

Simulation Product Line

Research and Development

Fontys University

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Use Case 1

Assignment 1

Calculated throughput

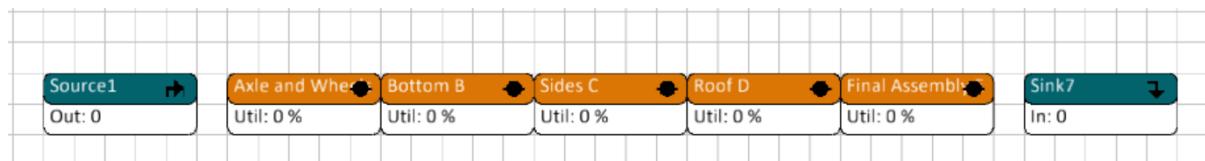
Lowest throughput bottleneck time per hour * hours per day * workdays

$$3 * 8 * 5 = 120$$

Loss of production = 10%

$$120 * 0,90 = \underline{108 \text{ trailers per week}}$$

Assignment 2



Standard

Result

Experiment Report

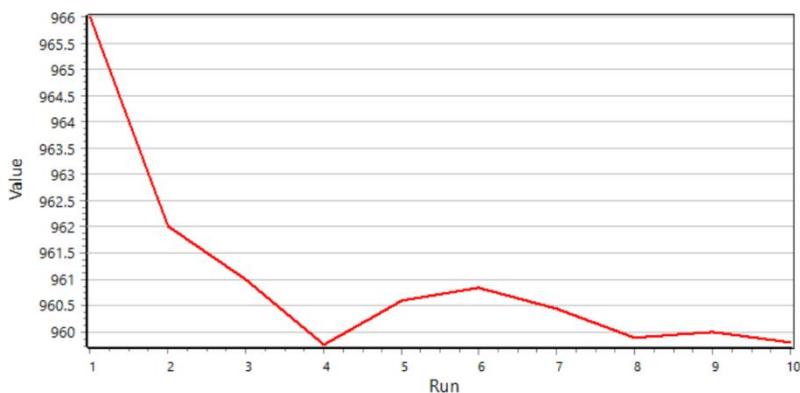
Experiment information

Model:	flowshop1.mod
Observation period:	14400000
Warmup period:	144000
Number of replications:	10
Simulation method:	Separate runs
Description:	

Sink7

THROUGHPUT	Average	S.Dev.	LB (95%)	UB (95%)	Minimum	Maximum
	959.80	3.36	957.40	962.20	956.00	966.00

Cumulative average : Sink7, THROUGHPUT



Strategy 1 - Reduced repair time

Result

Experiment Report

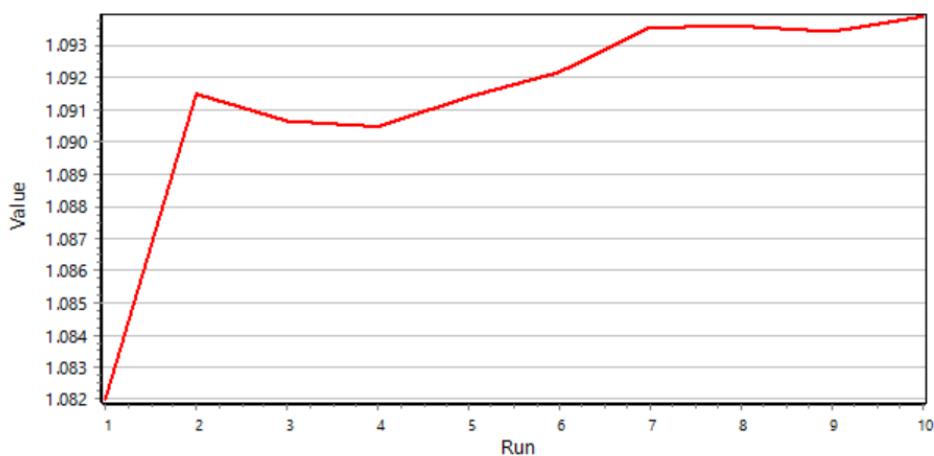
Experiment information

Model: flowshop1.mod
Observation period: 14400000
Warmup period: 144000
Number of replications: 10
Simulation method: Separate runs
Description:

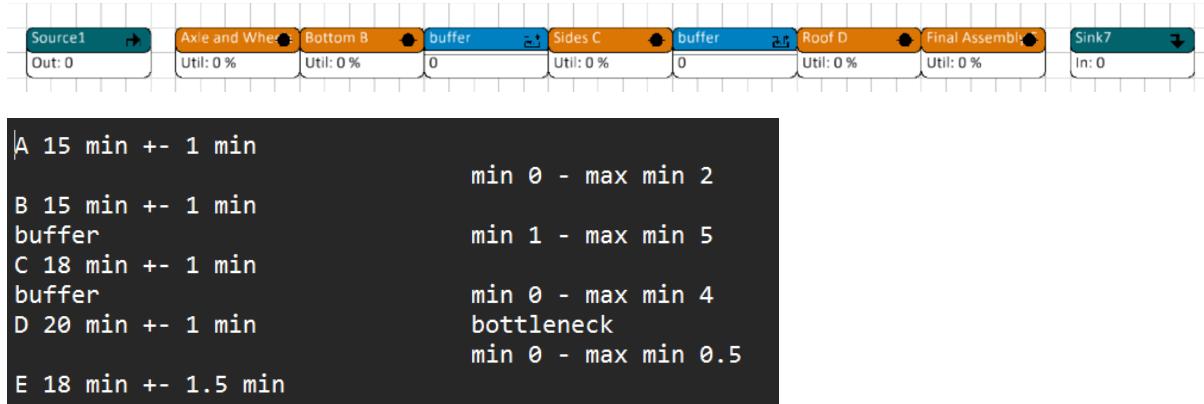
Sink7

THROUGHPUT	Average	S.Dev.	LB (95%)	UB (95%)	Minimum	Maximum
	1093.90	5.99	1089.62	1098.18	1082.00	1102.00

Cumulative average : Sink7, THROUGHPUT



Strategy 2 – buffer zones



On the right side you can see the min a max waiting time between each of the server nodes. As you can see the transfer from server B to server C has a minimal transfer time of 1 minute. Because of that it has the highest priority to get a buffer to reduce transfer times. After that we look at the max possible transfer times. The transfer from server C to server D has the second max transfer time. So, this transfer has the second highest priority to get a buffer for transfer time reduction.

Results

Experiment Report

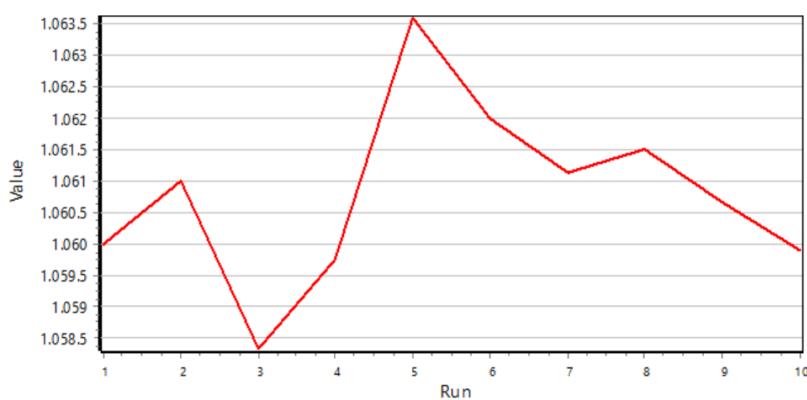
Experiment information

Model:	flowshop1.mod
Observation period:	14400000
Warmup period:	144000
Number of replications:	10
Simulation method:	Separate runs
Description:	

Sink7

THROUHGP	Average	S.Dev.	LB (95%)	UB (95%)	Minimum	Maximum
	1059.90	8.05	1054.14	1065.66	1053.00	1079.00

Cumulative average : Sink7, THROUHPUT



Overall results

SCENARIO	WEEK PRODUCTION
STANDARD	95,98
REDUCED REPAIR	109,39
BUFFER BEFORE C AND D	105,99

Use Case 2

Assignment 1

Analyse each strategy accurately. On the basis of (theoretical) utilizations, try to estimate which system will operate the most efficiently.

My estimation will be that strategy 5 will operate the most efficient based on (theoretical) utilizations, because it won't put valuable resources to use when it's not completely necessary. All the other strategy's make use of a fixed personnel utilization.

The strategy to change the service time on a per item basis won't do allot in my estimation, because based on the probability distribution of "number of items per shopper" that was given. The average service time per customer, only on item basis, will roughly be the same as the service not on item basis. And when you add the payment time, I estimate the time will be a bit longer.

Assignment 2

Build simulation models for all strategies and define for each the average queue and waiting time (in strategy 3 for both customer types).

checkouts open on Saturday from 9:00 to 17:00
 average 1400 shoppers in a day (random distribution)

To write the correct 4dScript for the Interval-arrival Time in the Source Node I must calculate the average time between the shoppers. To do this I get the total time the shop is open and divide it by the number of shoppers. To get the random distribution of shoppers during the day I will use the negative Exponential over the average Interval-arrival Time between the shoppers.

The shop is open for 8 hours. That is a total of $3600 * 8$ seconds = 28800 seconds

Now I will divide the open hours by the number of shoppers

$28800 / 1400 \approx 20,57$ seconds

To determine the best stochastic distribution for modeling customer service, I conducted some research. I found that the Poisson distribution is widely used due to its memoryless property, meaning the probability of a new customer arriving is independent of the time since the last customer arrived. Additionally, the Poisson distribution maintains a consistent average arrival rate, making it a reliable choice for such modeling.

The final 4dScript for the Interval-arrival Time will be “Poisson(20,57)”.

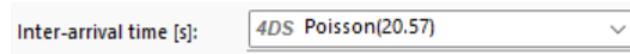


Figure 2 - Source node

Strategy 1

(fixed personnel, service time independent on the number of groceries)

In this case, all checkouts are open and the service time for each customer is taken from a negative exponential distribution with an average of 2.5 minutes

layout

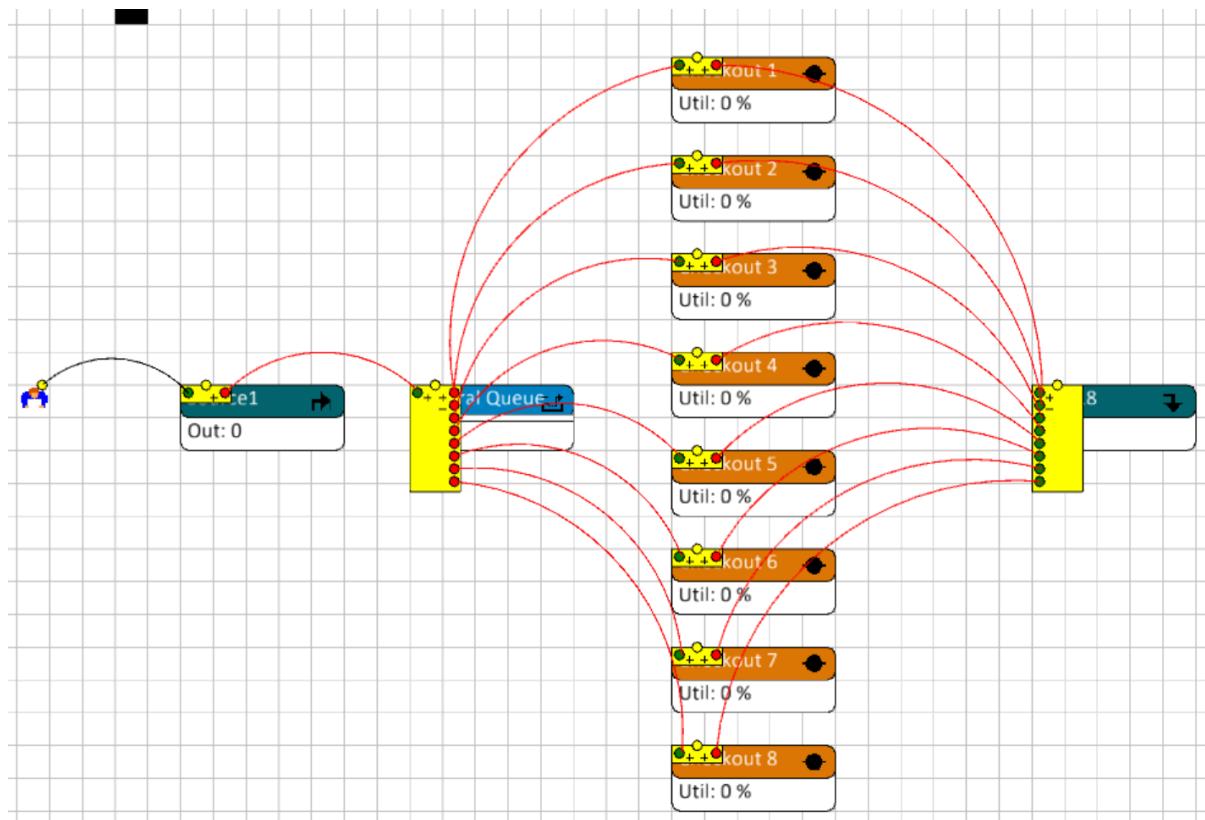


Figure 1 - strategy 1 layout

Settings	
Setup time [s]:	0
Cycletime [s]:	4DS negexp(mins(2.5))
Send to:	1
Input strategy:	1. Any inputchannel - First channel filled

Figure 3 - Checkout node

Experiment information

Model:	supermarket1.mod.bak
Observation period:	288000
Warmup period:	0
Number of replications:	10
Simulation method:	Separate runs
Description:	

1_Entrance

	Average	S.Dev.	LB (95%)	UB (95%)	Minimum	Maximum
	1397.30	8.58	1391.16	1403.44	1383.00	1414.00

2_Main Queue

	Average	S.Dev.	LB (95%)	UB (95%)	Minimum	Maximum
AvgContent	3.31	2.12	1.80	4.83	0.98	8.10
AvgStay	Average	S.Dev.	LB (95%)	UB (95%)	Minimum	Maximum
	68.19	43.95	36.75	99.63	19.60	167.70
MaxContent	Average	S.Dev.	LB (95%)	UB (95%)	Minimum	Maximum
	18.40	6.52	13.74	23.06	11.00	29.00
MaxStay	Average	S.Dev.	LB (95%)	UB (95%)	Minimum	Maximum
	365.05	134.85	268.59	461.52	186.95	603.28

3_Checkouts Elements : Checkout 1, Checkout 2, Checkout 3, Checkout 4, Checkout 5

	Average	S.Dev.	LB (95%)	UB (95%)	Minimum	Maximum
AvgStay	149.20	4.46	146.01	152.39	145.45	160.29
MaxStay	Average	S.Dev.	LB (95%)	UB (95%)	Minimum	Maximum
	1138.02	142.07	1036.39	1239.65	979.38	1427.92

4_Exit

	Average	S.Dev.	LB (95%)	UB (95%)	Minimum	Maximum
Exited	1387.10	10.71	1379.44	1394.76	1374.00	1409.00

Figure 2 - Experiment info strategy 1

	Avg Checkout Stay (seconds)	Avg Queue length (Customers)	Avg Queue Stay (seconds)
Strategy 1	149.20	3.31	68.19

Table 1 - info strategy 1

Strategy 2

(fixed personnel, service time dependent on the number of groceries)

This is a variation of the first strategy where the service time depends on the number of items purchased. We assume that the scanning time per item is 6 seconds, and that payment takes 30 seconds.

Measurements have shown that the following empirical probability distribution can be used for the number of groceries:

Number Of items	Probability (in %)	Number Of items	Probability (in %)	Number Of items	Probability (in %)
1	2	18	3	35	1
2	2	19	3	36	1
3	2	20	3	37	1
4	2	21	3	38	1
5	2	22	3	39	1
6	3	23	3	40	1
7	3	24	3	41	1
8	3	25	3	42	1
9	3	26	2	43	1
10	3	27	2	44	1
11	3	28	2	45	1
12	3	29	2	46	1
13	3	30	2	47	1
14	3	31	1	48	1
15	3	32	1	49	1
16	3	33	1	50	1
17	3	34	1		

Figure 3 - probability distribution strategy 4

Layout

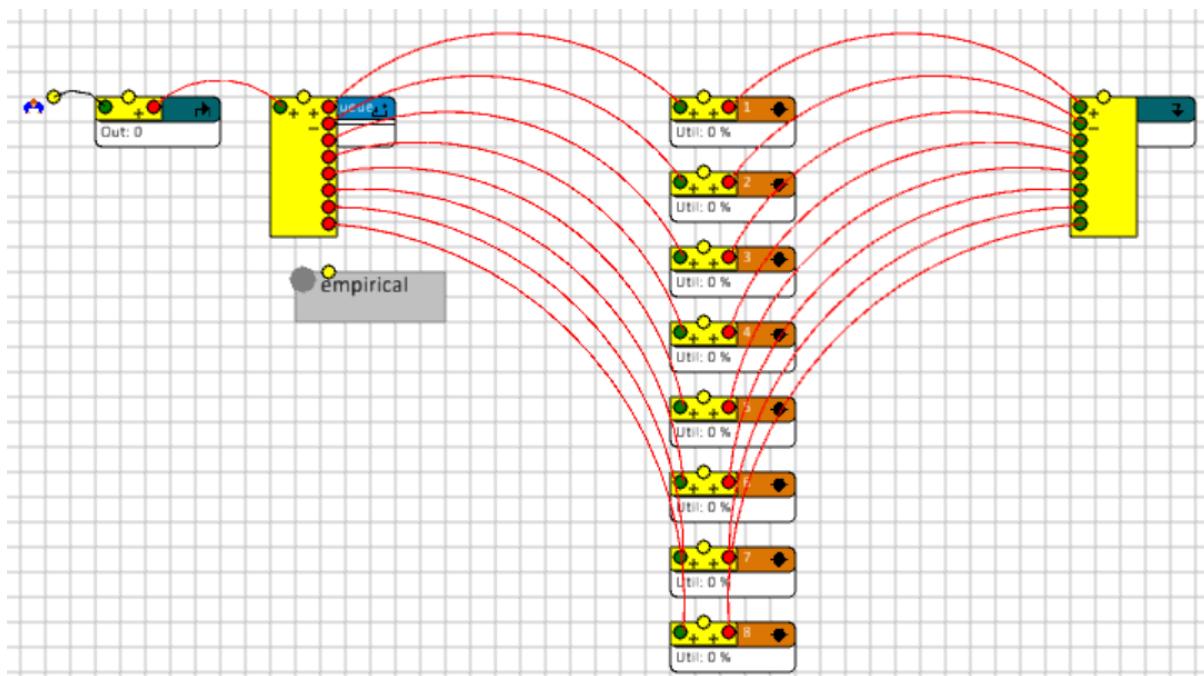


Figure 4 - strategy 2 layout

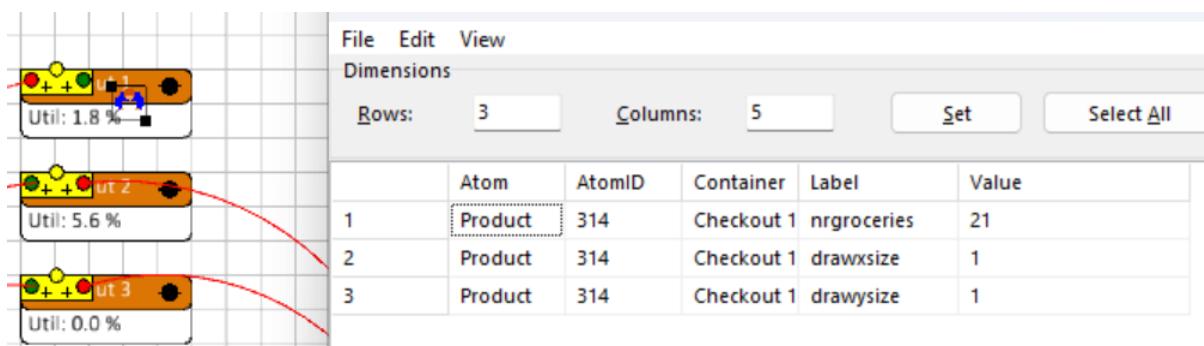


Figure 5 - Label Number of groceries on atom



Figure 6 - server cycletime [s]

Experiment information

Model:	supermarket1_st2.mod.bak.mod
Observation period:	288000
Warmup period:	0
Number of replications:	10
Simulation method:	Separate runs
Description:	

1_Entrance

Entered	Average	S.Dev.	LB (95%)	UB (95%)	Minimum	Maximum
	1397.90	7.50	1392.53	1403.27	1386.00	1409.00

2_Main Queue

AvgContent	Average	S.Dev.	LB (95%)	UB (95%)	Minimum	Maximum
	1.33	0.42	1.03	1.63	0.74	1.93
AvgStay	Average	S.Dev.	LB (95%)	UB (95%)	Minimum	Maximum
	27.38	8.52	21.29	33.48	15.36	39.47
MaxContent	Average	S.Dev.	LB (95%)	UB (95%)	Minimum	Maximum
	8.80	1.40	7.80	9.80	7.00	12.00
MaxStay	Average	S.Dev.	LB (95%)	UB (95%)	Minimum	Maximum
	165.50	29.83	144.16	186.84	122.00	210.00

3_Checkouts Elements : Checkout 1, Checkout

AvgStay	Average	S.Dev.	LB (95%)	UB (95%)	Minimum	Maximum
	153.33	2.76	151.36	155.31	147.57	156.90
MaxStay	Average	S.Dev.	LB (95%)	UB (95%)	Minimum	Maximum
	330.00	0.00	330.00	330.00	330.00	330.00

4_Exit

Exited	Average	S.Dev.	LB (95%)	UB (95%)	Minimum	Maximum
	1389.40	6.40	1384.82	1393.98	1375.00	1397.00

Figure 7 - Experiment info strategy 2

	Avg Checkout Stay (seconds)	Avg Queue length (Customers)	Avg Queue Stay (seconds)
Strategy 2	153.33	1.33	27.38

Table 2 - info strategy 2

Strategy 3

(fixed personnel, service time dependent on the number of groceries and separation of customer types)

In this strategy, the first checkout is an express lane: only customers with 10 items or less are allowed to use this checkout. In this case, we assume that all these customers will actually use the express lane

Layout

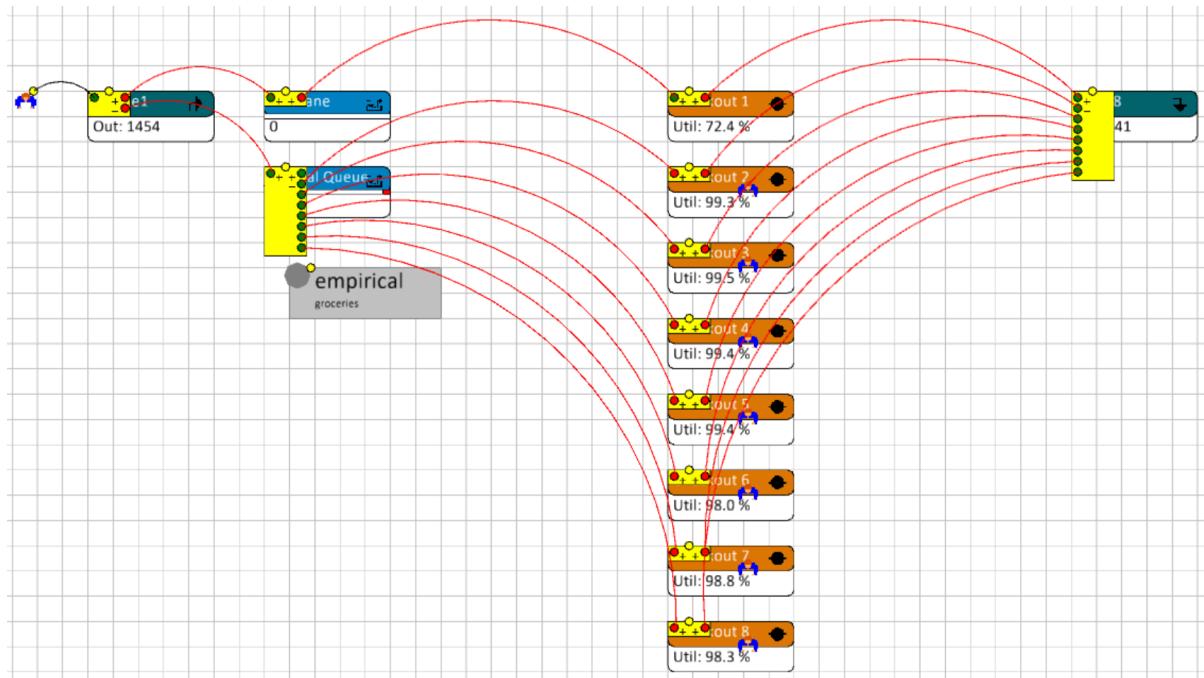


Figure 8 - Strategy 3 layout

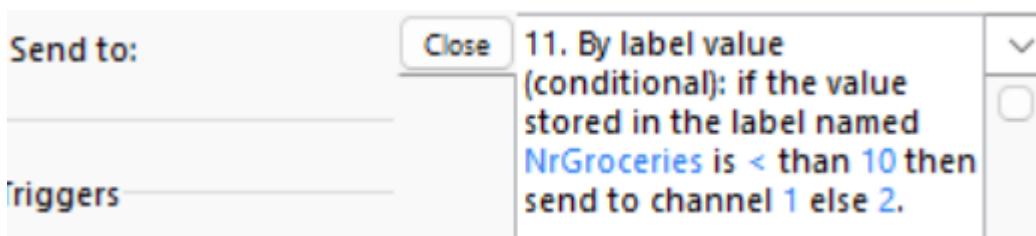


Figure 9 - Source send conditional

Experiment information

Model:	supermarket1_st3.mod						Model:	supermarket1_st3.mod					
Observation period:	288000						Observation period:	288000					
Warmup period:	0						Warmup period:	0					
Number of replications:	10						Number of replications:	10					
Simulation method:	Separate runs						Simulation method:	Separate runs					
Description:							Description:						
1_Entrance							1_Entrance						
Entered	Average	S.Dev.	LB (95%)	UB (95%)	Minimum	Maximum	Entered	Average	S.Dev.	LB (95%)	UB (95%)	Minimum	Maximum
	1401.80	8.18	1395.95	1407.65	1392.00	1418.00		1404.20	7.38	1398.92	1409.48	1394.00	1417.00
2_Fast lane							2_Fast lane						
AvgStay	Average	S.Dev.	LB (95%)	UB (95%)	Minimum	Maximum	AvgStay	Average	S.Dev.	LB (95%)	UB (95%)	Minimum	Maximum
	43.63	11.94	35.09	52.17	30.50	70.04		5630.71	1253.63	4733.91	6527.50	4083.70	7839.38
Total	Average	S.Dev.	LB (95%)	UB (95%)	Minimum	Maximum	Total	Average	S.Dev.	LB (95%)	UB (95%)	Minimum	Maximum
	305.90	10.19	298.61	313.19	285.00	319.00		188.70	11.04	180.81	196.59	171.00	206.00
2_Main Queue							2_Main Queue						
AvgStay	Average	S.Dev.	LB (95%)	UB (95%)	Minimum	Maximum	AvgStay	Average	S.Dev.	LB (95%)	UB (95%)	Minimum	Maximum
	104.24	54.40	65.33	143.15	31.86	187.26		28.62	13.34	19.08	38.16	14.75	51.95
Total	Average	S.Dev.	LB (95%)	UB (95%)	Minimum	Maximum	Total	Average	S.Dev.	LB (95%)	UB (95%)	Minimum	Maximum
	1092.30	8.92	1085.92	1098.68	1078.00	1104.00		1089.40	14.90	1078.74	1100.06	1058.00	1114.00
2_Queue Elements : 2_Fast lane, 2_Main Queue							2_Queue Elements : 2_Fast lane, 2_Main Queue						
AvgContent	Average	S.Dev.	LB (95%)	UB (95%)	Minimum	Maximum	AvgContent	Average	S.Dev.	LB (95%)	UB (95%)	Minimum	Maximum
	4.44	2.11	2.93	5.95	1.60	7.73		62.65	14.09	52.57	72.72	47.06	89.16
AvgStay	Average	S.Dev.	LB (95%)	UB (95%)	Minimum	Maximum	AvgStay	Average	S.Dev.	LB (95%)	UB (95%)	Minimum	Maximum
	91.18	43.08	60.37	122.00	32.98	156.17		852.45	181.26	722.78	982.11	680.67	1233.06
MaxStay	Average	S.Dev.	LB (95%)	UB (95%)	Minimum	Maximum	MaxStay	Average	S.Dev.	LB (95%)	UB (95%)	Minimum	Maximum
	397.40	137.20	299.26	495.54	244.00	697.00		11342.99	1754.01	10088.24	12597.73	9357.20	13741.67
3_Checkouts Elements : Checkout 1, Checkout							3_Checkouts Elements : Checkout 1, Checkout						
AvgStay	Average	S.Dev.	LB (95%)	UB (95%)	Minimum	Maximum	AvgStay	Average	S.Dev.	LB (95%)	UB (95%)	Minimum	Maximum
	152.34	1.71	151.11	153.56	149.43	154.89		151.43	3.59	148.86	154.00	147.83	159.14
MaxStay	Average	S.Dev.	LB (95%)	UB (95%)	Minimum	Maximum	MaxStay	Average	S.Dev.	LB (95%)	UB (95%)	Minimum	Maximum
	330.00	0.00	330.00	330.00	330.00	330.00		1141.50	106.37	1065.41	1217.59	994.42	1295.83
4_Exit							4_Exit						
Exited	Average	S.Dev.	LB (95%)	UB (95%)	Minimum	Maximum	Exited	Average	S.Dev.	LB (95%)	UB (95%)	Minimum	Maximum
	1390.70	7.42	1385.39	1396.01	1381.00	1404.00		1271.30	18.69	1257.93	1284.67	1246.00	1303.00

Figure 11 - Experiment info strategy 3 – Groceries Count

Figure 10 - Experiment info strategy 3 - Exp timing

	Avg Checkout Stay (seconds)	Avg Queue length (Customers)	Avg Queue Stay (seconds)
Strategy 3 Groceries-Count*	152.34	4.44	91.18
Strategy 3 Exp-Timing*	151.43	62.65	852.45

Table 3 - info strategy 3

*Groceries-Count – The checkout time is based on the number of groceries

*Exp-Timing – the checkout time is based on negative exponential distribution

Strategy 4

(fixed personnel, service time dependent on the number of groceries, with priority to the customers with the least groceries)

This alternative is interesting from the point of view of flows, but would lead to major problems in supermarkets. Modify the second model so that customers with the fewest items are served first

Layout

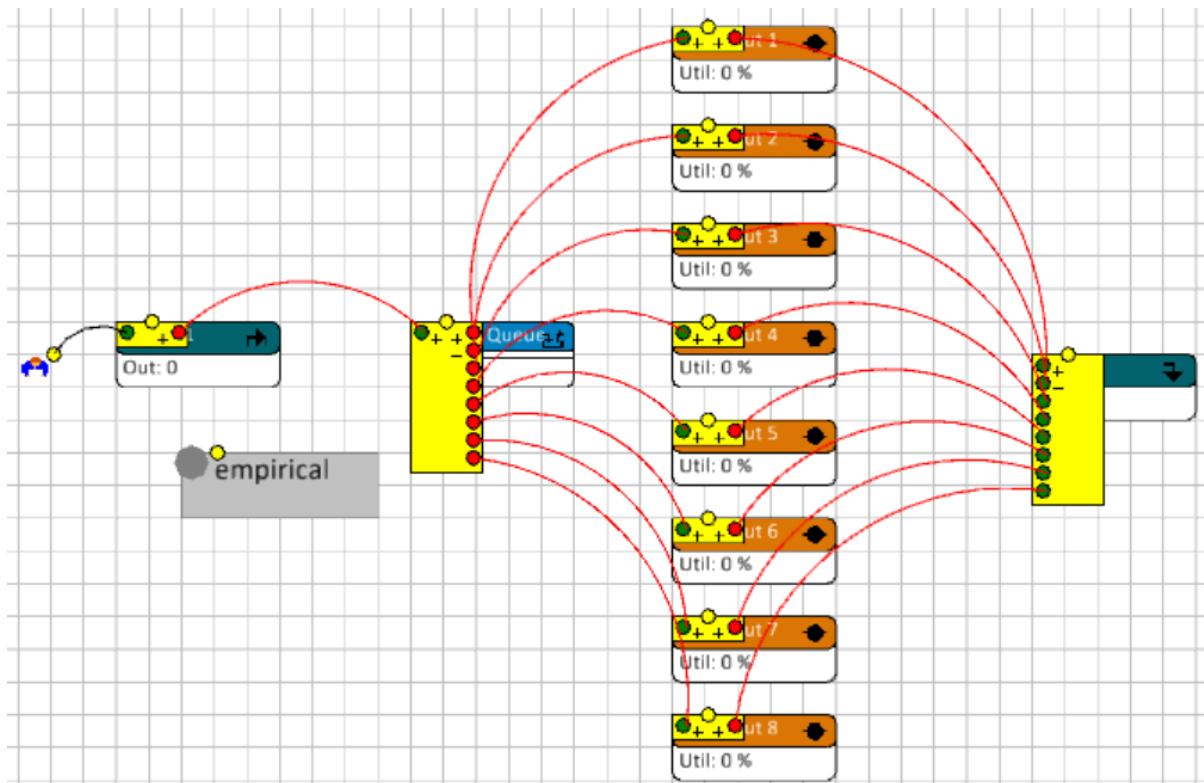
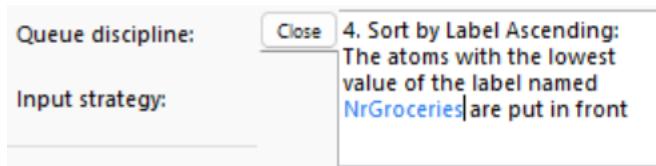


Figure 12 - strategy 4 layout



Experiment information

Model: supermarket1_st4.mod
 Observation period: 288000
 Warmup period: 0
 Number of replications: 10
 Simulation method: Separate runs
 Description:

1_Entrance

Entered	Average	S.Dev.	LB (95%)	UB (95%)	Minimum	Maximum
	1404.40	7.47	1399.06	1409.74	1388.00	1414.00

2_Main Queue

AvgContent	Average	S.Dev.	LB (95%)	UB (95%)	Minimum	Maximum
	1.03	0.26	0.84	1.21	0.68	1.59
AvgStay	Average	S.Dev.	LB (95%)	UB (95%)	Minimum	Maximum
	20.99	5.25	17.23	24.75	13.91	32.51
MaxContent	Average	S.Dev.	LB (95%)	UB (95%)	Minimum	Maximum
	6.70	0.82	6.11	7.29	6.00	8.00
MaxStay	Average	S.Dev.	LB (95%)	UB (95%)	Minimum	Maximum
	830.50	378.62	559.65	1101.35	359.00	1374.00

3_Checkouts Elements : Checkout 1, Checkout 2, Checkout 3, Checkout 4, Checkout 5

AvgStay	Average	S.Dev.	LB (95%)	UB (95%)	Minimum	Maximum
	153.55	1.76	152.29	154.81	150.83	156.55
MaxStay	Average	S.Dev.	LB (95%)	UB (95%)	Minimum	Maximum
	330.00	0.00	330.00	330.00	330.00	330.00

4_Exit

Exited	Average	S.Dev.	LB (95%)	UB (95%)	Minimum	Maximum
	1395.30	6.88	1390.38	1400.22	1381.00	1404.00

Figure 13 - Experiment info strategy 4

	Avg Checkout Stay (seconds)	Avg Queue length (Customers)	Avg Queue Stay (seconds)
Strategy 4	153.55	1.03	20.99

Table 4 - info strategy 4

Strategy 5

(variable personnel, service time dependent on the number of people waiting)

The availability of checkouts is now linked to the number of customers in the queue: if 0 to 3 customers are waiting, checkout 1 opens, 4 to 6 customers, checkout 2 etc. up to a total of 8 checkouts for 22 customers or more. When the number of customers queuing decreases, the corresponding number of checkouts closes

Layout

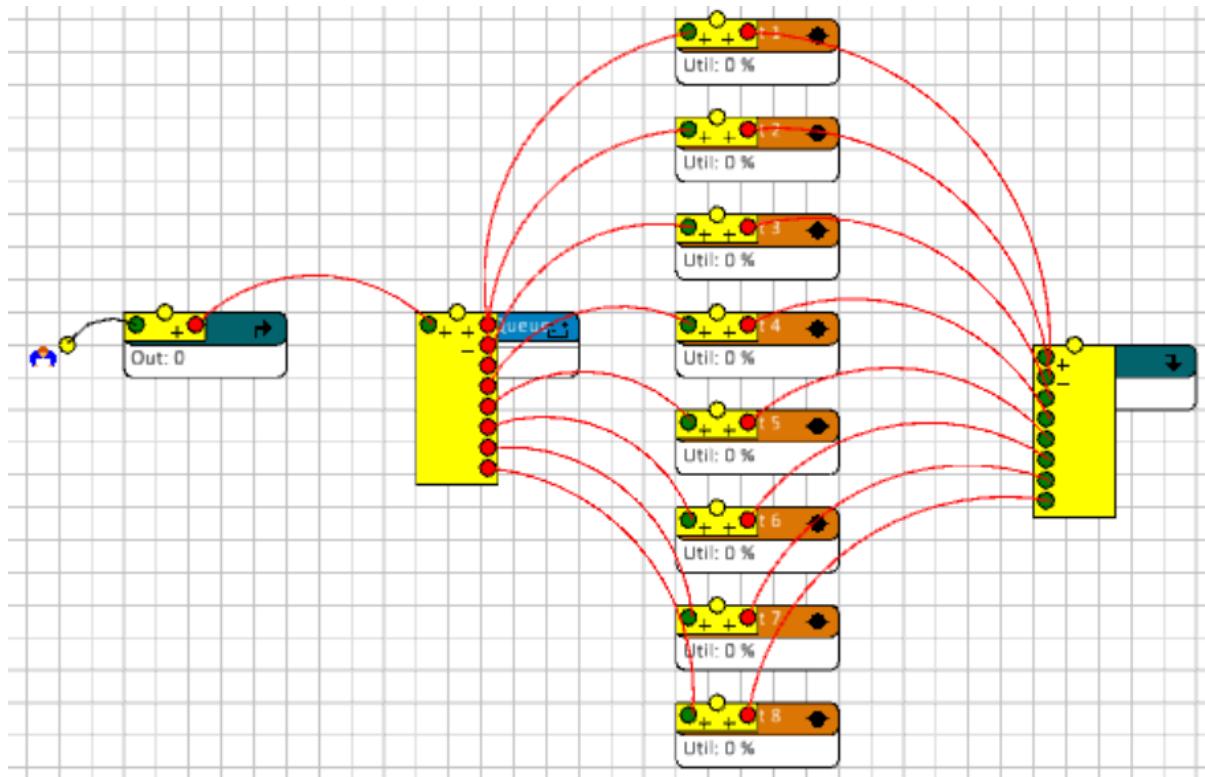


Figure 14 - Strategy 5 layout

```

do (
    if(Content(c) > 21, OpenInput(out(1,c)), CloseInput(out(1,c))),
    if(Content(c) > 18, OpenInput(out(2,c)), CloseInput(out(2,c))),
    if(Content(c) > 15, OpenInput(out(3,c)), CloseInput(out(3,c))),
    if(Content(c) > 12, OpenInput(out(4,c)), CloseInput(out(4,c))),
    if(Content(c) > 9, OpenInput(out(5,c)), CloseInput(out(5,c))),
    if(Content(c) > 6, OpenInput(out(6,c)), CloseInput(out(6,c))),
    if(Content(c) > 3, OpenInput(out(7,c)), CloseInput(out(7,c))),
    if(Content(c) > 0, OpenInput(out(8,c)), CloseInput(out(8,c)))
)

```

Figure 15 - 4dScript queue entry and exit



Figure 16 - Trigger settings queue

Experiment information

Model:	supermarket1_st5.mod
Observation period:	288000
Warmup period:	0
Number of replications:	10
Simulation method:	Separate runs
Description:	

1_Entrence

Entered	Average	S.Dev.	LB (95%)	UB (95%)	Minimum	Maximum
	1394.70	7.35	1389.44	1399.96	1387.00	1410.00

2_Main Queue

AvgContent	Average	S.Dev.	LB (95%)	UB (95%)	Minimum	Maximum
	20.38	1.04	19.63	21.12	19.11	22.58
AvgStay	Average	S.Dev.	LB (95%)	UB (95%)	Minimum	Maximum
	423.49	23.05	407.00	439.98	398.19	471.48
MaxContent	Average	S.Dev.	LB (95%)	UB (95%)	Minimum	Maximum
	35.80	3.05	33.62	37.98	32.00	40.00
MaxStay	Average	S.Dev.	LB (95%)	UB (95%)	Minimum	Maximum
	726.66	62.80	681.74	771.59	641.42	818.09

3_Checkouts Elements : Checkout 1, Checkout 2, Checkout 3, Checkout 4, Checkout 5

AvgStay	Average	S.Dev.	LB (95%)	UB (95%)	Minimum	Maximum
	150.85	3.31	148.48	153.22	145.92	155.46
MaxStay	Average	S.Dev.	LB (95%)	UB (95%)	Minimum	Maximum
	1148.78	205.82	1001.55	1296.01	955.82	1508.91

4_Exit

Exited	Average	S.Dev.	LB (95%)	UB (95%)	Minimum	Maximum
	1363.20	12.68	1354.13	1372.27	1339.00	1385.00

Figure 17 - Experiment info strategy 5

	Avg Checkout Stay (seconds)	Avg Queue length (Customers)	Avg Queue Stay (seconds)
Strategy 5	150.85	20.38	423.49

Table 5 - info strategy 5

Results

	Strategy 1	Strategy 2	Strategy 3		Strategy 4	Strategy 5
			Groc-Count	Exp-Time		
<i>Queues</i>						
Avg Content (customers)	3.31	1.33	4.44	62.65	1.03	20.38
Avg Stay (seconds)	68.19	27.38	91.18	852.45	20.99	423.49
Max Content (customers)	18.40	8.80	/	/	6.70	35.80
Max Stay (seconds)	365.05	165.50	397.40	11342.99	830.50	726.66
<i>Checkouts</i>						
Avg Stay (seconds)	149.20	153.33	152.34	151.43	153.55	150.85
Max Stay (seconds)	1387.10	330.00	330.00	1141.50	330.00	1148.78

Strategy Explained*	
Strategy 1	<ul style="list-style-type: none"> server time negExp(min(2.5))
Strategy 2	<ul style="list-style-type: none"> server time depends on amount of items item = 6 seconds payment = 30 seconds
Strategy 3	<ul style="list-style-type: none"> service time depends on amount of items item = 6 seconds payment = 30 seconds express lane for items ≤ 10
Strategy 4	<ul style="list-style-type: none"> service time depends on amount of items item = 6 seconds payment = 30 seconds least items first out
Strategy 5	<ul style="list-style-type: none"> server time negExp(min(2.5)) variable checkouts <ul style="list-style-type: none"> 1 open = $0 < \text{customers} \leq 3$ 2 open = $3 < \text{customers} \leq 6$ 3 open = $6 < \text{customers} \leq 9$ 4 open = $9 < \text{customers} \leq 12$ 5 open = $12 < \text{customers} \leq 15$ 6 open = $15 < \text{customers} \leq 18$ 7 open = $18 < \text{customers} \leq 21$ 8 open = $21 < \text{customers}$

*

- 8 checkout lanes
- checkouts open on Saturday from 9:00 to 17:00
- average 1400 shoppers in a day (random)
- fifo
- checkout operators work with the same speed

(I use poisson distribution for the random distribution of shoppers)

Assignment 3

Which system would you recommend? Can they be compared with each other? Are there better alternatives?

When I look at the results of the different strategies, I deduct that the different strategies in service time is negligible in the case of average service time. But the standard deviation is considerably higher when using the negative exponential distribution compared to the empirical distribution with the number of items. I assume that these higher deviations have a correlation with the extended average staying times in the queue.

I would recommend using the empirical distribution in case of service times.

Looking at the different strategies with the use of the empirical distribution. I deduct that strategy 3 has a significant higher queueing time compared to strategy 2 and strategy 4. This make me want to rule out strategy 3 and the use of a fast lane, because I don't see a significant benefit from it.

Strategy 4, which prioritizes customers with fewer items by placing them at the front of the queue, results in the shortest average queueing time. However, it also produces significant outliers. In contrast, Strategy 2, which follows a first-in, first-out (FIFO) approach, is more consistent, showing a substantial reduction in outliers.

I recommend using strategy 2. It doesn't significantly punish the queueing time of the customer on the number of items bought and it is very stable. If the punishment of customers with a larger number of groceries is not a problem, then go for strategy 4 with the lower overall stay time.

Conclusion

Variant	Queue	Waiting time (in seconds)
1	6.8 ± 1.0	139 ± 20
2	5.5 ± 0.8	112 ± 15
3 (customers with 10 or less items)	1.6 ± 0.2	129 ± 13
3 (customers with more than 10 items)	6.3 ± 1.2	171 ± 30
4	4.2 ± 0.6	85 ± 12
5	22.3 ± 0.8	458 ± 13

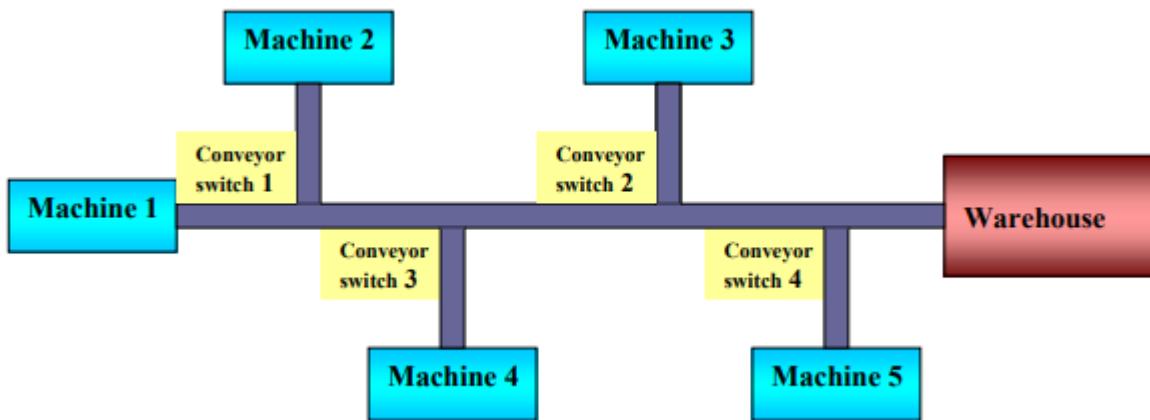
Figure 18 - Answer results

I notice that the results of the given answers are very different compared to the result I found. Only the results from strategy 5 are comparable.

I found that the reason for this difference is the stochastic distribution that is used for the Inter-arrival time. When I change the inter-arrival time to a negative exponential distribution the resulted values are similar.

I used the poisson distribution for the simulation, because the simulated process is a M/M/c queueing model. And I found that this is the most commonly used stochastic distribution for this type of queueing model, mainly because of its memoryless property.

Use Case 3



Assignment 1

Make your own calculation / reasoned estimate beforehand regarding the transport system capacity in the case of an equal production per machine (in boxes per hour). Where will the system first jam?

In my capacity estimates for the system, I'll be disregarding potential jams due to the complexity of calculating them accurately.

Each machine produces 4 products per minute, which equals 240 boxes per hour. Multiplying this by the number of machines gives us the theoretical maximum production rate: 1200 boxes per hour for the entire system.

Process time:

- Machine line 1 : 0 sec
- machine line 2 : 2 sec
- machine line 3 : 2 sec
- machine line 4 ; 10 sec
- machine line 5 : 5 sec

The longest process time occurs at Conveyor Switch 3, where boxes are most likely to accumulate due to the delay. This makes Conveyor Switch 2 the likely point for jams to occur.

Assignment 2

Determine with simulation if a production of 4 boxes per minute per machine is possible and the maximum feasible system capacity if all machines generate the same production.

Looking at the experiment results under “Experiment” you can see that the standard deviation for both the average content and average stay on each conveyor belt is either 0 or 0.01. Which I assume would mean that there are no concerning product jams that should be taken care off.

I expect that the maximum feasible system capacity will be around 6 boxes per minute. The way I got that assumption is because of machine line 4 it's transfer time. It has a transfer time of 10 sec which, I assume, should mean that if the production of that line goes above that it will jam. But apparently when I create a Uniform distribution

layout

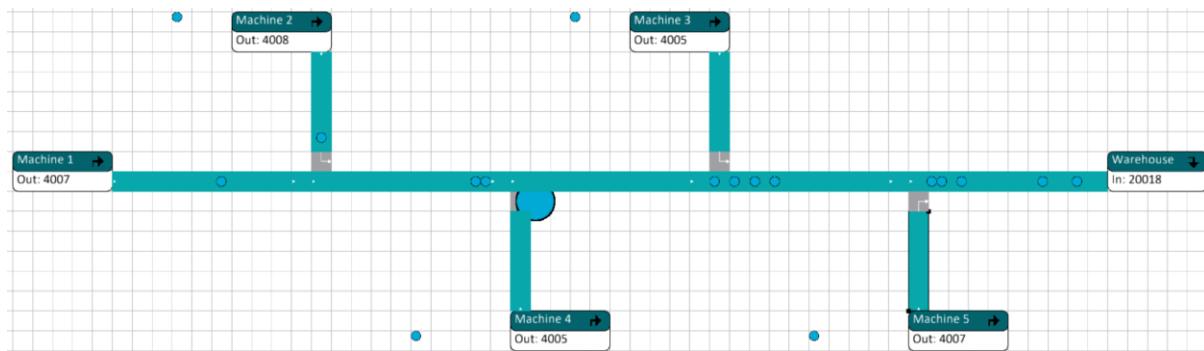


Figure 19 - transport system layout

```
Triggers
1 Do (
2  CloseInput(out(2,c)),
3  LoopUntil(Content(Central(1,c)) = 0, Break)
4 )
```

Figure 20 - Corner Transfer Unit, Entry trigger 4dscript

```
Trigger on exit: 1 OpenInput(out(2,c))
```

Figure 22- Corner Transfer Unit, Exit trigger 4dscript

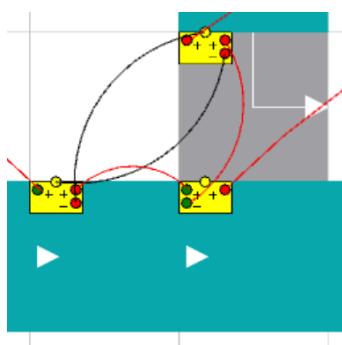


Figure 21 - Intersection channel connections

Experimental information

Experiment information

Model: transport1.mod
 Observation period: 288000
 Warmup period: 0
 Number of replications: 10
 Simulation method: Separate runs
 Description:

Machines Elements : Machine 1, Machine 2,

Machine	Production	Average	S.Dev.	LB (95%)	UB (95%)	Minimum	Maximum
	9597.00	2.40		9595.28	9598.72	9593.00	9601.00

Main conveyor Elements : Accumulating

Machine	AVGCONTE	Average	S.Dev.	LB (95%)	UB (95%)	Minimum	Maximum
	AVGSTAY	10.66	0.08	10.60	10.72	10.53	10.81
	AVGSTAY	Average	S.Dev.	LB (95%)	UB (95%)	Minimum	Maximum

Side Accumulating Conveyor 1

Machine	AvgContent	Average	S.Dev.	LB (95%)	UB (95%)	Minimum	Maximum
	AvgStay	0.33	0.00	0.33	0.33	0.33	0.33
	AvgStay	Average	S.Dev.	LB (95%)	UB (95%)	Minimum	Maximum

Side Accumulating Conveyor 2

Machine	AvgContent	Average	S.Dev.	LB (95%)	UB (95%)	Minimum	Maximum
	AvgStay	0.33	0.00	0.33	0.33	0.33	0.33
	AvgStay	Average	S.Dev.	LB (95%)	UB (95%)	Minimum	Maximum

Side Accumulating Conveyor 3

Machine	AvgContent	Average	S.Dev.	LB (95%)	UB (95%)	Minimum	Maximum
	AvgStay	0.33	0.00	0.33	0.33	0.33	0.33
	AvgStay	Average	S.Dev.	LB (95%)	UB (95%)	Minimum	Maximum

Side Accumulating Conveyor 4

Machine	AvgContent	Average	S.Dev.	LB (95%)	UB (95%)	Minimum	Maximum
	AvgStay	0.33	0.00	0.33	0.33	0.33	0.33
	AvgStay	Average	S.Dev.	LB (95%)	UB (95%)	Minimum	Maximum

Warehouse

Output	Average	S.Dev.	LB (95%)	UB (95%)	Minimum	Maximum
	9583.10	2.69	9581.18	9585.02	9578.00	9586.00

Model: transport1.mod
 Observation period: 288000
 Warmup period: 0
 Number of replications: 10
 Simulation method: Separate runs
 Description:

Machines Elements : Machine 1, Machine 2,

Machine	Production	Average	S.Dev.	LB (95%)	UB (95%)	Minimum	Maximum
		11299.70	2.91	11297.62	11301.78	11297.00	11305.00

Main conveyor Elements : Accumulating

Machine	AVGCONTE	Average	S.Dev.	LB (95%)	UB (95%)	Minimum	Maximum
	AVGSTAY	45.37	0.02	45.35	45.38	45.33	45.39
	AVGSTAY	Average	S.Dev.	LB (95%)	UB (95%)	Minimum	Maximum

Side Accumulating Conveyor 1

Machine	AvgContent	Average	S.Dev.	LB (95%)	UB (95%)	Minimum	Maximum
	AvgStay	9.82	0.00	9.82	9.83	9.82	9.83
	AvgStay	Average	S.Dev.	LB (95%)	UB (95%)	Minimum	Maximum

Side Accumulating Conveyor 2

Machine	AvgContent	Average	S.Dev.	LB (95%)	UB (95%)	Minimum	Maximum
	AvgStay	0.50	0.00	0.50	0.50	0.50	0.50
	AvgStay	Average	S.Dev.	LB (95%)	UB (95%)	Minimum	Maximum

Side Accumulating Conveyor 3

Machine	AvgContent	Average	S.Dev.	LB (95%)	UB (95%)	Minimum	Maximum
	AvgStay	9.66	0.02	9.65	9.68	9.63	9.69
	AvgStay	Average	S.Dev.	LB (95%)	UB (95%)	Minimum	Maximum

Side Accumulating Conveyor 4

Machine	AvgContent	Average	S.Dev.	LB (95%)	UB (95%)	Minimum	Maximum
	AvgStay	0.50	0.00	0.50	0.50	0.50	0.50
	AvgStay	Average	S.Dev.	LB (95%)	UB (95%)	Minimum	Maximum

Warehouse

Output	Average	S.Dev.	LB (95%)	UB (95%)	Minimum	Maximum
	11230.40	2.91	11228.32	11232.48	11228.00	11236.00

Figure 24 - Experiment info Uniform(14.5 ,15.5)

Figure 23 - Experiment info Uniform(9.5,10.5)

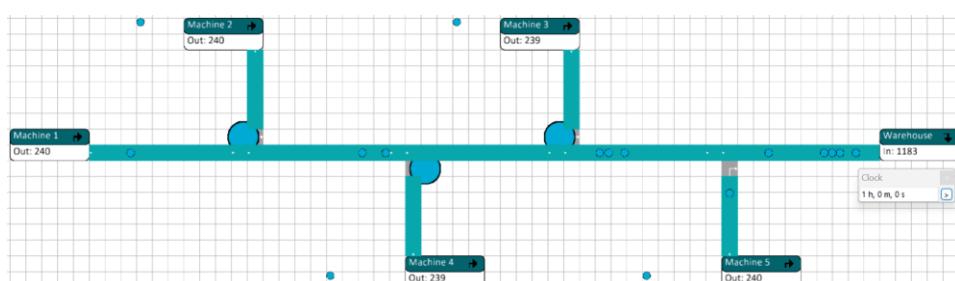


Figure 25 - Experiment Uniform (14.5,15.5)

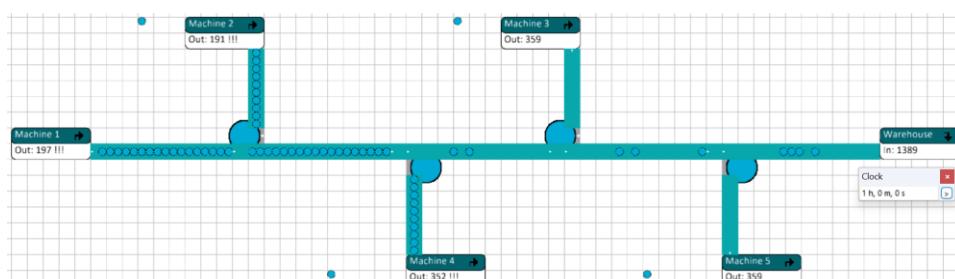


Figure 26 - Exirment Uniform (9.5,10.5)

Model: transport1.mod
 Observation period: 288000
 Warmup period: 0
 Number of replications: 10
 Simulation method: Separate runs
 Description:

Machines Elements : Machine 1, Machine 2,

Production	Average	S.Dev.	LB (95%)	UB (95%)	Minimum	Maximum
	13331.20	3.74	13328.53	13333.87	13324.00	13338.00

Main conveyor Elements : Accumulating

AVGCONTE	Average	S.Dev.	LB (95%)	UB (95%)	Minimum	Maximum
	18.29	1.00	17.57	19.00	17.04	20.43
AVGSTAY	Average	S.Dev.	LB (95%)	UB (95%)	Minimum	Maximum
	7.91	0.43	7.60	8.22	7.37	8.83

Side Accumulating Conveyor 1

AvgContent	Average	S.Dev.	LB (95%)	UB (95%)	Minimum	Maximum
	0.47	0.00	0.46	0.47	0.46	0.48
AvgStay	Average	S.Dev.	LB (95%)	UB (95%)	Minimum	Maximum
	5.02	0.05	4.99	5.06	5.00	5.16

Side Accumulating Conveyor 2

AvgContent	Average	S.Dev.	LB (95%)	UB (95%)	Minimum	Maximum
	0.46	0.00	0.46	0.46	0.46	0.46
AvgStay	Average	S.Dev.	LB (95%)	UB (95%)	Minimum	Maximum
	5.00	0.00	5.00	5.00	5.00	5.00

Side Accumulating Conveyor 3

AvgContent	Average	S.Dev.	LB (95%)	UB (95%)	Minimum	Maximum
	0.48	0.00	0.48	0.48	0.48	0.49
AvgStay	Average	S.Dev.	LB (95%)	UB (95%)	Minimum	Maximum
	5.22	0.01	5.22	5.23	5.21	5.24

Side Accumulating Conveyor 4

AvgContent	Average	S.Dev.	LB (95%)	UB (95%)	Minimum	Maximum
	0.46	0.00	0.46	0.46	0.46	0.46
AvgStay	Average	S.Dev.	LB (95%)	UB (95%)	Minimum	Maximum
	5.00	0.00	5.00	5.00	5.00	5.00

Warehouse Output	Average	S.Dev.	LB (95%)	UB (95%)	Minimum	Maximum
	13309.20	6.66	13304.43	13313.97	13295.00	13320.00

Figure 27 - Experiment info Uniform (10.3,11.3)

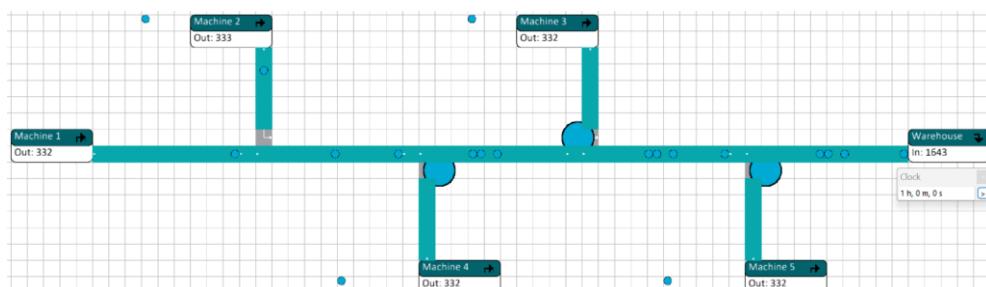


Figure 28 - Experiment Uniform (10.3,11.3)

Results

The maximum feasible system capacity if all machines generate the same production seems to be around the uniform distribution of (10.3, 11.3). Anything lower will result in a product jam beginning at the intersection with machine line 4.

This is a machine production of around 5.56 boxes per minute.

Assignment 3

Can the total system production be increased by varying the production quantity per machine? Investigate this by means of simulation. Warning! The maximum technical capacity of the machines is 8 boxes per minute.

Experiment information

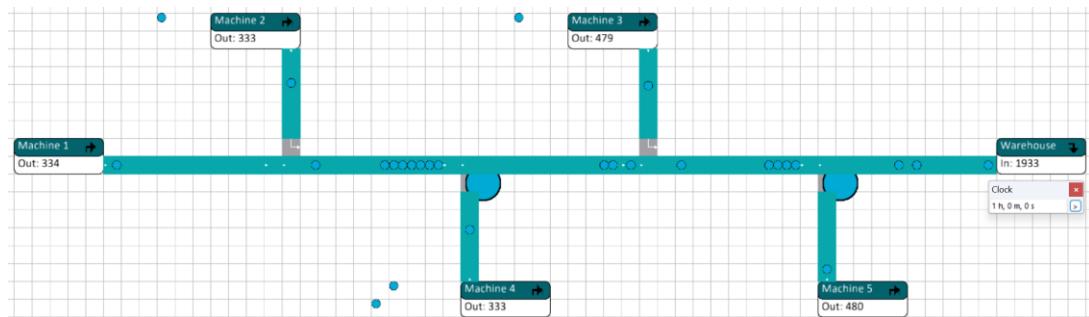


Figure 29 - Experiment variable production

Machine nr.	Inter-Arrival time	Δ Box per min
Machine 1	Uniform(10.3, 11.3)	5,56
Machine 2	Uniform(10.3, 11.3)	5,56
Machine 3	Uniform(10.3, 11.3)	5,56
Machine 4	Uniform(7, 8)	8
Machine 5	Uniform(7, 8)	8

Table 6 - variable production machines

Result

In “Table 6 - variable production machines” the minimum interval-arrival time without the stalling of machines can be seen. The production can be increased more, but this will go against the machine utilization. The machines will stall because of product jams on the conveyor belt.

I notice that the front 2 side conveyors don't have any problems with product jams even when machine 3 and machine 5 are at maximum production capacity. The main congestion starts to happen the conveyor switch 2 (machine line 4), because of its high transfer time compared to the rest of machine lines.

Assignment 4

What are your suggestions in order to improve the system? Does increasing the speed of the conveyors produce an effect?

Experimental information

Increased conveyor speed

The conveyor speed is increased from 1 m/s to 2 m/s.

Machine nr.	Inter-Arrival time	Δ Box per min
Machine 1	Uniform(7, 8)	8
Machine 2	Uniform(7, 8)	8
Machine 3	Uniform(10.3, 11.3)	5,56
Machine 4	Uniform(7, 8)	8
Machine 5	Uniform(7, 8)	8

Table 7 - Variable production increased conveyor speed

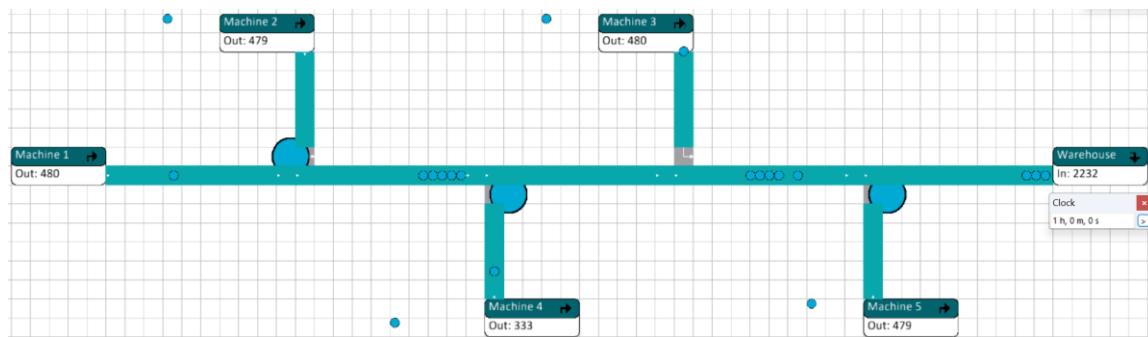


Figure 30 - Experiment variable production increased conveyor speed

Model: transport3.mod
 Observation period: 288000
 Warmup period: 0
 Number of replications: 10
 Simulation method: Separate runs
 Description:

Machines Elements : Machine 1, Machine 2,						
Production	Average	S.Dev.	LB (95%)	UB (95%)	Minimum	Maximum
18024.80	4.73	18021.41	18028.19	18017.00	18031.00	
Status Busy	Average	S.Dev.	LB (95%)	UB (95%)	Minimum	Maximum
1.00	0.00	1.00	1.00	1.00	1.00	1.00

Figure 31 - Experiment info variable production increased conveyor speed

Transfer unit switch

The transfer unit of machine 2 and machine 3 are switched.

Machine line nr.	Inter-Arrival time	Δ Box per min	Transfer-time (s)
Machine 1	Uniform(7, 8)	8	0
Machine 2	Uniform(10.3, 11.3)	5,56	10
Machine 3	Uniform(7, 8)	8	2
Machine 4	Uniform(7, 8)	8	2
Machine 5	Uniform(7, 8)	8	5

Table 8 - Variable production Transfer unit switch

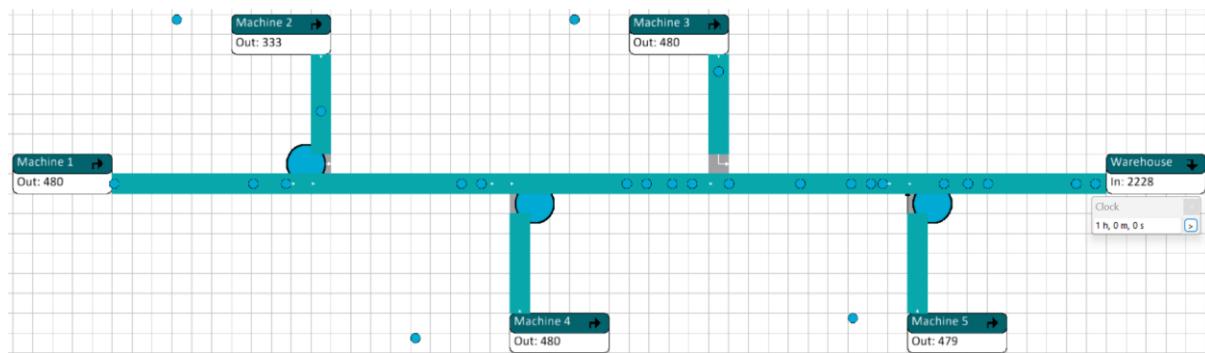


Figure 32 - Experiment variable production transfer unit switch

Model: transport3.mod
 Observation period: 288000
 Warmup period: 0
 Number of replications: 10
 Simulation method: Separate runs
 Description:

Machines Elements : Machine 1, Machine 2,

Production	Average	S.Dev.	LB (95%)	UB (95%)	Minimum	Maximum
	18024.10	4.53	18020.86	18027.34	18017.00	18031.00
Status Busy	Average	S.Dev.	LB (95%)	UB (95%)	Minimum	Maximum
	1.00	0.00	1.00	1.00	1.00	1.00

Figure 33 - Experiment info variable production transfer unit switch

Result

Increased conveyor speed

The increase in conveyor speeds results in a higher capacity load for the transport line, without a loss of machine utilization. This can be seen in “Figure 31 - Experiment info variable production increased conveyor speed”. The busy status performance measure stays at 1.00 which means that there are no dips in utilization. Even when the machine production for machine 1 and machine 2 is set to its maximum production capability.

It is still important to leave a slight gap for machine 4 in production time compared to the transfer time. Otherwise, there will be no time for products to surpass the conveyor switch 3 and will create a product jam.

Transfer unit switch

The change in transfer units for machine line 2 and machine line 4 has the same affect as the increase in conveyor speed. Machine 1 and machine 4 can be set to maximum capacity without it affecting any machine utilization. As can be seen in “Figure 33 - Experiment info variable production transfer unit switch“.

Recommendation

I would recommend the transfer unit switch method with variable production quantity, because it will have the same benefits as the increased conveyor speed. And in this case, there is no increase in conveyer speed necessary. Which results in less power consumption compared to the other option.

Research

Stochastics (random probability distribution)¹

Stochasticity refers to the modeling approach of the phenomenon of randomness. But these terms are often used synonymously. Stochastics are often used in probability theory.

Enterprise Dynamics has several built-in stochastic math functions to simulate randomness.

Discrete distribution

A discrete distribution applies to a discrete random variable, which can take on a countable set of distinct values. These values can be whole numbers or other countable data points, such as the number of heads in coin tosses, or the number of students in a class.

Poisson distribution²

The Poisson process is a stochastic process with several definitions and applications. It's a counting process, which is a stochastic process in which a random number of points or occurrences are displayed over time. A time-dependent Poisson random variable is defined as the number of points in a process that falls between zero and a certain time. Non-negative numbers make up the index set of this process, but natural numbers make up the state space. Because it can be conceived of as a counting operation, this procedure is often referred to as the Poisson counting process.

The poisson process is a non-negative discrete distribution

Continuous distribution

A continuous distribution applies to a continuous random variable, which can take on an infinite number of values within a given range. These values are not countable because they include every possible number between any two points.

Negative Exponential distribution

Empirical Distribution

An empirical distribution refers to a probability distribution that is based directly on observed data rather than on a theoretical model. It is used to describe the distribution of a set of observed values, showing the relative frequencies of outcomes in the data.

¹ InControl Enterprise Dynamics [Computer program]. (2023). *HTML Help 4DScript category stochastic*. InControl Enterprise Dynamics.

Bartholomew, D. J. (2015). *Stochastic models*. In Elsevier eBooks (pp. 467–472). <https://doi.org/10.1016/b978-0-08-097086-8.43095-3>

Young, J. (2024, May 31). *Discrete Probability Distribution: Overview and examples*. Investopedia. <https://www.investopedia.com/terms/d/discrete-distribution.asp>

OpenAI. (2024). *ChatGPT* (Sep 19 version) [Large language model]. <https://chat.openai.com/chat>

² Lendave, V. (2024, July 15). *A guide to stochastic Process and its applications in machine learning*. AIM. <https://analyticsindiamag.com/developers-corner/a-guide-to-stochastic-process-and-its-applications-in-machine-learning/>

Queueing Theory

M/M/c queueing model³

M/M/C is a multi server system with customers arrival follows a poisson process and exponential service time. When a customer enters an Empty system, he gets the service at once. If the system is non-empty the incoming customer joins the Queue. M/M/C model is a poisson birth death process.

Birth Occurs → Customer arrives

Death Occurs → Customer departs

Both are modeled as Memoryless Markov process.

In M/M/C , M refers to this memoryless/Morkov feature of the arrival and service

Experiments⁴

Performance Measures (pfm)

Groups

The average stay for group experiments is calculated on a weighted basis of total output. This is done to remove biases of different elements in the group with a lower output.

Average stay: Weighted average of the elements of the group, divided by sum of the output of the elements k of the group.

$$\frac{\sum_k \text{avgstay}(k) * \text{output}(k)}{\sum_k \text{output}(k)}$$

³ Sundari, S. M., & Srinivasan, S. (2011). *M/M/C queueing model for waiting time of customers in bank sectors*. ResearchGate.

https://www.researchgate.net/publication/267176376_MMC_queueing_model_for_waiting_time_of_customers_in_bank_sectors

⁴ InControl Simulation Solutions. (2023, November 14). *Experimentation: Enterprise Dynamics 10 (Version 10)*. InControl Simulation Solutions. <https://www.incontrolsim.com>