Department of Industrial Engineering
University of Stellenbosch

Simulasie 442 : Simulation 442
2025

MEMORANDUM

Tutoriaal 10 *Tutorial 10*	Punt: 78 *Mark:*	Ingeedatum: **10-10-2025** (10:00) B3003 *Due date:*

Instruksies:	Formatteer alle syfers sinvol. Ontwikkel die modelle individueel. U mag in groepe van **twee** of minder werk om die vrae te beantwoord. Handig slegs een **PDF** dokument in. Gebruik Tecnomatix en Excel vir u berekenings. **Hierdie tutoriaal en prakties is verpligtend. Indien u nalaat om die vereistes betyds na te kom, sal u die module sak.**
Instructions:	*Format all numbers sensibly.* *Develop the models individually.* *You may work in groups of **two** or less when answering the questions.* *Submit one **PDF** document only.* *Use Tecnomatix and Excel for your calculations.* ***This tutorial and practical are compulsory. You will fail the module if you do not comply with the requirements, on time.***

Question 1: The Mine-Hoist model [18]

Complete the table below to show your understanding of the model.

State the:	Mine-hoist Model	
Essence of the problem	Ore loads appear at discrete points in time; the trucks arrive at the mine face and hoist transfer station at discrete points in time; the hoist arrives at the bottom and top of the shaft at discrete points in time. It is dynamic as the process evolves over time. It is stochastic as the ore loads are delivered following a triangular distribution.	[2]
Objective of the simulation	Multi-objective optimization (MOO) problem. Maximise profit while maximising the throughput.	[1]
Input variables	Load arrival rate TRIA(0:03, 0:01, 0:04) Ore transfer time from mine face to truck Ore transfer time from truck to hoist Hoist speed Number of trucks	[1]
Decision variables	• Hoist Speed • Number of trucks Why are the *Hoist speed* and *Number of trucks* included under Input AND Decision variables? Input variables are all input we need for the model to run: transfer times, number of trucks, hoist speed *etc*. Some of these we choose to specify once; others we want to vary. The decision variables are those we vary and they thus form a subset of the Input variables set.	[2]
Output parameters	• Cost • Profit • Throughput	[2]
Assumptions made	• No spillage occur. • There are no production interrupts (e.g. resource failures, personnel shortages). • The hoist moves at a constant speed regardless of load. • There is always a load available at the mine face.	[2]
Validation considerations	• Trucks must be at the start of the path to load. • Trucks can only unload once the hoist is in position. • As more ore is mined, the travel path for the trucks increase; to implement this, the truck speed should reduce by 0,003 m/s after each cycle.	[2]
/////		
Apply Shannon's world view:		
Entity	A load of ore being conveyed by a truck or the hoist.	[1]
Attributes	Weight of ore load	[1]
Resources	Truck(s), hoist	[1]
Conditions	Trucks and/or mine-hoist are available.	[1]
Events	Start of loading/unloading ore. End of unloading. Hoist starts to load/unload ore.	[1]
System State	Throughput at time T; truck utilization at time T; hoist utilization at time T Hint: The answers to this question are always 'Utilization of resource 'X' at time T; number of units produced/received/rejected at time T; when there are buffers/queues in the model: number of MUs in queue at time T.	[1]

Question 2: The Mine-Hoist model [22]

1. Production targets need to be increased at the mine. While adding trucks is an option, safety regulations limit the maximum number to six trucks in the underground area. The hoist system can be upgraded to move faster, but speeds are restricted to no more than 3 m/s to prevent the hoist cable breaking under excessive acceleration.

   Suggest and motivate a solution – ignore the cost for the moment, but minimise the number of trucks and hoist speed.

   Provide the following results for the Throughput: Basic results, detailed results, confidence intervals plot, p-values and commentary on the results. [10]

Experiment	root.NumTrucks	root.HoistSpeed	root.Throughput
Exp 01	1	0.5	91.8
Exp 02	2	0.5	100.5
Exp 03	3	0.5	102.3
Exp 04	4	0.5	102.7
Exp 05	5	0.5	102.8
Exp 06	6	0.5	102.8
Exp 07	1	1.0	112.1
Exp 08	2	1.0	138.2
Exp 09	3	1.0	147.1
Exp 10	4	1.0	152.1
Exp 11	5	1.0	154.2
Exp 12	6	1.0	154.9
Exp 13	1	1.5	116.6
Exp 14	2	1.5	150.2
Exp 15	3	1.5	166.7
Exp 16	4	1.5	176.5
Exp 17	5	1.5	181.5
Exp 18	6	1.5	185.5
Exp 19	1	2.0	117.6
Exp 20	2	2.0	156.3
Exp 21	3	2.0	176.7
Exp 22	4	2.0	188.0
Exp 23	5	2.0	195.9
Exp 24	6	2.0	200.2

Figure 1: The basic results for the throughput

Experiment	root.Throughput	Standard Deviation	Minimum	Maximum	Left interval bound	Right interval bound
Exp 01	91.8	4.1	85	97	88.9	94.7
Exp 02	100.5	2.8	96	104	98.5	102.5
Exp 03	102.3	2.8	97	106	100.3	104.3
Exp 04	102.7	2.4	98	106	101.0	104.4
Exp 05	102.8	2.3	98	106	101.2	104.4
Exp 06	102.8	2.3	98	106	101.2	104.4
Exp 07	112.1	4.1	105	118	109.1	115.1
Exp 08	138.2	5.2	130	145	134.5	141.9
Exp 09	147.1	6.0	134	154	142.8	151.4
Exp 10	152.1	6.2	140	159	147.7	156.5
Exp 11	154.2	5.9	143	160	150.0	158.4
Exp 12	154.9	6.2	143	161	150.4	159.4
Exp 13	116.6	4.9	108	124	113.1	120.1
Exp 14	150.2	5.9	141	157	146.0	154.4
Exp 15	166.7	6.2	155	173	162.3	171.1
Exp 16	176.5	6.3	165	183	172.0	181.0
Exp 17	181.5	7.4	168	191	176.2	186.8
Exp 18	185.5	8.0	170	196	179.7	191.3
Exp 19	117.6	5.0	109	125	114.0	121.2
Exp 20	156.3	6.1	145	164	151.9	160.7
Exp 21	176.7	7.5	163	186	171.3	182.1
Exp 22	188.0	7.8	173	197	182.4	193.6
Exp 23	195.9	8.1	181	208	190.1	201.7
Exp 24	200.2	8.3	185	213	194.3	206.1

Figure 2: The detail results for the throughput

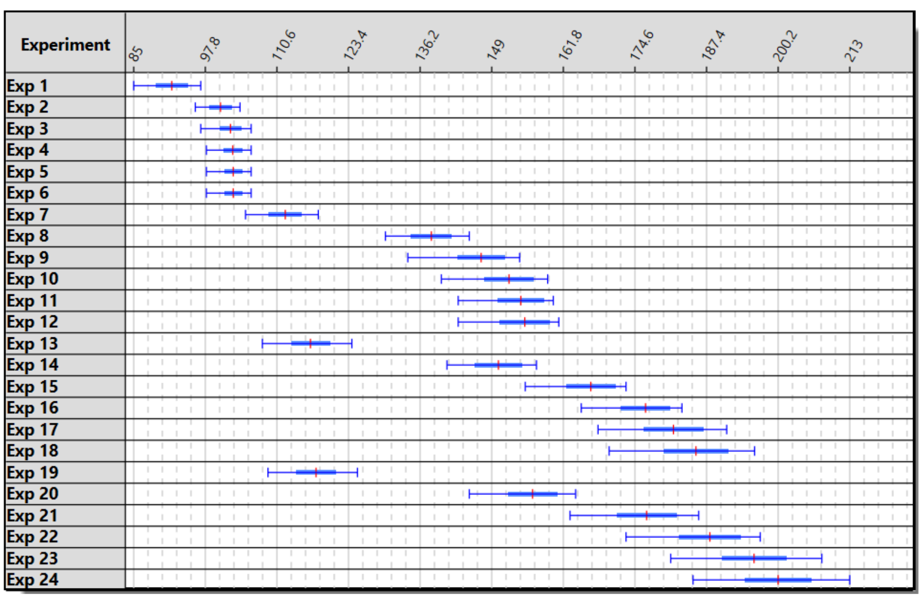

Figure 3: The CIs and ANOVA plot for the throughput

	Exp 2	Exp 3	Exp 4	Exp 5	Exp 6	Exp 7	Exp 8	Exp 9	Exp 10	Exp 11	Exp 12	Exp 13	Exp 14	Exp 15	Exp 16	Exp 17	Exp 18	Exp 19	Exp 20	Exp 21	Exp 22	Exp 23	Exp 24
Exp 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Exp 2		0.164	0.074	0.059	0.059	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Exp 3			0.731	0.662	0.662	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Exp 4				0.924	0.924	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Exp 5					1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Exp 6						0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Exp 7							0	0	0	0	0	0.039	0	0	0	0	0	0.016	0	0	0	0	0
Exp 8								0.002	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Exp 9									0.083	0.016	0.011	0	0.262	0	0	0	0	0	0.003	0	0	0	0
Exp 10										0.446	0.326	0	0.492	0	0	0	0	0	0.145	0	0	0	0
Exp 11											0.799	0	0.148	0	0	0	0	0	0.445	0	0	0	0
Exp 12												0	0.101	0	0	0	0	0	0.619	0	0	0	0
Exp 13													0	0	0	0	0	0.655	0	0	0	0	0
Exp 14														0	0	0	0	0	0.037	0	0	0	0
Exp 15															0.002	0	0	0	0.001	0.005	0	0	0
Exp 16																0.122	0.013	0	0	0.949	0.002	0	0
Exp 17																	0.263	0	0	0.169	0.073	0.001	0
Exp 18																		0	0	0.021	0.491	0.01	0.001
Exp 19																			0	0	0	0	0
Exp 20																				0	0	0	0
Exp 21																					0.004	0	0
Exp 22																						0.039	0.003
Exp 23																							0.254

Figure 4: The p-values for the throughput

Conclusion, based on n* = 10: Experiment 23 and 24 do not differ significantly ($p = 25.4\% > 5\%$), therefore it is not worth it to add the sixth truck. The mine must use five trucks, with a hoist speed of 2 m/s. Experiments 1, 7, 13 and 19 show low throughput values for the chosen hoist speed – it is due to only one truck being used. The hoist speeds do not contribute much to the throughput. It shows that a system cannot be improved at one point only; all links in the chain must be improved.

2. **Now consider cost.**

   For this analysis, you will have to modify your model. This often happens in practice: you build a model, and then it must be modified to accommodate new stakeholder requirements. (If any numbers differ from the model guide, these number prevail.)

   - The mine receives R400 per load delivered by the hoist, and it costs R500 per day to rent a truck.
   - It costs R300 per hour to operate a truck (all costs are included here).
   - It costs R500 per day to operate the hoist at 0.5 m/s.
   - It costs R600 per day to operate the hoist at 1.0 m/s.
   - It costs R800 per day to operate the hoist at 1.5 m/s.

   To accommodate these changes, open the EndSim Method. Add the following code: **The code snippit will be placed on STEMLearn. Ensure that you use the code that corresponds to the TPS version you use.**

```
is
    CurrentHoistCost : real;
do
    Throughput := Drain.statNumIn;
    if HoistSpeed == 0.5 then
        CurrentHoistCost := 500;
        elseif HoistSpeed == 1 then
            CurrentHoistCost := 600;
        else
            CurrentHoistCost := 800;
    end;

        Cost := NumTrucks*500 +
        NumTrucks*.MUs.Truck.statTranspWorkingPortion*300*eventController.simTime/3600 +
        .MUS.Hoist.statTranspWorkingPortion*CurrentHoistCost*eventController.simtime/3600;

        Profit := Throughput*400 - Cost;
end;
```

Figure 5: Code snippit to include (for FIRGA)

```
   var CurrentHoistCost: real

Throughput := Drain.statNumIn
if HoistSpeed = 0.5
    CurrentHoistCost := 500
elseif HoistSpeed = 1
        CurrentHoistCost := 600
else
        CurrentHoistCost := 800
end

Cost := NumTrucks*500 +
    NumTrucks*.UserObjects.Truck.statTranspWorkingPortion*300*eventController.simTime/3600 +
    .UserObjects.Hoist.statTranspWorkingPortion*CurrentHoistCost*eventController.simtime/3600

    Profit := Throughput*400 - Cost
```

Figure 6: Code snippit to include

This will calculate the profit at the end of the simulation run, based on the chosen number of trucks, their utilisation, and the selected hoist speed. The value "statTranspWorkingPortion" is a statistic that Technomatix returns to indicate the percentage of time the trucks are working. We multiply that by the simulation run time (one day, in eventController.simTime). The latter is always presented in seconds when working in SimTalk, so we divide by 3 600 to convert the calculated time to days.

Now please follow these instructions:

(a) Add a variable and name it "Profit". Its type is Real.

(b) Add another variable and name it "Cost", with type Real.

(c) Open the Experiment Manager, then click the "Define Output Variables" button. Press Enter to add a new line, then drag the variable "Profit" into the blank line.

(d) Create a number of experiments with different truck numbers and hoist speeds. Recommended: 1–6 trucks for each hoist speed, giving a total of 18 experiments.

(e) Now execute the experiments, with at least 10 replications each.

(f) When the report appears, look at the output summaries, especially the p-values in the ANOVA table (provide a screenshot of the p-value table and the confidence intervals plot).

[8]

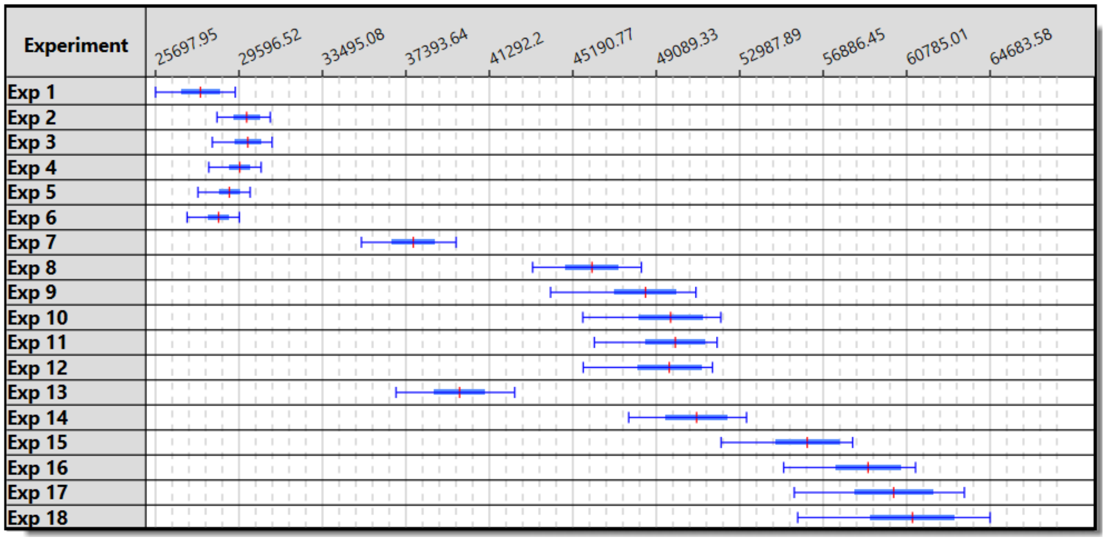

Figure 7: The CIs and ANOVA plot for the profit

	Exp 2	Exp 3	Exp 4	Exp 5	Exp 6	Exp 7	Exp 8	Exp 9	Exp 10	Exp 11	Exp 12	Exp 13	Exp 14	Exp 15	Exp 16	Exp 17	Exp 18
Exp 1	0	0	0.001	0.01	0.085	0	0	0	0	0	0	0	0	0	0	0	0
Exp 2		0.901	0.364	0.033	0.001	0	0	0	0	0	0	0	0	0	0	0	0
Exp 3			0.297	0.024	0.001	0	0	0	0	0	0	0	0	0	0	0	0
Exp 4				0.146	0.006	0	0	0	0	0	0	0	0	0	0	0	0
Exp 5					0.114	0	0	0	0	0	0	0	0	0	0	0	0
Exp 6						0	0	0	0	0	0	0	0	0	0	0	0
Exp 7							0	0	0	0	0	0.006	0	0	0	0	0
Exp 8								0.009	0.001	0	0.001	0	0	0	0	0	0
Exp 9									0.221	0.141	0.25	0	0.018	0	0	0	0
Exp 10										0.816	0.942	0	0.207	0	0	0	0
Exp 11											0.759	0	0.283	0	0	0	0
Exp 12												0	0.184	0	0	0	0
Exp 13													0	0	0	0	0
Exp 14														0	0	0	0
Exp 15															0.008	0.001	0
Exp 16																0.274	0.079
Exp 17																	0.471

Figure 8: The p-values for the profit

(g) Specify the best solution to implement, and motivate your answer. [2]

When money is a consideration (as it is in business), the emphasis of the solution changes. The maximum throughput is generated by Experiment 18. Since the table of *p*-values shows that Experiments

16, 17 and 18 do not differ statistically significantly from each other, so we take the result of Experiment 16 and implement four trucks and a hoist speed of 1.5 m/s.

(h) Why is it important to consider the simulation from two perspectives? [2]

To illustrate that engineers usually solve a problem from an efficiency point of view, but finances usually dictate, so a different solution might be accepted by Management.

Question 3: The Transfer station model [19]

Complete the table below to show your understanding of the model.

State the:	Transfer station Model	
Essence of the problem	Trucks arrive at a transfer station with raw materials, this gets unloaded by workers, and the truck is reloaded at bays with finished goods. Too few bays reduce throughput, and having more workers than bays is inefficient, but too many bays and workers can also be wasteful if they sit idle waiting for finished goods production.	[2]
Objective of the simulation	Find a good combination of workers and number of docks required to maximise throughput.	[1]
Input variables	• Arrival rate of trucks • Processing time of unloading dock • Processing time of loading dock • Rate of full trailer loads	[2]
Decision variables	• Number of workers • Number of loading docks • Number of unloading docks	[3]
Output parameters	• Throughput	[1]
Assumptions made	• The workers are homogeneous, i.e. all workers are the same in terms of performance. • The shift change-overs do not affect operations.	[2]
Validation considerations	• The number of trucks in the queue between unload and load may never exceed two. • The throughput must decrease as the number of workers and docks set sizes are decreased and versa vica.	[2]
/////		
Apply Shannon's world view:		
Entity	Load(s)	[1]
Attributes	Load dimensions	[1]
Resources	Workers, truck spaces (bays)	[1]
Conditions	A truck space (bay) and worker is available	[1]
Events	Loading/unloading trucks.	[1]
System State	Number of trucks in the LoadBuffer. / Utilisation of the UnloadDocs. / Number of finished products that exited the system up to time T. / The total time a worker waits in the WorkerPool up to time T.	[1]

Question 4: The Transfer station model [19]

1. Find a good combination for the number of workers, number of unloading docks and number of loading docks to ensure maximum throughput. Inform Management with sufficient operational data to make an informed decision before they expand the system.

[15]

We know that the max. number of docks *etc.* are five each. So let's find an upper limit for workers first. We specify experiments with five Unload docks and five Load docks, and 2, 4, 6, 8, 10 and 12 workers. We found this result, for 20 replications:

Experiment	root.UnloadDockCapacity	root.LoadDockCapacity	root.NumWorkers	root.Throughput
Exp 1	5	5	2	391.30
Exp 2	5	5	4	754.05
Exp 3	5	5	6	1001.20
Exp 4	5	5	8	1018.15
Exp 5	5	5	10	1018.85
Exp 6	5	5	12	1018.60

The good ol' p-table says:

	Exp 2	Exp 3	Exp 4	Exp 5	Exp 6
Exp 1	0	0	0	0	0
Exp 2		0	0	0	0
Exp 3			0.272	0.254	0.261
Exp 4				0.933	0.957
Exp 5					0.976

Seems as if six workers is the upper limit. In this model, we must think carefully about the scenarios we state: we can test all possible combinations, *e.g.* (1,1,1); (1,1,2), …(5,5,6). But I would not try try six workers and two unload/load docks, because we only use some workers and the others are idle. (5,5) and one worker also does not make sense. To build a dock costs money – it is a brick, mortar and concrete exercise. We can thus eliminate many scenarios and avoid unnecessary work, especially when it comes to analysing the p-table.

Experiment	root.UnloadDockCapacity	root.LoadDockCapacity	root.NumWorkers	root.Throughput
Exp 01	1	1	1	207.80
Exp 02	2	2	1	190.00
Exp 03	3	3	1	190.10
Exp 04	4	4	1	189.50
Exp 05	5	5	1	188.60
Exp 06	1	1	2	331.60
Exp 07	2	2	2	385.10
Exp 08	3	3	2	386.50
Exp 09	4	4	2	385.50
Exp 10	5	5	2	385.10
Exp 11	1	1	3	350.50
Exp 12	2	2	3	579.40
Exp 13	3	3	3	579.70
Exp 14	4	4	3	580.70
Exp 15	5	5	3	580.60
Exp 16	1	1	4	350.70
Exp 17	2	2	4	707.40
Exp 18	3	3	4	776.20
Exp 19	4	4	4	775.40
Exp 20	5	5	4	776.20
Exp 21	1	1	5	350.70
Exp 22	2	2	5	712.60
Exp 23	3	3	5	954.30
Exp 24	4	4	5	961.80
Exp 25	5	5	5	960.00

Figure 9: Experiment results

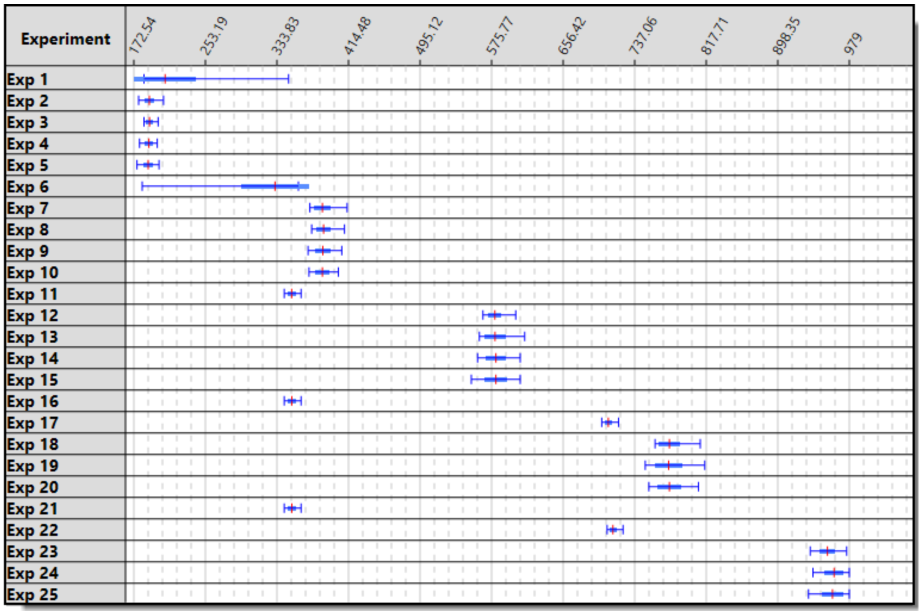

Figure 10: CI Chart

	Exp 2	Exp 3	Exp 4	Exp 5	Exp 6	Exp 7	Exp 8	Exp 9	Exp 10	Exp 11	Exp 12	Exp 13	Exp 14	Exp 15	Exp 16	Exp 17	Exp 18	Exp 19	Exp 20	Exp 21	Exp 22	Exp 23	Exp 24	Exp 25
Exp 1	0.287	0.287	0.274	0.254	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Exp 2		0.972	0.875	0.69	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Exp 3			0.823	0.625	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Exp 4				0.791	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Exp 5					0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Exp 6						0.011	0.01	0.011	0.011	0.291	0	0	0	0	0.286	0	0	0	0	0.286	0	0	0	0
Exp 7							0.798	0.945	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Exp 8								0.855	0.791	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Exp 9									0.943	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Exp 10										0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Exp 11											0	0	0	0	0.945	0	0	0	0	0.945	0	0	0	0
Exp 12												0.962	0.832	0.854	0	0	0	0	0	0	0	0	0	0
Exp 13													0.893	0.907	0	0	0	0	0	0	0	0	0	0
Exp 14														0.99	0	0	0	0	0	0	0	0	0	0
Exp 15															0	0	0	0	0	0	0	0	0	0
Exp 16																0	0	0	0	1	0	0	0	0
Exp 17																	0	0	0	0	0.076	0	0	0
Exp 18																		0.925	1	0	0	0	0	0
Exp 19																			0.93	0	0	0	0	0
Exp 20																				0	0	0	0	0
Exp 21																					0	0	0	0
Exp 22																						0	0	0
Exp 23																							0.23	0.383
Exp 24																								0.8

Figure 11: P-table

When we refer to the throughput values that were generated by the simulation model, we can see that the maximum throughput occurred at Experiment 24 *i.e.* four unload docks, five load docks and five workers.
We can now start comparing experiments to determine which combination of resources should be used to produce the best throughput. When we consider the CI plot and the ANOVA table, the Exp 23 and Exp 25 are not statistically significantly different from Exp 24 when their throughputs are compared.
To determine which one of these experiments is the best, we can compare the number of resources that were used to achieve their respective throughputs.
Exp 23 is the best and it is therefore recommended that the combination of Exp 23 should be used, *i.e.* three unload docks, three load docks and five workers.

2. You found the minimum number of workers in the previous question to be X. What is your main concern about this number?

[4]

The workers work shifts. There are laws governing the frequency of night shifts and the number of hours a person can work per week, and the number of days a worker must be off between swopping day and night shifts. If one should schedule these workers, one might need a higher number of physical workers than reported by the simulation model.

Total: Cross-check: 78