
	Overall	60.03%	0.4285	0.1886	0.8000	0.00%	1233
Data	Collection:	20 to	100	hours	CPU	Seconds =	22.7500

Figure 4. Show Server Analysis. Current situation

From the analysis related to the use of machines (fig.4) it is observed that the M10 and M11 machines have the lowest degree of loading, namely: 20.92% and 16.44%, and the number of products processed on each of these two machines is of 56 and 44 pieces. In this case, the solution would be to remove the M11 machine, which would increase the load of the M10 machine.

Also in the table with the analysis of service stations a load of over 100% can be observed on the M1 and M7 machines, machines that can be considered "narrow place". This can be remedied by supplementing with another machine of each type.



-10-20	Queue Name	Average Q. Length (Lq)	Current Q. Length	Maximum Q. Length	Average Waiting (Wq)	Std. Dev. of Wq	Maximum of Wq
1	Queue1	9.3636	15	16	5.1510	1.8832	8.5224
2	Queue2	0.0547	0	2	0.0327	0.0820	0.4665
3	Queue3	0	0	1	0	0	0
4	Queue4	0.1944	0	2	0.1161	0.1853	0.9383
5	Queue5	0	0	1	0	0	0
6	Queue6	0	0	1	0	0	0
7	Queue7	22.7407	38	39	12.5446	4.9217	21.1172
8	Queue8	11.2421	22	23	6.5121	3.4880	13.2032
9	Queue9	24.3272	41	42	14.5764	5.9108	25.0123
10	Queue10	26.2575	42	42	15.6439	6.2850	26.0832
11	Queue11	10.7978	18	18	7.6063	2.8866	12.5565
12	Queue12	0	0	1	0	0	0
13	Queue13	0	0	1	0	0	0
	Overall	104.9781	176	42	4.3180	6.3346	26.0832
Data	Collection:	20 to	100	hours	CPU	Seconds =	22.7500

Figure 5. Show Queue Analysis. Current situation

From the analysis of intermediate stocks (fig.5) it can be seen that queue 10 has the longest average length, of 26.2575 products, as well as the longest average waiting time of 15.6439 hours. Queue 10 consists of parts R2 waiting to be assembled with parts R1 on the machine M8. The possible causes of the wait are: either the machine M8 is fully occupied, or in queue 9 there are no parts R1 to be

assembled with the parts R2 on the machine M8. The Show Server Analysis table shows that the M8 machine has a load rate of 100%, so this is the cause of the wait in the system and not the one related to queue 9, which has the second largest average length equal to 24.3272 products. To fix the problem, another M8 machine will be introduced into the system.

Following the three analyzes performed, three solutions are proposed:

1. disposal of the M11 machine;
2. additional M1 and M7 machines;
3. supplementing the M8 machine.

2.2. Supplementation with service stations

The production system is supplemented with three more machines (M1b, M7b and M8b) and we obtain the three analyzes presented in the section 2.1. (fig. 6, 7 and 8).

10-11-2020	Result	R1	R2	R3	R4	Overall
1	Total Number of Arrival	145	133	145	133	556
2	Total Number of Balking	0	0	0	0	0
3	Average Number in the System (L)	14.4917	1.1616	14.8868	0.9167	31.4568
4	Maximum Number in the System	21	3	21	3	48
5	Current Number in the System	20	1	21	1	43
6	Number Finished	133	0	0	0	133
7	Average Process Time	4.3435	0	0	0	4.3435
8	Std. Dev. of Process Time	0.0785	0	0	0	0.0785
9	Average Waiting Time (Wq)	13.1894	0	0	0	13.1894
10	Std. Dev. of Waiting Time	4.3592	0	0	0	4.3592
11	Average Transfer Time	0	0	0	0	0
12	Std. Dev. of Transfer Time	0	0	0	0	0
13	Average Flow Time (W)	8.7134	0	0	0	8.7134
14	Std. Dev. of Flow Time	2.2582	0	0	0	2.2582
15	Maximum Flow Time	11.8860	0	0	0	11.8860
	Data Collection: 20 to	100 hours				
	CPU Seconds =	23.9220				

Figure 6. Show Customer Analysis. Modified system 1

10-11-2020	Server Name	Server Utilization	Average Process Time	Std. Dev. Process Time	Maximum Process Time	Blocked Percentage	# Customers Processed
1	Machine1a	54.60%	0.5983	0.0383	0.7106	0.00%	73
2	Machine1b	53.64%	0.5960	0.0442	0.7311	0.00%	72
3	Machine2	66.89%	0.4024	0.0311	0.4835	0.00%	133
4	Machine3	54.63%	0.2994	0.0203	0.3368	0.00%	146
5	Machine4	82.25%	0.4947	0.0506	0.6223	0.00%	133
6	Machine5	53.87%	0.2993	0.0212	0.3414	0.00%	144
7	Machine6	41.53%	0.2517	0.0209	0.3112	0.00%	132
8	Machine7a	56.87%	0.7000	0.0003	0.7000	0.00%	65
9	Machine7b	58.62%	0.7000	0.0001	0.7000	0.00%	67
10	Machine8a	69.00%	0.8000	0	0.8000	0.00%	69
11	Machine8b	63.00%	0.8000	0	0.8000	0.00%	63
12	Machine9	33.00%	0.2000	0.0002	0.2000	0.00%	132
13	Machine10	30.47%	0.3010	0.0192	0.3593	0.00%	81
14	Machine11	19.20%	0.2954	0.0211	0.3359	0.00%	52
	Overall	52.68%	0.4332	0.1950	0.8000	0.00%	1362
Data	Collection:	20 to	100	hours	CPU	Seconds =	23.9220

Figure 7. Show Server Analysis. Modified system 1

Following the three analyzes made on the new production system, the following conclusions can be drawn:

- the number of finished products obtained increased by 33 pieces;
- on average, there are fewer parts of each type per hour and also the maximum number of parts decreased from 60 to 21 for part R1, from 43 to 3 for part R2, 58 to 21 for the R3 part and 24 to 3 for the R4 part,
- the total time spent by a finished product decreased from 32.9214 hours to 11.886 hours;
- the average time spent on a finished product decreased from 20.1854 hours to 8.7134 hours;
- the loading of the machines is not very good, especially for the M11 machine, being 19.20%, which again leads to the elimination of the M11 machine (the first solution proposed in section 2.1)

10-11-2020	Queue Name	Average Q. Length (Lq)	Current Q. Length	Maximum Q. Length	Average Waiting (Wq)	Std. Dev. of Wq	Maximum of Wq
1	Queue1	0	0	1	0	0	0
2	Queue2	0.0748	0	1	0.0450	0.0895	0.3932
3	Queue3	0	0	1	0	0	0
4	Queue4	0.0991	0	2	0.0596	0.0977	0.5852
5	Queue5	0	0	1	0	0	0
6	Queue6	0	0	1	0	0	0
7	Queue7	13.0546	19	20	7.2418	2.2249	10.3671
8	Queue8	0	0	1	0	0	0
9	Queue9	9.3878	15	17	5.2479	1.8171	8.9457
10	Queue10	0.0053	0	1	0.0032	0.0148	0.1077
11	Queue11	0.1331	0	2	0.0807	0.1765	0.7094
12	Queue12	1.3301	1	5	0.8093	0.9587	2.8988
13	Queue13	0	0	1	0	0	0
	Overall	24.0848	35	20	1.0157	2.3961	10.3671
Data	Collection:	20 to	100	hours	CPU	Seconds =	23.9220

Figure 8. Show Queue Analysis. Modified system 1

2.3. Removing a service station

One of the solutions proposed in section 2.1 was the elimination of the M11 machine, which was also reached following the analyzes performed in section 2.2. The results obtained are almost identical to those obtained in section 2.2. The only change appears in Show Server Analysis, where the M10 machine increased the loading degree from 30.47% to 49.68%, meaning it also took over the loading degree of the removed machine (fig.9).

10-11-2020	Server Name	Server Utilization	Average Process Time	Std. Dev. Process Time	Maximum Process Time	Blocked Percentage	# Customers Processed
1	Machine1a	54.60%	0.5983	0.0383	0.7106	0.00%	73
2	Machine1b	53.64%	0.5960	0.0442	0.7311	0.00%	72
3	Machine2	66.89%	0.4024	0.0311	0.4835	0.00%	133
4	Machine3	54.63%	0.2994	0.0203	0.3368	0.00%	146
5	Machine4	82.25%	0.4947	0.0506	0.6223	0.00%	133
6	Machine5	53.87%	0.2993	0.0212	0.3414	0.00%	144
7	Machine6	41.53%	0.2517	0.0209	0.3112	0.00%	132
8	Machine7a	56.87%	0.7000	0.0003	0.7000	0.00%	65
9	Machine7b	58.62%	0.7000	0.0001	0.7000	0.00%	67
10	Machine8a	69.00%	0.8000	0	0.8000	0.00%	69
11	Machine8b	63.00%	0.8000	0	0.8000	0.00%	63
12	Machine9	33.00%	0.2000	0.0002	0.2000	0.00%	132
13	Machine10	49.68%	0.2988	0.0201	0.3593	0.00%	133
	Overall	56.74%	0.4332	0.1950	0.8000	0.00%	1362
Data	Collection:	20 to	100	hours	CPU	Seconds =	24.0160

Figure 9. Show Server Analysis. Modified system 2

A comparative graphical representation of the average and maximum processing times on the 13 machines is illustrated in Figure 10.

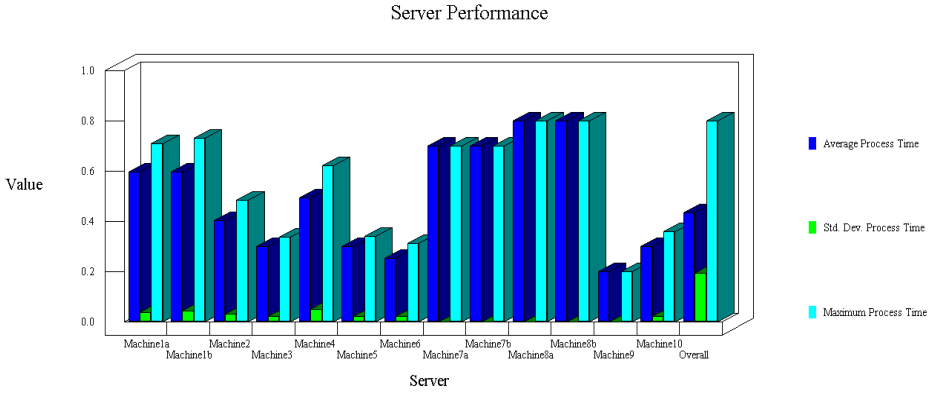


Figure 10. Graphical representation of the average and maximum processing times. Modified system 2

2.4. Removal of an additional service station

In section 2.2, the production system was supplemented with three machines, namely: M1b, M7b and M8b. Following the Show Server Analysis performed in section 2.1, the M1 machine was considered a “narrow place”, just like the M7 machine, although due to the fact that the number of products processed on the M1 machine is 134, identical to that of the other machines, it would not have been appropriate to supplement with another machine in this case.

10-11-2020	Result	R1	R2	R3	R4	Overall
1	Total Number of Arrival	146	129	146	145	566
2	Total Number of Balking	0	0	0	0	0
3	Average Number in the System (L)	14.1330	1.5430	13.2576	1.8888	30.8225
4	Maximum Number in the System	23	4	23	5	55
5	Current Number in the System	22	1	21	0	44
6	Number Finished	131	0	0	0	131
7	Average Process Time	4.3515	0	0	0	4.3515
8	Std. Dev. of Process Time	0.0821	0	0	0	0.0821
9	Average Waiting Time (Wq)	12.6417	0	0	0	12.6417
10	Std. Dev. of Waiting Time	4.5193	0	0	0	4.5193
11	Average Transfer Time	0	0	0	0	0
12	Std. Dev. of Transfer Time	0	0	0	0	0
13	Average Flow Time (W)	8.0077	0	0	0	8.0077
14	Std. Dev. of Flow Time	2.5197	0	0	0	2.5197
15	Maximum Flow Time	12.5426	0	0	0	12.5426
	Data Collection: 20 to	100 hours				
	CPU Seconds =	24.4380				

Figure 11. Show Customer Analysis. Modified system 3

10-11-2020	Server Name	Server Utilization	Average Process Time	Std. Dev. Process Time	Maximum Process Time	Blocked Percentage	# Customers Processed
1	Machine1	99.70%	0.5997	0.0404	0.7225	0.00%	133
2	Machine2	64.79%	0.3987	0.0336	0.4818	0.00%	130
3	Machine3	54.23%	0.2971	0.0181	0.3553	0.00%	146
4	Machine4	91.43%	0.5010	0.0484	0.6363	0.00%	146
5	Machine5	50.28%	0.3002	0.0191	0.3428	0.00%	134
6	Machine6	40.44%	0.2508	0.0166	0.2821	0.00%	129
7	Machine7a	63.87%	0.7000	0	0.7000	0.00%	73
8	Machine7b	63.00%	0.7000	0	0.7000	0.00%	72
9	Machine8a	68.00%	0.8000	0	0.8000	0.00%	68
10	Machine8b	63.00%	0.8000	0	0.8000	0.00%	63
11	Machine9	32.50%	0.2000	0.0002	0.2000	0.00%	130
12	Machine10	49.38%	0.3016	0.0203	0.3656	0.00%	131
	Overall	61.72%	0.4373	0.1960	0.8000	0.00%	1355
Data	Collection:	20 to	100	hours	CPU	Seconds =	24.4380

Figure 12. Show Server Analysis. Modified system 3

In this section the machine M1b is eliminated and the results are obtained, shown in figures 11, 12 and 13.

10-11-2020	Queue Name	Average Q. Length (Lq)	Current Q. Length	Maximum Q. Length	Average Waiting (Wq)	Std. Dev. of Wq	Maximum of Wq
1	Queue1	9.4093	16	16	5.1892	1.9953	8.3575
2	Queue2	0.0275	0	1	0.0170	0.0441	0.2329
3	Queue3	0	0	1	0	0	0
4	Queue4	0.9055	0	4	0.4996	0.5041	1.6847
5	Queue5	0	0	1	0	0	0
6	Queue6	0	0	1	0	0	0
7	Queue7	2.5076	5	6	1.3699	1.0190	2.9940
8	Queue8	0.0738	0	2	0.0404	0.1125	0.5614
9	Queue9	1.0720	3	4	0.6403	0.6987	2.1803
10	Queue10	0.4677	0	3	0.2948	0.3731	1.2650
11	Queue11	8.9183	14	16	5.0259	2.7902	8.9297
12	Queue12	0.0252	0	1	0.0154	0.0672	0.4968
13	Queue13	0.0000	0	1	0.0000	0.0003	0.0035
	Overall	23.4068	38	16	0.9952	2.0415	8.9297
Data	Collection:	20 to	100	hours	CPU	Seconds =	24.4380

Figure 13. Show Queue Analysis. Modified system 3

A comparative graphic image of the average and maximum processing times on the 12 machines is presented in fig.14. Also, in fig.15 are represented graphically the average and maximum values of the intermediate stocks, respectively of the average and maximum lengths of the queues in the system.

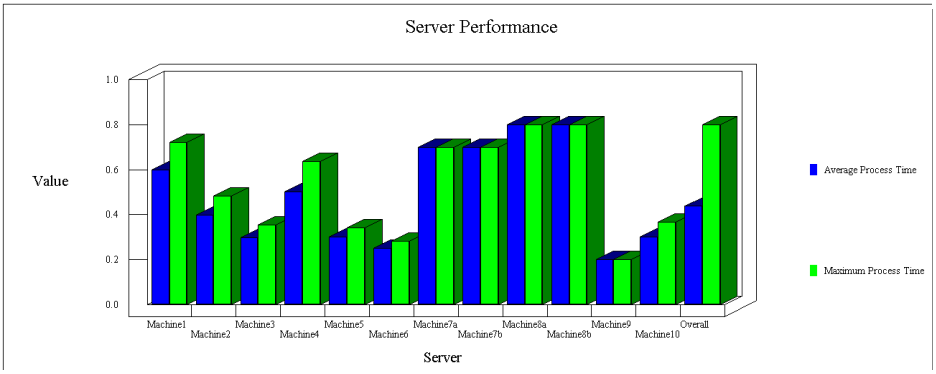


Figure 14. Graphical representation of average and maximum processing times. Modified system 3

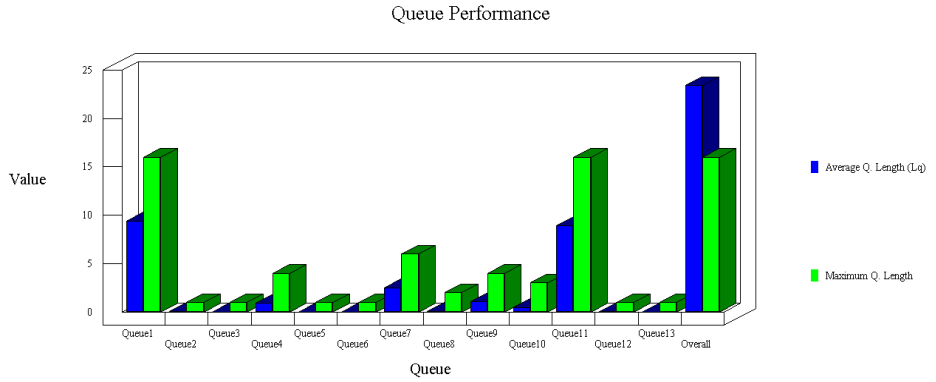


Figure 15. Graphical representation of average and maximum Q lengths. Modified system 3

In the table with comparative results in Figure 16, with the elimination of the M1b machine, the total number of finished products decreased from 133 to 131.

	The current system	Modified system 1	Modified system 2	Modified system 3
Show Customer Analysis				
Number Finished	100	133	133	131
Average Process Time	4.3316	4.3435	4.3435	4.3515
Average Waiting Time	56.5872	13.1894	13.1894	12.6417
Average Flow Time	20.1584	8.7134	8.7134	8.0077
Show Server Analysis				
M1a-Server Utilization/Customers Processed	100.13/134	54.6/73	54.6/73	99.7/133
M1b-Server Utilization/Customers Processed	-	53.64/72	53.64/72	-
M2-Server Utilization/Customers Processed	66.49/135	66.89/133	66.89/133	64.79/130
M3-Server Utilization/Customers Processed	54.17/145	54.63/146	54.63/146	54.23/146
M4-Server Utilization/Customers Processed	83.95/134	82.25/133	82.25/133	91.43/146
M5-Server Utilization/Customers Processed	50.17/134	53.87/144	53.87/144	50.28/134
M6-Server Utilization/Customers Processed	42.23/135	41.53/132	41.53/132	40.44/129
M7a-Server Utilization/Customers Processed	100.62/115	56.87/65	56.87/65	63.87/73
M7b-Server Utilization/Customers Processed	-	58.62/67	58.62/67	63/72
M8a-Server Utilization/Customers Processed	100/100	69/69	69/69	68/68
M8b-Server Utilization/Customers Processed	-	63/63	63/63	63/63
M9-Server Utilization/Customers Processed	25.25/101	33/132	33/132	32.5/130
M10-Server Utilization/Customers Processed	20.92/56	30.47/81	49.68/133	49.38/131
M11-Server Utilization/Customers Processed	16.44/44	19.2/52	-	-

Figure 16. Comparative results

3. Conclusion

The waiting theory shows us that the average time spent by a consumer in the system consists of the average time spent in the queue and the time needed to serve. In this case, where the consumer in the waiting system is a finished product, the average time spent in the system is obtained by following the path taken by the part to achieve the finished product.

In the present paper we started from a production system consisting of 11 machines (servers), on which 100 finished products were processed and assembled. Following the supplementation of the system with 3 machines, it was observed that as the loading degree of the machines decreases (server utilization coefficient), the average downtime of the finished products in the system decreases, as well as the average waiting time and the number of finished products increases. But this decrease in the degree of loading of the machines also led to the situation where most of the queues are non-existent, in which case no intermediate stocks are needed due to the processing times of the parts or not enough parts enter the system.

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Addresses:

- Lect. Dr. Eng. Olga-Ioana Amariei, Babeş-Bolyai University, Faculty of Engineering, Piaţa Traian Vuia, nr. 1-4, 320085, Reşiţa, o.amariei@uem.ro
- Prof. Dr. Eng. Codruţa-Oana Hamat, Babeş-Bolyai University, Faculty of Engineering, Piaţa Traian Vuia, nr. 1-4, 320085, Reşiţa, c.hamat@uem.ro
  (*corresponding author)