WARWICK BUSINESS SCHOOL

Undergraduate Programme

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Assignment Question: Simulating Manufacturing Process Report.

See Assignment Brief for Full Question.

Contents

Main Report

Introduction

John Peters Ltd, a family-run manufacturing firm in the Midlands, is seeking to enhance its efficiency by increasing production without incurring significant additional costs. With growing competition from new rival firms in recent years, they want their system to run more efficiently and aim to boost production by at least 20% of their current throughput. They are willing to consider the layout of the machines, staffing and newer machines that they could update to, but they do not wish to make significant investments unless it is necessary.

Conceptual model

Model Objectives

Achievement: Increase throughput and improve efficiency of the manufacturing process without a significant increase in costs.

Performance: Increase throughput by at least 20%.

Potential Changes: (i) Number of staff (ii) Number of machines (iii) Staff roster (iv) Staff Assignment

Constraints: No space and budget constraints are specified but client does not wish to make significant investments unless necessary.

Project Objectives

- **Time Scale:** Recommendations by March 14th
- **Nature of Model**
    - **Flexibility:** Model should not need to be changed beyond varying the stated experimental factors (staff, machines, processing time, and roster).
    - **Run Speed:** Number of possible scenarios reasonably small, so run time not critical.
    - **Visual Display:** 2D simulation
    - **Ease of use:** Clients will not directly interact with model so separate interface is not necessary.

Model Inputs and Outputs

Model Inputs (Experimental Factors):

- Arrival rates of the RM
- Number of machines of each type
- Number of staff working on machines A1, A2, B1, B2, B3, D1, D2, D3, and C4
- Working hours of factory floor staff

Model Outputs (KPIs):

- To analyse the achievement of objectives:
    - Number of finished articles
- To analyse reasons for failure to meet objectives:
    - Bar chart of waiting time for each WP in the queue(s)
    - Summary statistics of job processing times (mean, standard deviation, minimum value, maximum value)

- Utilisation of resources: machines and staffs
- Time series of average queue size

Model Scope

Component	Include/Exclude	Justification
Entities		
RM1/WP1	Include	Flow from A1 to A4 through factory floor.
RM2/WP2	Include	Flow from C1 to C4 through factory floor.
Other raw materials	Exclude	Do not affect the processing system.
Activities		
Machines processing	Include	Activity involving processing.
Warehouse processing	Exclude	Raw materials will be delivered directly to the factory floor at fixed interval.
Testing area (T1, T2, T3)	Exclude	Testing products go straight to destruction and do not affect the overall production.
Queues		
Queues for manufacturing process	Include	Required for outputs and each machines have a buffer.
Queues for testing areas	Exclude	Not required for outputs.
Queues for raw materials from warehouse	Exclude	Not required for outputs.
Queues for finished articles to warehouse	Exclude	Not required for outputs - finished articles are automatically moved into the warehouse packaging department.
Resources		
Manufacturing machines	Include	Input (Experimental factor) needed for manufacturing process
Factory staff	Include	Input (Experimental factor) needed for operating the machines
Testing machines	Exclude	No input. Unable to change for the existence of regulations
Warehouse machines	Exclude	No input. Does not affect the system
Testing staff	Exclude	No input. Not needed to operate machines
Warehouse staff	Exclude	No input. Not needed to operate machines

Assumptions and Simplifications

Assumptions	Simplifications
• Machines do not break. • Consistently takes 12 seconds from machine to buffer. • No staff absentees (breaks or sick day etc.) • Inputs consistently arrive on the hour. • Staff always work to same level. • We assume all data and information provided to us is valid.	• Exclude Testing Area from model • Excluding dedicated staff • Exclude Test staff • Exclude Warehouse staff • Use distributions based on observed activity times for machines select machines.

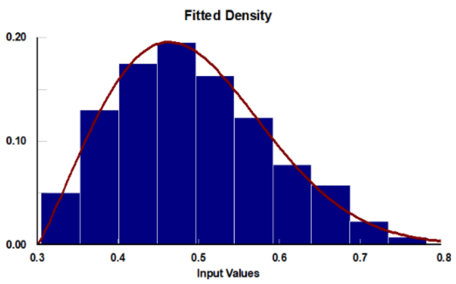
For justifications see *Figure A1* in Appendix.

Data Analysis

We've been provided with 400 observations of the activity time of machines A2, B1, B2, B3~~,~~ and C4. We need to account for the context in which we are using the distribution. For example, there were many instances where a beta distribution is put forward. However, the beta distribution is not appropriate as it typically used to analyse the probability of a binary outcome, such as the probability of a machine failing. Thus, for the purposes of this analysis we will only be considering the Gamma, Weibull, Uniform and Triangle distributions.

When fitting a distribution to the observed activity times we chose to set a suitable lower bound for each machine. Were we to not set this, the distributions fitted would allow for the possibility of extremely low activity times that could not practically be achieved. We select this value by considering the minimum observed value along with the range. See Figure C5 in the appendix.

The Selection Process



For A2, we set a minimum of 0.3. In *AppendixC1*, we can see Stat::Fit "does not reject" 6 different distributions that passed the goodness of fit tests but two, Weibull and Beta, clearly appear superior with far higher rank and aicc prob. As explained before we know using a Beta distribution is not appropriate in this context leaving us to only consider the Weibull distribution. Hence, we implemented the Weibull (2.14,0.219) distribution with an offset of 0.3 in our model. We can visually validate the use of this distribution, seeing the density of the distribution following a very similar trend to the histogram of the raw data.

We repeated this process for the selection of all the distributions based on the raw data provided. This gave us the following:

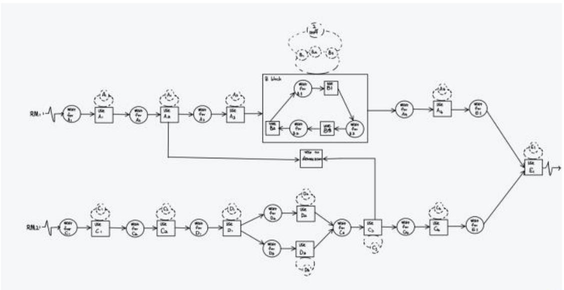
Machine	Distribution
A2	Weibull(0.3,2.14,0.219)
B1	Triangular(0.7,0.898,1)
B2	Uniform(0.601,0.899)
B3	Triangular(0.6,0.984,0.803)
C4	Weibull(5.5,2.19,2.76)

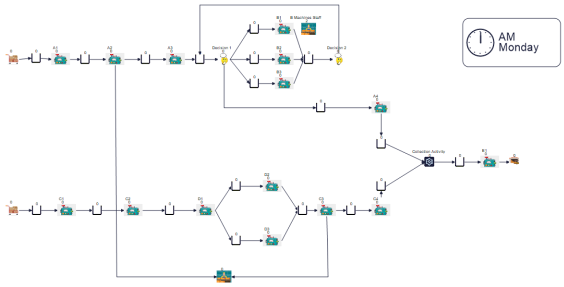
For B2 we considered fitting an empirical distribution, see appendix Figure C4 for the justification as to why we did not.

Verification and Validation

Verification

Verification ensures that we correctly transform the conceptual model into the computer model. We created our model based on the process flow diagram and ensured all parts were consistent by taking a systematic approach. For example, we implemented all the Activity Times at the same time to decrease the likelihood of missing any input. For each activity, we had one member implementing the inputs and another checking afterwards to ensure they were in correspondence with the conceptual model. Were we to have the opportunity to contact expertized clients, we would check that the conceptual and computer model match their expectations.





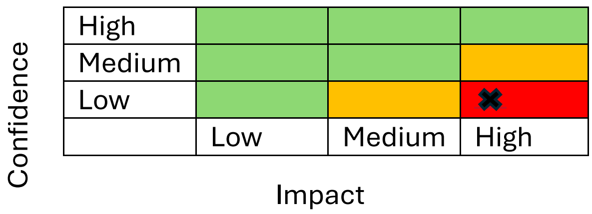
Trials Prep

In practice, the system we are modelling is in-session 24/7, meaning it is important to avoid potential initialisation biases and so we need to check if a warm-up is required for our system to be operating in its "typical state". In our model we coded visual logic (*AppendixD2*) to collect data required for producing a time series plot *(AppendixD3)* and for use in the MSER-5 method (*AppendixD4*) to find the necessary warm-up period. Using the MSER-5 method we found when running trials, we should include a warm-up period of 100 minutes so our model can reach its steady state.

We wanted 95% Confidence Limits and so used the simul8 trials calculator to calculate the number of trials needed to achieve such CL. We visually validated the use of this number of trials using FigureD6.

Conceptual model validation

When creating the conceptual model there was a range of assumptions made. It is important to assess the confidence we have in these assumptions and the impact they would have on the model were they to prove incorrect.



In the figure we have assessed the level of concern of the assumption that there are no employee absentees. This is a very unlikely scenario as staff absentees are unavoidable, whether it be for sickness or another reason, giving us low confidence. Were a staff member to be absent there would be a significant impact on output as a machine that requires a staff member to operate would be left unmanned. This leads to this assumption to be of high concern. To nullify this concern, we would get the client to confirm whether they have staff available to cover shifts to ensure there are no absentees.

See *AppendixD1* for the full table of evaluated assumptions.

Data Validation

The data used in this project was provided by the client and assumed to be valid. We have no way to validate this data other than to contact and check with the client.

We are however able to validate our choices of distributions. Using the transaction log feature on simul8 we collected over 400 observations for the activity times of each of the 5 machines we are validating. Using Excel, we collected various summary statistics for this data to compare with the real-system data. For each machine we see a similar mean and standard deviation. We do however see the maximum being slightly larger in some cases due to some of the distributions fitted having no upper limit. This does not concern us however as throughout the 24-hour period these machines process many entities meaning that a few outliers with have little impact on the output of the model.

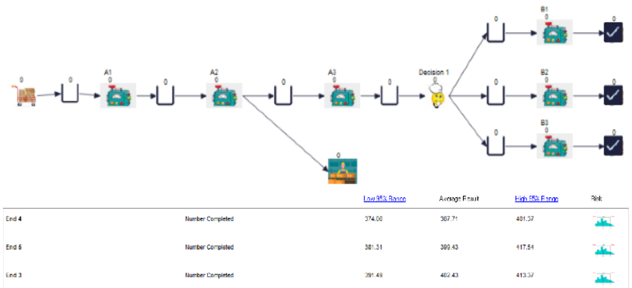
	A2		B1		B2		B3		C4	
	Actual Data	Model Data	AD	MD	AD	MD	AD	MD	AD	MD
Mean	0.49423688	0.49357	0.865893	0.86721	0.749033	0.748203	0.793376	0.802066	7.94476	8.0062
Range	0.47700335	0.56807	0.285296	0.28859	0.298331	0.29992	0.356996	0.36989	5.317475	6.66785
Min	0.30496794	0.30256	0.707895	0.70361	0.600559	0.6	0.60905	0.61085	5.61317	5.80991
Max	0.78197129	0.87063	0.993192	0.9922	0.898891	0.89992	0.966046	0.98074	10.93064	12.47776
Standard Deviation	0.09528336	0.090639	0.064616	0.061313	0.084845	0.085447	0.081196	0.083954	1.182723	1.212224

White box validation

A White-box validation consists of conducting a detailed check over each component of the model.

We inspected the behaviour of entities as they passed through our complete model to ensure that it was consistent with what we expected. This involved pausing the simulation and predicting the next occurrence to see if the entity behaved as necessary. Our visual checks were confirmed by the Trace Work Item tool, which highlighted the path a specific object took, in partnership with the Step Forward function.

We then inspected output reports of our model after having ran for 24 hours post warm-up. The staff assigned to machines B1, B2 and B3 had a utilization of 100% implying they are constantly operating a machine. This is as is expected given two people are operating three machines.



Isolating sections of the simulation was also helpful in the validation process. To check that our labelling system was properly assigning entities to a machine in block B with equal probability we created a smaller simulation that keeps track of how many entities are assigned to each machine in a 24-hour period. We would expect each machine to be assigned around 396 entities per day. This is within the 95% Confidence Interval for each machine and so we are confident that our model is performing in correspondence to the real-world system. Following a similar process (*AppendixD9*) we tested that the correct number of entities were being sent for testing. This also proved to be performing as desired.

See AppendixD10 for validation of fixed machine processing times.

Black box validation

Black-box validation consists of a general check that the whole model provides a sufficiently accurate representation of the real-world system. If the model is run under the same condition as the real system, then the model outputs (KPI) should be similar to the outputs of the actual system.

Let (I_{RS}) be the inputs to the Real System, (I_M) be inputs to the model, (O_{RS}) be outputs from real system and (O_M) be outputs from the model. In the model, we have $I_{RS} \approx I_M$; and $O_{RS} \approx 1188$. We present the Hypothesis:

- Null Hypothesis (H_0): If $I_{RS} \approx I_M$ then $O_{RS} \not\approx O_M$
- Alternative Hypothesis (H_1): If $I_{RS} \approx I_M$ then $O_{RS} \approx O_M$

Then conduct the following test at the 5% significance level:

$$H_0 \; vs \; H_1$$

Here is the summary of outputs from the model (O_M):

		Low 95% Range	Average Result	High 95% Range	Risk
Warehouse	Number Completed	1184.24	1187.25	1190.26	

As we can see the low 95% range of the output from the model is 1184.24, high 95% range of the output is 1190.26, the most likely value of the output is 1187.25. The 95% Confidence Interval contains the true value 1188 and so there is sufficient evidence to reject H_0 in favour of H_1. Thus, we are content that our model accurately produces the same level of output as the real-world system.

Concluding statement

We are happy that our model effectively simulates the operation of the factory floor and will be extremely useful in guiding the clients to reaching their objective of increasing throughput by 20%.

Appendices

Appendix A - Conceptual Model:

Figure A1: Assumptions and Simplification Justifications

Simplifications	Justifications
The testing procedures done on RM1 and RM2 are excluded from our Simul8 model.	Data on testing procedures fall into Category C data.
Dedicated staff for machines A1, A2, D1, D2, D3 and C4 are not explicitly shown in the model.	Staff is always available to operate the machines.
Staff for testing and disassembly areas and warehouse are not explicitly shown in the model.	Do not involve in the manufacturing process.
The distributions for job processing times for machines A2, B1, B2, B3 and C4 are based on the observed activity times.	Data on the job processing times fall into Category B data.

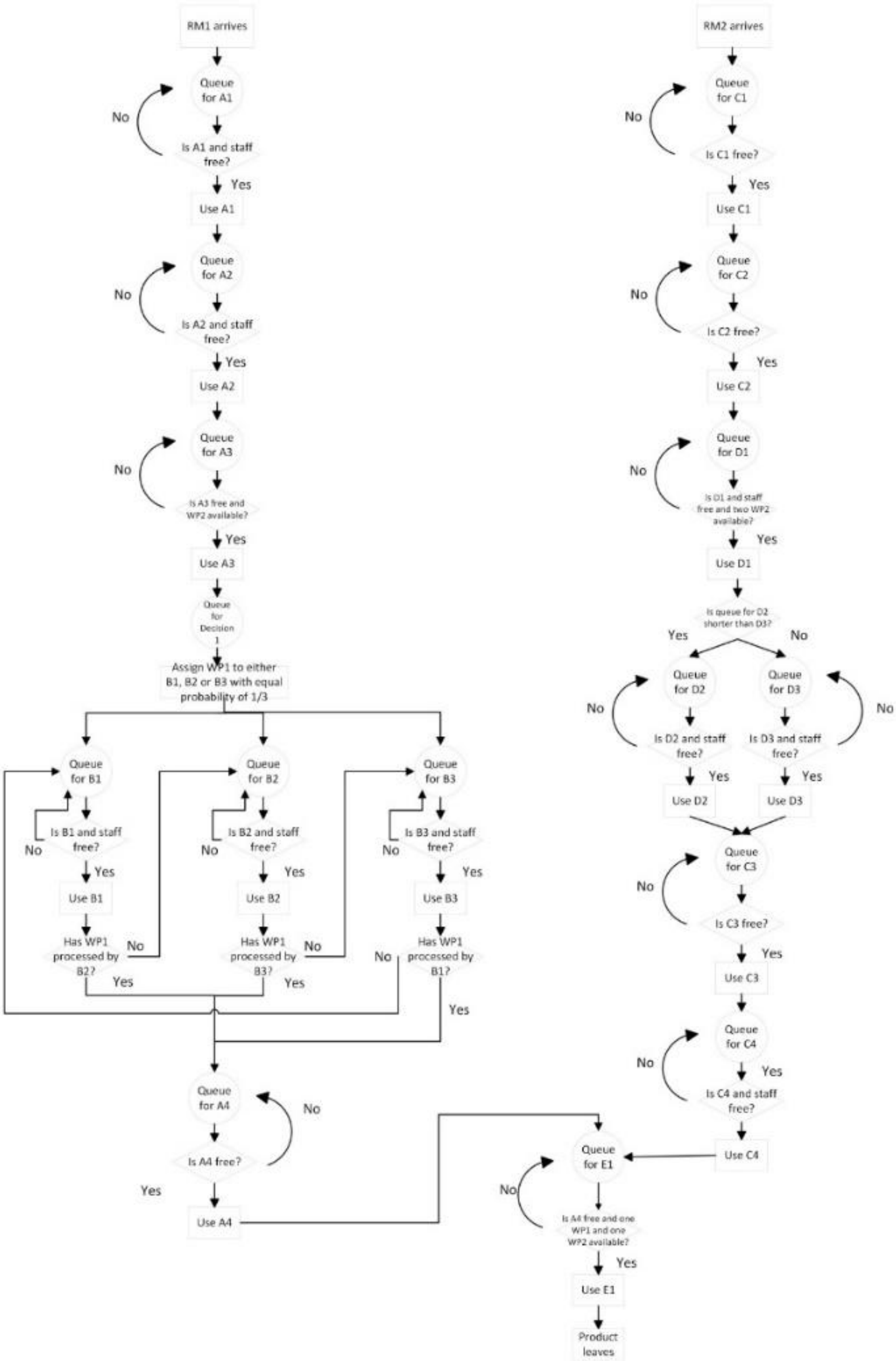
Assumptions	Justifications
Machines work at full capacity and do not break.	Not a significant problem.
WP consistently takes 12 seconds to travel between machine to the next buffer.	Choose to model more simply.
No staff absentees (i.e. no breaks or sick day)	Not frequent enough to affect our model outputs.
Staff always work at full capacity.	Staff efficiency is modelled into the machine processing time.
Data and information provided to us is valid.	We use the data and information provided in Project brief to create our model.
Inputs consistently moved to the buffer for machines A1 and C1 on the hour.	Inputs are readily available in the company warehouse.

Figure A2: Model Level of Detail

Component	Detail	Include/ Exclude	Comment
Entities			
RM1	Each entity represents for one unit	Include	No significant grouping observed
	Arrival pattern	Include	100 units arrive hourly
	Routing	Include	Goes to A1
RM2	Each entity represents for one unit	Include	No significant grouping observed
	Arrival pattern	Include	100 units arrive hourly
	Routing	Include	Goes to C1
WP1	Each entity represents for one unit	Include	No significant grouping observed
	Arrival pattern	Include	Depend on the previous machines
	Routing	Include	Flow from A1 to A4
WP2	Each entity	Include	No significant grouping observed

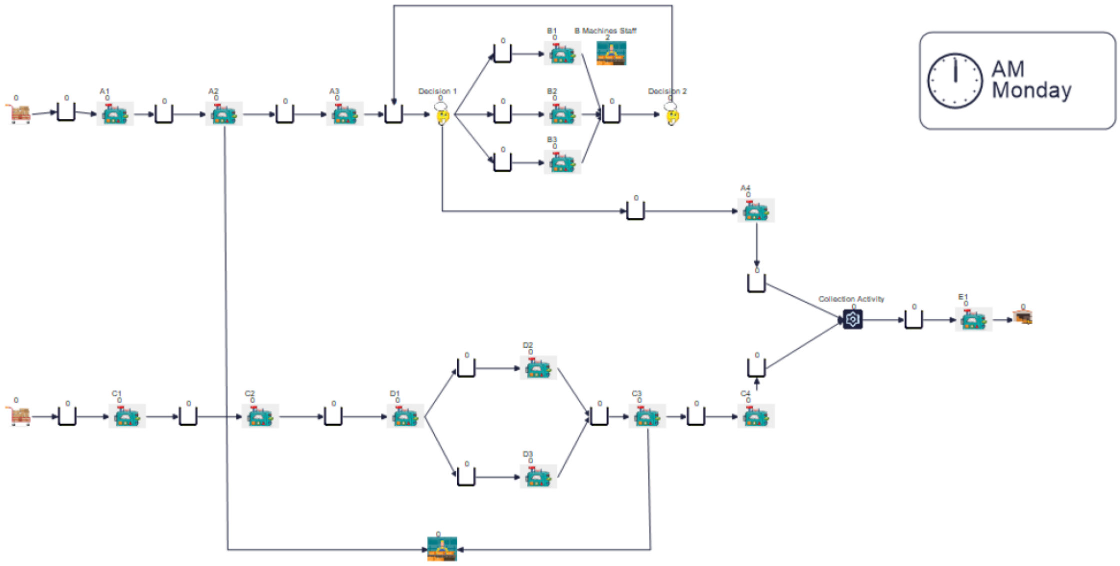
	represents for one unit		
	Arrival pattern	Include	Depend on the previous machines
	Routing	Include	Flow from C1 to C4
Activities			
Manufacturing process	Duration	Include	Depend on different machines
	Resource	Include	Depend on different machines
	Routing	Include	Entities follow the flow from WP1/ WP2 and get assembled at E1 and exit the model when complete.
Queues			
Queues for manufacturing process	Queue Discipline	Include	Last in First out
	Routing	Include	Shorter queues will be chosen
	Quantity	Include	Dedicated-one per manufacturing activity (expect E1 have 2 waiting queues)
	Capacity	Include	Different buffers have different capacities
	Dwell time	Exclude	No dwell time
	Reneging	Exclude	Assumed not significant
Resources			
Manufacturing machines	Quantity	Include	Dedicated-one per manufacturing activity
	Skill level	Include	Different machines have their own production probabilities
	Breakdown	Exclude	Not significant problem
	Roster	Exclude	Always available
Factory staff	Quantity	Include	Experimental factor
	Roster	Include	Experimental factor
	Skill level	Exclude	Included in machine time distribution
	Absenteeism	Exclude	Assume no absence

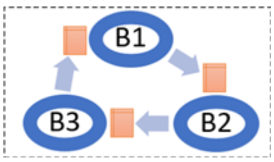
Logic Flow Diagram



Appendix B – Simul8 Model description:

We have built a Simul8 model (pictured below) which represents the operations of John Peters Ltd. As instructed, we have not carried out any experimentation, but we have set up a results manager that will assist the client in reaching the main model objective that takes into account the aforementioned experimental factors.

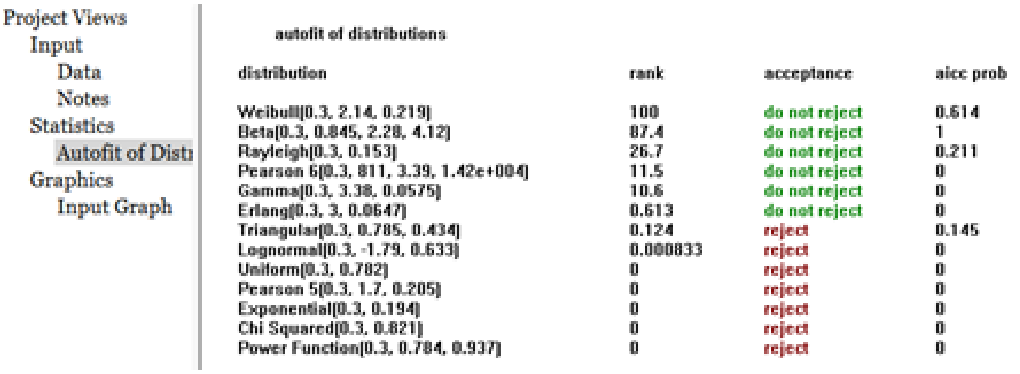


Arrivals and Labels	
We have two starting points, one for RM1 and another one for RM2. RM1 and RM2 arrive regularly and are stored in the factory warehouse. At fixed hourly intervals, 100 units of RM1 and RM2 are delivered to buffers of machines A1 and C1 respectively. Buffers have a maximum capacity of 200 units. Any new units that exceed the quantity will be returned to the factory warehouse. The labels "Route to Take" and "Activity Count" are also initialised with values assigned at the starting point for RM1.	
Activities & Queues	Distributions used for each activity time are explained in the data analysis section.
Queues for machines A, B, C, D, and E	Each buffer follows last in, first out queuing discipline. Buffers for A1, C1, and E1 can take a maximum of 200 units of WP each whereas the other buffers can take a maximum of 100 units of WP each.
Machines A	Machine A1 routes in only from the buffer containing WP1, and routes out to the queue for machine A2. Machine A2 behaves similarly to machine A1. Machine A3 will then collect 2 units of WP1 and assemble them into 1 unit. Note that 1% of WP1 will be taken out to undergo a testing procedure after being processed by machine A2.
Machines B 	Machine B routes in by percentage: 33.33% machine B1, 33.33% machine B2, and 33.33% machine B3. This distribution has been set to each WP1 by the "Route To Take" label assigned at C3. We use Visual Logic at Decision 1 Activity to route out WP1 to the following B machines after its first random assignment according to the circular order shown at the left (e.g. if WP1 is randomly assigned to B2, "Route To Take" will then assign it to B3 then B1). The label "Activity Count" is set to 0 at the starting point and will increase after WP1 is processed by any B machines at Decision 2 Activity by Visual Logic. Once "Activity Count" = 3, WP1 will route out to machine A4 buffer.
Machines C	Machine C1 routes in only from the buffer containing WP2, and routes out to the queue for machine C2. Machine C2, C3 and C4 behaves similarly to machine C1. Note that 1% of WP2 will be taken out to undergo a testing procedure after being processed by machine C3.

Machines D	Machine D1 collects 2 units of WP2 and assembles them into 1 unit. WP2 leaves D1 to either machine D2 or D3. WP2 will be moved into the buffer that currently holds the least amount of WP2.
Machine E	Machine E1 takes 1 unit of WP1 and 1 unit of WP2 from two separate buffers. Machine E1 won't take a unit of WP1 until there is a unit of WP2 available and vice versa.
Warehouse	The endpoint of our simulation model is when the finished articles are automatically moved into the warehouse packaging department.
Resources	
Factory staff	Staff work in shifts i) 8am – 4pm ii) 4pm – midnight iii) midnight – 8am.
Machines	Machine A1 and D2 have replications set to 3 to reflect the fact that they can process three jobs simultaneously. Machine A4 has replications set to 5 to reflect the fact that it can process five jobs simultaneously. Machine C2, C3 and C4 has replications set to 10 to reflect the fact that it can process ten jobs simultaneously.
Results Manager	In the results manager, we track model output KPI's as stated in the beginning of this report.

Appendix C - Data Analysis:

Figure C1: Stat::Fit results for A2



distribution	rank	acceptance	aicc prob
Weibull(0.3, 2.14, 0.219)	100	do not reject	0.614
Beta(0.3, 0.845, 2.28, 4.12)	87.4	do not reject	1
Rayleigh(0.3, 0.153)	26.7	do not reject	0.211
Pearson 6(0.3, 811, 3.39, 1.42e+004)	11.5	do not reject	0
Gamma(0.3, 3.38, 0.0575)	10.6	do not reject	0
Erlang(0.3, 3, 0.0647)	0.613	do not reject	0
Triangular(0.3, 0.785, 0.434)	0.124	reject	0.145
Lognormal(0.3, -1.79, 0.633)	0.000833	reject	0
Uniform(0.3, 0.782)	0	reject	0
Pearson 5(0.3, 1.7, 0.205)	0	reject	0
Exponential(0.3, 0.194)	0	reject	0
Chi Squared(0.3, 0.821)	0	reject	0
Power Function(0.3, 0.784, 0.937)	0	reject	0

Figure C2 and C3: Histograms for B1 and B3

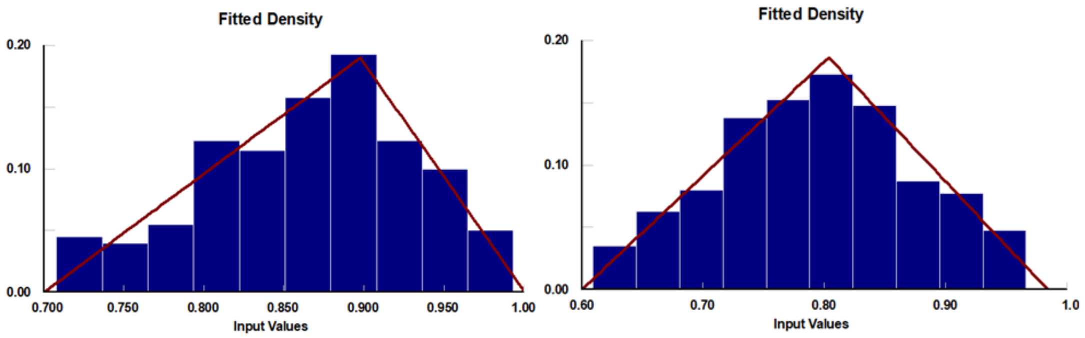


Figure C4: B2 Distribution Justification.

For machine B2 we considered fitting an empirical distribution due to the nature of the histogram as none of the fitted distributions appear to be a perfect fit. However, when dealing with a small number of observations we are hesitant to employ an empirical distribution due to the likeliness of overfitting where unusual, random changes in the patterns in the data lead to fitting a distribution that is unrepresentative of the true, underlying distribution. We concluded that fitting a Uniform(0.601,0.899) distribution is most suitable for this machine.

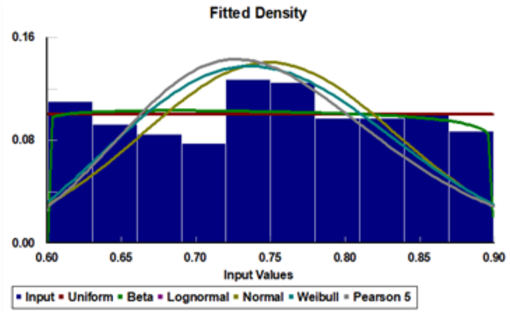


Figure C5: Lower Bounds Of Distributions

Machine	Lower Bound
A2	0.3
B1	0.7
B2	0.6
B3	0.6
C4	5.5

Appendix D – Verification & Validation

Conceptual Model Validation:

Figure D1:

Assumption/ Simplification	Confidence	Impact	Concern	Recommendation/ Next step
Testing process has no effect on overall production	Medium	Low	Low: Potential oversight in integrating testing outcomes with production	Consult with client to ensure this is the case.
Machines suffer no unexpected downtime	Medium: Depends on machine maintenance	High	Low: Unexpected machine downtime could easily halt the entire production process, but it is likely a rare event	Consult with the client about machine reliability. If a certain machine is particularly prone to downtime, this could be modelled
Employee efficiency is consistent	Low: Employees will get tired	Medium: Depends how much human involvement machines require	Medium: Efficiency may vary, affecting production	Consult with client to get information on staff breaks and other measures in place to keep staff performance high.
No staff absentees (breaks or sick day, etc.)	Low	High	High: Staff absence can significantly disrupt operations	Consult with client to see if there are measures in place to cover staff members' shifts if they are absent.
Inputs consistently arrive on the hour	Medium	Medium	Low: Delays in inputs can lead to idle resources and production delays	Consult with client about reliability of deliveries. Potentially ask for arrivals data to model arrivals more accurately.

We assume all data and information provided to us is valid	High: Assuming rigorous data collection	High	Low: Invalid data could lead to incorrect conclusions and model outputs	Confirm client has validated the data they have provided us with.

Warm Up Period:

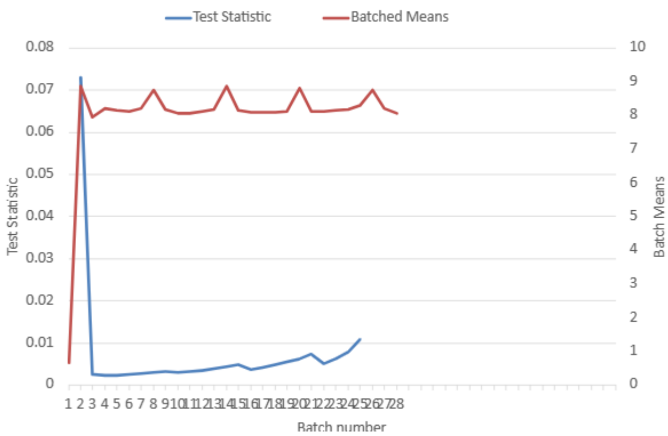
Figure D2: Visual Logic for collecting Time Series Data:

Figure D3: Time Series Plot

Figure D4: MSER-5 Method

MSER-5 Method

Batch Number	Batched Means		Number of Batch Means discarded	Test Statistic	Estimated Warm-up Period (in batches)
1	0.68		0	0.073094	2
2	8.86		1	0.002682	
3	7.96		2	0.002332	
4	8.22		3	0.002399	
5	8.14		4	0.002602	
6	8.12		5	0.002811	
7	8.2		6	0.003036	
8	8.76		7	0.003325	
9	8.18		8	0.003005	
10	8.06		9	0.003321	
11	8.06		10	0.0036	
12	8.12		11	0.003909	
13	8.18		12	0.004336	
14	8.86		13	0.004899	
15	8.14		14	0.003725	
16	8.08		15	0.004271	
17	8.1		16	0.00483	
18	8.08		17	0.00555	
19	8.12		18	0.006352	
20	8.8		19	0.007491	
21	8.12		20	0.005047	
22	8.12		21	0.006283	
23	8.16		22	0.007993	
24	8.18		23	0.010893	
25	8.28				
26	8.74				
27	8.22				
28	8.06				



Number Of Trials:

Figure D5: Trials Calculator

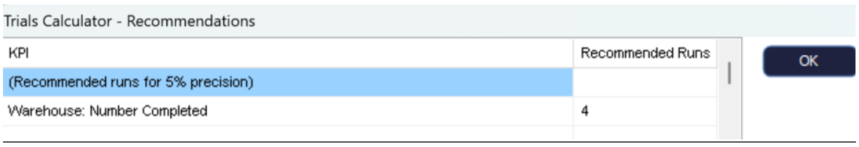
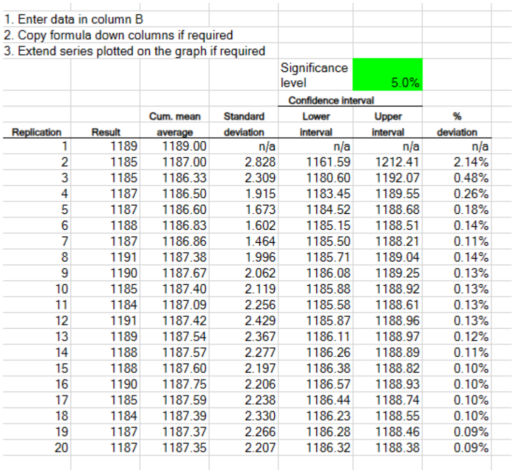


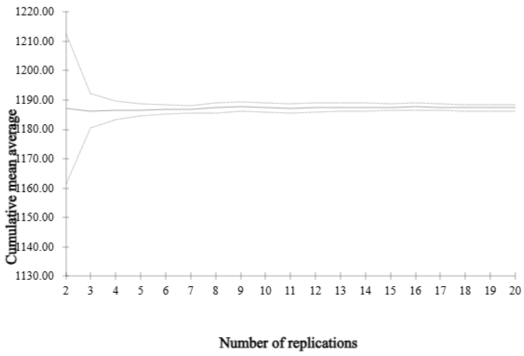
Figure D6: Replications Plot



1. Enter data in column B
2. Copy formula down columns if required
3. Extend series plotted on the graph if required

Significance level: 5.0%

Replication	Result	Cum. mean average	Standard deviation	Confidence interval Lower interval	Upper interval	% deviation
1	1189	1189.00	n/a	n/a	n/a	n/a
2	1185	1187.00	2.828	1161.59	1212.41	2.14%
3	1185	1186.33	2.309	1180.60	1192.07	0.48%
4	1187	1186.50	1.915	1183.45	1189.55	0.26%
5	1187	1186.60	1.673	1184.52	1188.68	0.18%
6	1188	1186.83	1.602	1185.15	1188.51	0.14%
7	1187	1186.86	1.464	1185.50	1188.21	0.11%
8	1191	1187.38	1.996	1185.71	1189.04	0.14%
9	1190	1187.67	2.062	1186.08	1189.25	0.13%
10	1185	1187.40	2.119	1185.88	1188.92	0.13%
11	1184	1187.09	2.256	1185.58	1188.61	0.13%
12	1191	1187.42	2.429	1185.87	1188.96	0.13%
13	1189	1187.54	2.367	1186.11	1188.97	0.12%
14	1188	1187.57	2.277	1186.26	1188.89	0.11%
15	1188	1187.60	2.197	1186.38	1188.82	0.10%
16	1190	1187.75	2.206	1186.57	1188.93	0.10%
17	1185	1187.59	2.238	1186.44	1188.74	0.10%
18	1184	1187.39	2.330	1186.23	1188.55	0.10%
19	1187	1187.37	2.266	1186.28	1188.46	0.09%
20	1187	1187.35	2.207	1186.32	1188.38	0.09%



Data Validation:

Figure D7: Transaction Log

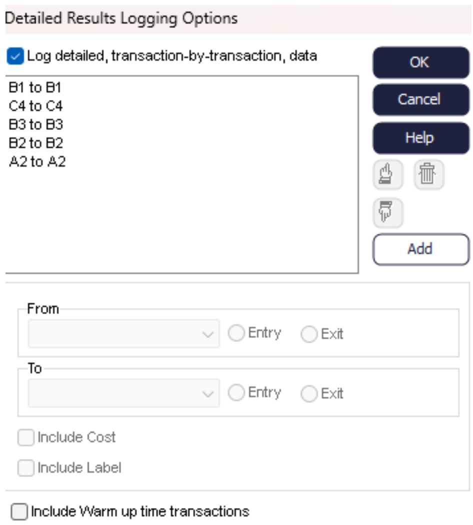


Figure D8: Excel Comparison of summary statistics

	A2		B1		B2		B3		C4	
	Actual Data	Model Data	AD	MD	AD	MD	AD	MD	AD	MD
Mean	0.49423688	0.49357	0.865893	0.86721	0.749033	0.748203	0.793376	0.802066	7.94476	8.0062
Range	0.47700335	0.56807	0.285296	0.28859	0.298331	0.29992	0.356996	0.36989	5.317475	6.66785
Min	0.30496794	0.30256	0.707895	0.70361	0.600559	0.6	0.60905	0.61085	5.61317	5.80991
Max	0.78197129	0.87063	0.993192	0.9922	0.898891	0.89992	0.966046	0.98074	10.93064	12.47776
Standard Deviation	0.09528336	0.090639	0.064616	0.061313	0.084845	0.085447	0.081196	0.083954	1.182723	1.212224

White Box Validation:

Figure D9: Isolated system displaying output to testing

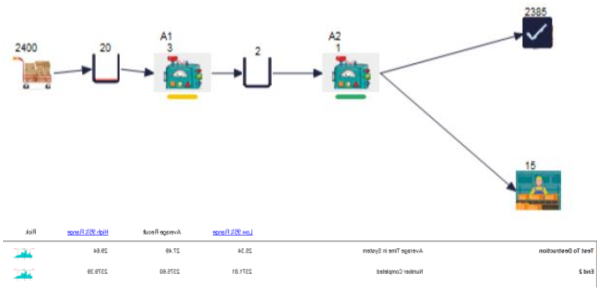


Figure D10:

Validating Fixed Activity Times
For activity A3, completed jobs is 1191, replicate=1, which implies time taken to process one unit of WP (in minutes) is (24×60) ÷ 1191 = 1.2min; it takes 1.2min in real world.
For activity A4, completed jobs is 1183, replicate=5, which implies time taken to process one unit of WP (in minutes) is (24×60) ÷ (1183÷5) = 6min; it takes 5.8min in real world.
For activity C1, completed jobs is 2400, replicate=1, which implies time taken to process one unit of WP (in minutes) is (24×60) ÷ 2400 = 0.6min; it takes 0.5min in real world.
We repeated this process for all machines with fixed activity times.

For the machines the utilization often falls short of 100% meaning the machines are not in operation constantly. As a result we would expect the time per output to be slightly longer than the machine time for each machine. Thus we are happy since there is only a very small, acceptable range; at a microscopic level, the model simulates real-world situation very well.

Records of meetings:

The following are minutes taken from each in-person meeting of the project recorded by U2009076:

Date	Attendees	Brief description
14/02/24	U2129719, U2105098, U2009076, U2224389, U2147135, U2041409	Made very rough basic conceptual model and approximate version made on Simul8, including the slightly more complex B block routing. Decided how we'd handle the processing in block B in simul8.
21/02/24	U2129719, U2105098, U2009076, U2224389, U2147135, U2041409	Looked at distributions for the data to work out which ones to put into simul8. Discussed staff member logistics. Ended up with a model which reflected what we hoped. Discussed how the report should be presented and decided to split into 2 teams for next meeting (V&V and writeup of conceptual model)
28/02/24	U2129719, U2105098, U2009076, U2224389, U2041409	Looked at V&V section in detail and discussed what aspects would be included in the report. As well as assign different parts of the V&V process to different people
06/03/24	U2129719, U2105098, U2009076, U2224389,	Discussed how to draw the randomized aspects on the logic flow diagram. Everyone was tasked to upload and finish any part of the project they had done over the weekend in order for it to be combined into one document

	U2147135, U2041409	
13/03/24	U2129719, U2105098, U2009076, U2224389, U2147135, U2041409	Final meeting where we all checked the document, managed to get the word count down to below 2000 and said what we were happy with along with any last minute changes that were needed

Student evaluation:

In our final meeting we each agreed that all students contributed around the following percentage to the final project, as well as what areas they contributed to the most:

Student	Contribution (%)	Areas of contribution
U2129719	16	Editing of final report, validation and verification, assumptions and simplifications, helping with the simul8 model.
U2105098	16	Data Analysis, Data Verification, Chief Whiteboard Operator in meetings, Editing of Final Report, Warm Up and Repetitions, Part of Simul8 Model.
U2009076	16	Project coordination, minutes, student evaluation, combining all the individual parts of the report, formatting the report, conceptual model validation
U2224389	16	Validation and Verification (white-box validation and black – box validation), helping with simul 8 model.
U2147135	16	Conceptual model (Model & Project Objectives, Model Outputs and Inputs), Logic flow diagram, Assumptions and Simplifications justifications, Simul8 model description
U2041409	16	Process flow graph, introduction for the problem, Conceptual model (Model scope and Model level of details)
U2258293	4	A&S confidence table and model icons. (Did not attend any meetings and was MIA until 1 week before the end when most things had been done).

These kinds of projects are incredibly complicated in scope and an exact percentage measure of what we feel we contributed doesn't really reflect the reality. The project also relied on us trading ideas a lot at meetings and much of the work was done in a group setting. Effort has also been made by us to stop potential bias from markers by referring to each student by their student number – in a lot of departments this is considered best practice. I am sorry if this causes any inconvenience.