Frankfurt School of Finance & Management

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Examination in the Bachelor of Science
Course title: Operations Management
Semester: Winter 2017/2018
Lecturer: Strohhecker/Müller
Groups: 162 BWL-WP, BWL-AIS, WI-DIF, MPE, BIM1, BIM2, BBF & 142/132
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Aids: Casio FX-991DE X, Casio FX 991 ES (Plus), Casio FX 991 DE plus, Casio FX 82 solar, Casio FX 85 MS, Casio FX 85 ES (plus), Casio FX 85 DE plus, Casio FX 85 GT plus, collection of formulae and statistical tables

Please enter your student ID (matriculation number) and your group!

Student ID	Group

Please note:

The exam consists of 5 questions of which you will have to answer **4** questions. If you answer all **5** questions only the first **4** will be evaluated. You have **80** minutes to complete the examination. The maximum of points to be reached is **80**. Please use the enclosed answer sheet to answer your questions and add your student ID on its cover.

Please always explain your solution in adequate depth with comments on each important step!

We wish you all the best for your examination!

Internal use only!

Question	1	2	3	4	5	**Total**
Possible points:	20	20	20	20	20	**80**
Points achieved:						

Question 1 (20 points)

An outpatient orthopedic clinic provides consultation and follow-up care to patients with orthopedic problems/injuries including postoperative checks and cast changes/removals.

Patients arrive evenly distributed each 2.5 minutes. They register at the reception desk and then wait in a waiting room for a physician becoming available. After having conducted a physical examination the physician decides if an x-ray has to be taken or if the patient can be released. The percentage of patients x-rayed is 40%. These patients then have to see a radiologist, who examines the x-ray and decides on the treatment. With a probability of 5 % the x-ray is of insufficient quality so that the patient has to be sent back to be x-rayed again (assume that the second x-ray is always of sufficient quality). Then these patients have to see a radiologist again. The last step in the service process includes some minor activities such as handing out the prescription or agreeing on a new appointment ("wrap up").

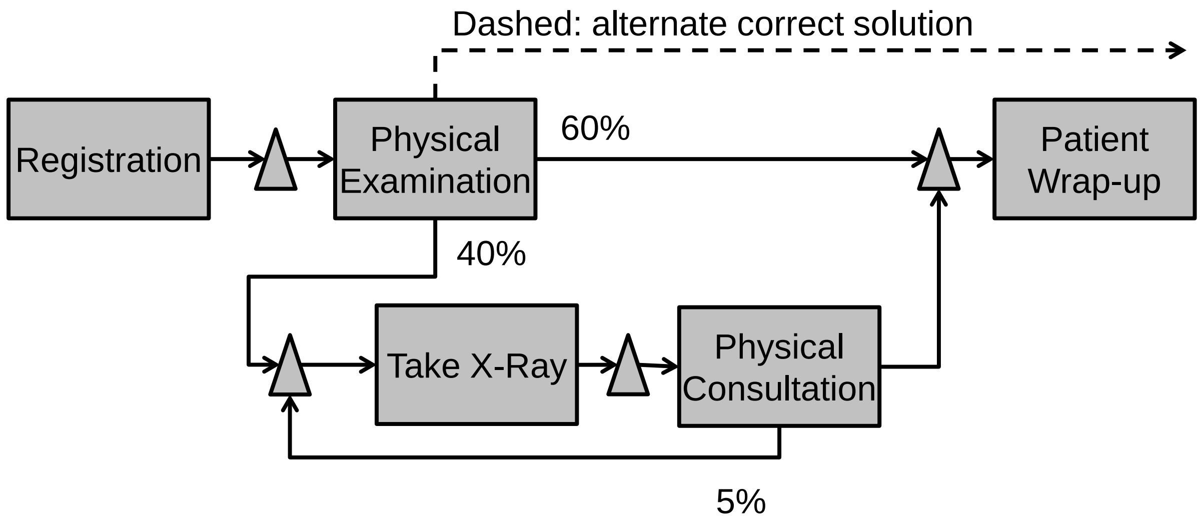
Data on each station are provided in the following table:

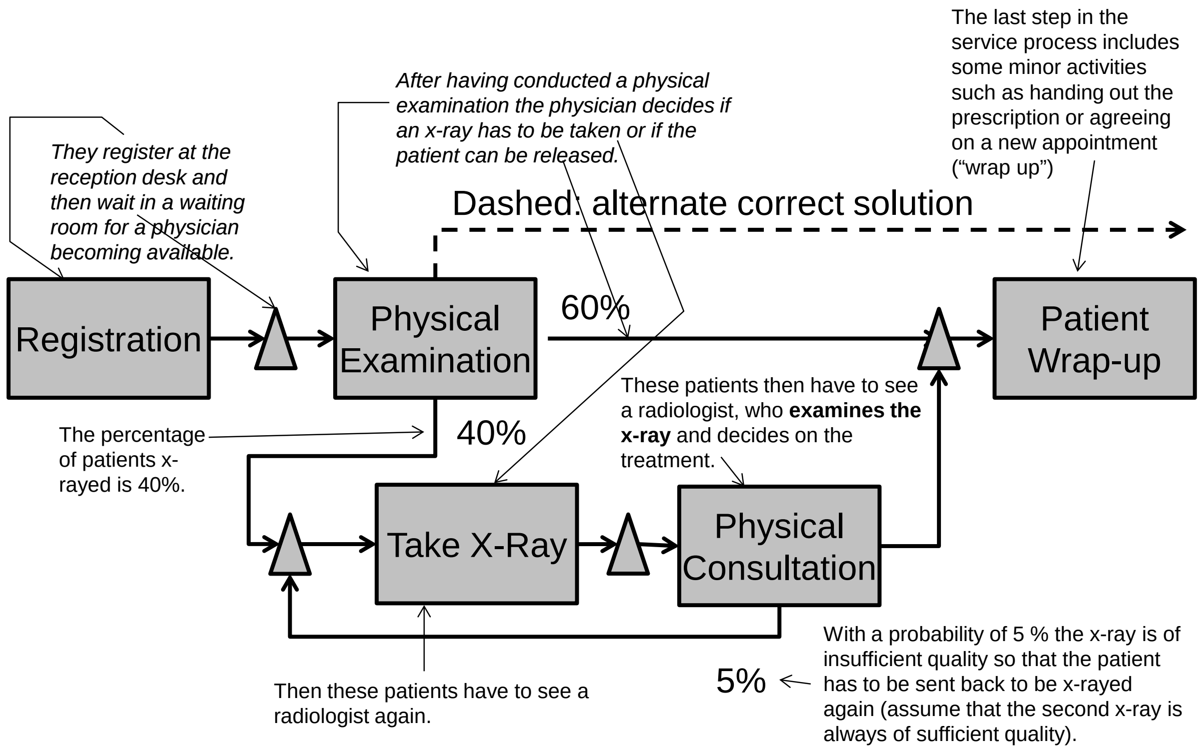
	Process time [min/Patient]	Employees [person]	
Registration	4.5	2	Nurse
Physical Examination	10	4	Physician
X-ray	12	2	Nurse
Physical Consultation	6	2	Radiologist
Wrap up	4	2	Nurse

Part a) (6 points)

Develop a process flow diagram that shows all percentages and all potential buffers.

Solution:





-0.5 P if "wating room" buffer (between registration and physical examination) is missing

-0.5 P if one or more other buffers are missing

-1 P if wrong process flow diagram symbols are used

-1 P per error regarding the flow of patients

-0.5 P per missing percentage

- 1 P per missing process

Part b) (14 points)

What is the capacity (in patients per hour) and the implied utilization (as a %) at the five stations? Where is the bottleneck station? Explain!

Solution:

$$\text{Implied utilization} = \frac{\text{Capacity requested by demand}}{\text{Available capacity}}$$

There are at least two alternative ways of solving the problem. The following solution focuses on the definition of a minute of work as flow unit.

In addition, we define three types of patients:	*Probability*
Patient A: Needs only physical examination	*0.6*
Patient B: Needs X-ray, good quality	*0.38*
Patient C: Needs X-ray, bad quality	*0.02*

We calculate expected workload as follows *(5 Points)*

We calculate capacity based on total expected workload *(5 Points)*

	Avail. Cap.	*Expected Workload [min/unit]*				*Capacity*
Resource	*[min/h]*	*Pat A*	*Pat B*	*Pat C*	*Total*	*[Patients/h]*
Registration	*120*	*2.700*	*1.710*	*0.090*	*4.500*	*26.667*
Physical Exam.	*240*	*6.000*	*3.800*	*0.200*	*10.000*	*24.000*
X-ray	*120*	*0.000*	*4.560*	*0.480*	*5.040*	*23.810*
Physical Cons.	*120*	*0.000*	*2.280*	*0.240*	*2.520*	*47.619*
Wrap up	*120*	*2.400*	*1.520*	*0.080*	*4.000*	*30.000*

Lastly, we calculate the implied utilization for each station

(2.5 points)

	Capacity	*Capacity*	*Implied*
Resource	*[Patients/h]*	*Utilization*	*Utilization*
Registration	*26.667*	*0.893*	*0.9*
Physical Exam.	*24.000*	*0.992*	*1*
X-ray	*23.810*	*1.000*	*1.008*
Physical Cons.	*47.619*	*0.500*	*0.504*
Wrap up	*30.000*	*0.794*	*0.8*

As we work with different types of patients and as we have a rework process, we cannot use capacity to determine the bottleneck. Instead, the implied utilization is the only measure that allows us to determine the bottleneck resource correctly.

X-ray is the bottleneck as this station has the highest implied utilization. *(1.5 P)*

*Calculation of capacity/expected capacity 5 * 1 P = 5 P*
-1 P if capacity is not measured in patients per hour

Calculation of Expected Workload or Expected Demand at each station
5 1 P = 5 P*

*Calculation of implied utilization 5*0.5 P = 2.5 P*

Identification of bottleneck as resource with the highest implied utilization 1P

Clear answer to the bottleneck question 0.5 P

No deduction of points if calculation assumes that patients without x-ray do not have to be wrapped up.

-2 P if calculation of workload/demand at X-ray station is not including rework -> implied utilization of X-ray station is calculated too low -> bottleneck is wrongly assigned to physical examination

Question 2 (20 points)

Ra Co manufactures six versions of its popular metal pyramid, Cheops. It currently sells an average of 3,600 pyramids per week (600 of each version) to its retailers. In simplified terms, pyramid making at Ra involves three basic operations: cutting, drilling, and assembling. Changing over between versions requires setup time at the cutting and drilling station due to the different shapes and colors of the pyramids. The table below lists the setup times for a batch and the processing times for each unit at each step. Unlimited space for buffer inventory exists between the steps. Assume that a setup can only start once the batch has arrived at the resource and that all flow units of a batch need to be processed at a resource before any of these units can be moved to the next resource.

Process Step	**1 Cutting**	**2 Drilling**	**3 Assembling**
Setup Time	40 minutes	20 minutes	None
Processing Time	18 seconds	27 seconds	36 seconds

Part a) (3 points)

What is the process capacity in units per hour with a batch size of 400 pyramids?

Solution:

*Cap1 = 400 P/(40 min + 400*0.3 min) = 400 P/160 min = 2.5 P/min = 150 P/h*
*Cap2 = 400 P/(20 min + 400*0.45 min) = 400 P/200 min = 2 P/min = 120 P/h*
Cap3 = 1/(0.6 min/P) = 5/3 P/min = 100 P/h. -> bottleneck
Hence the process capacity is 100 pyramids per hour. *(3 P)*

Part b) (4 points)

Which batch size would minimize inventory without decreasing the process capacity?

Solution:

Find the recommended batch size for steps 1 and 2:
Set Flow Rate = process capacity = 100 P/h = 5/3 P/min. *(1 P)*
*RBS1 = 5/3*40/(1-5/3*18/60) = 400/3 = 133.3.* *(1 P)*
*RBS2 = 5/3*20/(1-5/3*27/60) = 400/3 = 133.3.* *(1 P)*
⇒ RBS = 134. *(1 P)*

Part c) (5 points)

Which batch size would minimize inventory without decreasing the current flow rate?

Solution:

Find the recommended batch size for steps 1 and 2:
Demand = 3,600 P/week / 40 hours/week = 90 P/h. *(1 P)*
Set Flow Rate = Min [process capacity; demand] = 90 P/h = 3/2 P/min. *(1 P)*
*RBS1 = 3/2*40/(1-3/2*18/60) = 1200/11 = 109.1.* *(1 P)*
*RBS2 = 3/2*20/(1-3/2*27/60) = 1200/13 = 92.3.* *(1 P)*
⇒ RBS = 110. *(1 P)*

Part d) (8 points)

Watching the FS Christmas Tree, you cannot seem to get Little's Law out of your mind. You ask yourself if this great Law could help you to calculate the time the friendly worker Mr. Kovac needed to install the lights at the Christmas tree.
He told you he can hang 32 chains of light at the tree per hour, but he doesn't remember how long he worked to complete his gigantic project.
The Christmas tree is illuminated from December 1st till December 29th, 24 hours a day without being switched off for a minute. Udo Steffens told you that the electricity expenses for the FS Christmas Tree during the advent season are 24,944.64 €.
You further found out that the price for one kilowatt-hour (kWh) is 20 cent. Each chain consists of 20 lights, and each light has a power of 10 watt (W).
Can you find out the time Mr. Kovac needed to decorate the tree?

Solution:

We look for the flow time T in hours. (1 P)
We need the Inventory I in chains and the Flow Rate R in chains per hour. (2 P)
The Flow Rate is given by R = 32 chains/hour. (1 P)
We find:
24,944.64 € / 0.2 €/kWh = 124,723.2 kWh;
*124,723.2 kWh / 29*24 h = 179.2 kW = 179,200 W;*
179,200 W / 10 W/light = 17,920 lights;
17,920 lights / 20 lights/chain = 896 chains. (3 P)

This corresponds to T = I / R = 896 chains / 32 chains/hour = 28 hours. (1 P)

Question 3 (20 points)

QQ Inc sells its very popular wows. They sell one wow for 13 €, and their total costs for one wow are 4€. A wow customer buys wows once a week; on average he buys 20 wows. It takes some time to find the best wows, so it takes on average 16 minutes to serve a customer, the standard deviation is 16 minutes. On average a customer comes in every 5 minutes, the standard deviation here is 10 minutes. There are 8 counters in the QQ store, and QQ is open six days a week from 6:00 till 22:00.

Part a) (6 points)

If a customer comes in and no counter is available he will leave the store and never come back again. In this case, he changes from wows to boors.
How many customers will QQ lose every week (as an integer value)?

Solution:

*Find r with r = p/a = 16/5 = 3,2 (r = m*u = 8*0.4 = 3.2).* (1 P)
Find in Erlang Loss Table for 8 servers p_8 (3,2) = 0.0112 = 1.12%. (2 P)
*QQ is open 16 hours/day*6 days/week = 96 hours/week.* (1 P)
The Flowrate is R = 1/a = 1/5 cust/Min = 12 cust/hour = 1,152 cust/week. (1 P)
*The weekly Loss is 1,152 cust/week*1.12% = 13 cust/week.* (1 P)

Part b) (8 points)

The general manager of QQ decides that he does not want to lose any more customers, but he also doesn't want to make less profit.
He creates the rule "Dear customer. If you have to wait, please take a seat in our luxury chairs, have free drinks, and get x,xx € for every minute you have to wait."
How much should QQ pay its customers for every minute of waiting? You don't have to take into account the costs for seats and drinks.

Solution:

*Utilization = p/(a*m) = 16/(5*8) = 0.4 = 40%.* *(1 P)*
CV_a = 10/5 = 2; CV_p = 16/16 = 1. *(1 P)*

$$T_q = \left(\frac{Processing\ time}{m}\right) \times \left(\frac{Utilization^{\sqrt{2(m+1)}-1}}{1 - Utilization}\right) \times \left(\frac{CV_a{}^2 + CVp^2}{2}\right)$$

$$T_q = \left(\frac{16}{8}\right) \times \left(\frac{0.4^{\sqrt{2(8+1)}-1}}{1 - 0.4}\right) \times \left(\frac{2^2 + 1^2}{2}\right)$$

$$T_q = 0.427\ min$$ *(2 P)*

Each customer creates a weekly profit of 20(13-4) € = 180 €.*
13 lost customers per week cost (because of lost profit)
*13 cust/week * 180 €/cust = 2,340 €/week.* *(1 P)*
Payment for waiting must be equal to or smaller than 2,340 €/week. *(1 P)*
Waiting minutes per week are
*0.427 min/cust * 1,152 cust/week = 492 min/week.* *(1 P)*
QQ should pay 2,340 €/week / 492 min/week = 4.76 €/min. *(1 P)*

Part c) (3 points)

How many customers are in the store on average?

Solution:

*Served customers: Ip = m*u = 8*40% = 3.2.* *(1 P)*
Waiting customers: Iq = Tq/a = 0.0427/5 = 0.085. *(1 P)*
Total customers: I = Ip + Iq = 3.285. *(1 P)*

Part d) (3 points)

Which of the following will **decrease** the waiting time in a call center in which the incoming call get assigned to the first available server? Please justify your answer in 1 – 2 sentences.

a) Implement the Shortest Processing Time Rule.
b) Increase the service time coefficient of variation.
c) Increase the average service time.
d) Decrease the inter-arrival time.

Solution:

a! Implement the SPT Rule. *(1 P)*
The other three possibilities definitely INCREASE the waiting time (see waiting time formula). *(2 P)*
Alternatively: If the customers with the shortest processing time are served at first, the other customers have to wait in sum shorter. (But the rule maybe is difficult to implement.) *(2 P)*

Alternatively: Example: $p1=4$, $p2=2$; $p3=1$; $p4=3$. ⇒ FCFS: $Tq=4+6+7=17$;
SPT: $Tq=1+3+6=10$. *(2 P)*

Question 4 (20 points)

After its big success with the wows QQ Inc now sells also yups. QQ sells the yups exclusively in its online store. The forecasted yearly demand is 10,000 yups, and the forecasted standard deviation is 3,000 yups. Unfortunately QQ has to order the whole yearly quantity in November of the previous year because the production of the yups is a big secret. QQ buys yups for 6 € a piece, and sells them for 30 €. The yups that QQ cannot sell must be destroyed; the cost for destroying are 2 € per yup.

Part a) (4 points)

What is the probability that QQ sells more than 16,000 yups?
What is the probability that QQ sells 4,000 yups or less?

Solution:

z = (16,000-10,000)/3,000 = 2; F(2) = 0.9772 *(1 P)*

p(D>16.000) = 1-p(D≤16.000) = 1-F(2) = 1-0,9772 = 0,0228 = 2,28%. *(1 P)*

z = (4,000-10,000)/3,000 = -2; F(-2) = 0.0228 *(1 P)*

p(D≤4,000) = F(-2) = 0.0228 = 2.28%. *(1 P)*

[Alternativ Argumentation, dass beide p gleich sein müssen wegen gleichen Abstandes vom Mean.]

Part b) (6 points)

How many yups should QQ order to maximize its expected profit?
If ordering the optimal quantity, how many yups expects QQ to sell and how many yups expects QQ to destroy at the end of the year (in full numbers)?

Solution:

Cu = 30-6 = 24; Co = 6+2 = 8; CR = Cu/(Cu+Co) = 24/32 = 0.75; *(2 P)*
Find (using round up rule) z = 0.68;

⇒ Q = 10,000 + 0.68*3,000 = 12,040 (yups to order);* *(1 P)*

*ELS = L(0.68)*3,000 = 14.78%*3,000 = 443;* *(1 P)*

ES = 10,000 – 443 = 9,557 (yups to sell); *(1 P)*

ELOI = 12,040 – 9,557 = 2,483 (yups to destroy). *(1 P)*

Part c) (4 points)

How much are the mismatch cost of QQ if the optimal quantity is ordered? Please express the mismatch cost as a percentage of the maximum profit.

Solution:

*Maximum Profit = 10,000*24 = 240,000;* *(1 P)*
*Expected Profit = 24*9,557 – 8*2,483 = 229,368 – 19,864 = 209,504,* *(1 P)*
Mismatch Cost = 240,000 – 209,504 = 30,496; *(1 P)*
MMC as percentage = 30,496/240,000 = 12.7% *(1 P)*

*[Alternatively: MMC = 24*443 + 8*2,483 = 10,632 + 19,864 = 30,496;* *(2 P)*
Maximum Profit is also needed to calculate percentage!]

Part d) (6 points)

Which of the following **CANNOT reduce** the mismatch cost, as a percentage of the maximum profit? Please justify your answer in depth.

a) Reduce the standard deviation.
b) Reduce the salvage cost.
c) Raise the price.
d) The opportunity to place an additional order in April of the actual year.
e) Create a higher demand, thus a higher mean.

f) None of the above.

Solution:

f ! None of the above. *(2 P)*
a and d reduce the variability and so reduce the ELS and the ELOI, what leads to lower MMC. b leads to lower Co, what also leads to lower MMC. c leads to a higher Cu and indeed to higher ABSOLUTE MMC, but also to a higher maximum profit; though the percentage MMC/MP becomes lower. A higher mean leads to the same ABSOLUTE MMC, but to a higher maximum profit; hence the percentage of the MMC becomes lower.
Alternatively: b and c lead to a higher critical ratio thus to lower MMC.
(4 P)

Question 5 **(20 points)**

Declie AG is a veggie food distributor with 17 warehouses across Europe. Sabrina Newhouse, one of the warehouse managers, wants to make sure that the base stock policy used by her warehouse are minimizing inventory while still maintaining quick delivery to Declie's customers. Since the warehouse carries hundreds of different products, Sabrina decided to study one. She picked Joylent Green (JG). Demand for JGs averages 300 per day with a standard deviation of 198. Since Declie orders at least one truck from Balican each day (Balican owns Joylent Green), Declie can essentially order any quantity of JGs it wants each day. Sabrina notes that any order for JGs arrives four days after the order. Further, it costs € 0.02 per day to keep JG in inventory, while a back order is estimated to cost Declie € 0.42.
Please round your results to integer values.

Part a) (6 points)

What base stock level (= order up to level) should Sabrina choose to minimize holding and back-order costs?

Solution:

Mean demand over (l+1) periods equals demand for 5 days with *(1 P)*

μ_{5d} *= 5*300 = 1,500 and* *(1 P)*

δ_{5d} *= sqrt(5)*198 = 442.7 = 443* *(1 P)*

CR = b/(b+h) = 0.42/0.44 = 0.9545. *(1 P)*

Find z = 1.69. *(1 P)*

*S = 1,500 + 1.69*443 = 1,500 + 748.67 = 2,249.* *(1 P)*

Part b) (4 points)

Suppose the base stock level 2,000 is chosen. What is the average amount of inventory on order? Please justify your answer in 1 sentence.

Solution:

The base stock level has no influence on the amount of OOI. (You just have to consider the average demand of one period (here 1 day) and the lead time (not l+1 periods)). *(2 P)*

OOI = l μd = 4*300 = 1,200* *(2 P)*

Part c) (7 points)

Suppose the base stock level 2,000 is chosen. What is the annual holding cost? Assume 250 days per year.

Solution:

S = 2,000 ⇒ z = (2,000-1,500)/443 = 1.13. *(1 P)*
Find L(1.13) = 0.0646. *(1 P)*
*EBO = 0.0646*443 = 28.62 = 29.* *(1 P)*
*ED (5 days) = 5*300 = 1,500* *(1 P)*
EOHI = 2,000 – 1,500 + 29 = 529. *(1 P)*
*EHC = 529 units * 0.02 €/(unit*day) * 250 days/year = 2,645 €/year.* *(2 P)*

Part d) (3 points)

What base stock level minimizes inventory while maintaining a 98 percent in-stock probability?

Solution:

p_{IS} = 98% ⇒ *Find* $z = 2.06$ *(1 P)*

$S = 1{,}500 + 2.06 * 443 = 1{,}500 + 912.58 = 2{,}413.$ *(2 P)*