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(Signature)

Instructions
1. 2 hour exam, total number of points = 25.
2. Numeric calculators and one 8.5x11” sheet (both sides) of notes are permitted.
3. Write in the space provided. You may write on the back of a page for extra space.
4. You may not ask any questions. If you are unclear on a question, write down your interpretation and state any assumptions in your answer.
5. There is no partial credit for multiple-choice questions. For other questions, show your work when appropriate: correct work and correct reasoning may receive partial credit.

Grading

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The following description is for questions 1-5.
Consider the following project AON representation. The duration of each activity (in weeks) is listed above each task. For example, the duration of task A is 3 weeks. Also:

1. [1 point] What is/are the critical path(s)?

Critical path is Start-C-F-G-H-End

2. [1 point] Suppose that you must complete the project one week sooner than in the AON above. The cost to expedite each task per week is below. Which task would you choose to expedite and why?

<table>
<thead>
<tr>
<th>Task</th>
<th>Cost/week</th>
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<tbody>
<tr>
<td>A</td>
<td>$500</td>
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<tr>
<td>B</td>
<td>$600</td>
</tr>
<tr>
<td>C</td>
<td>$1700</td>
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<td>D</td>
<td>$800</td>
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<tr>
<td>F</td>
<td>$1200</td>
</tr>
<tr>
<td>G</td>
<td>$2000</td>
</tr>
<tr>
<td>H</td>
<td>$1500</td>
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</tbody>
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Task F is the cheapest one to expedite/crash that is on the critical path.
3. [1 point] Suppose task B takes an additional 3 weeks to complete, what is the new project completion time and what is/are the critical path(s)?

The project completion time is still 13, but now two critical paths.

Critical path #1 is Start-C-F-G-H-End

Critical path #2 is Start-B-G-H-End

4. [1 point] The planner noticed that they forgot to include activity E in the AON above. This activity requires 1 week to complete, begins only after D is complete, and is a predecessor to activity G. How much does this increase the project completion time?

No change, it adds a week to the path Start-A-D-E-G-H-End, which is now 13 weeks.

5. [1 point] Suppose there is now uncertainty associated with the duration of task B. The fastest duration for task B is 2 wks, the most likely duration is 4 wks, and the slowest duration is 6 wks. What @Risk function can represent this type of uncertainty in Excel (i.e. write down the formula you would enter into a cell to represent the duration of task B)?

=RiskTriang(2,4,6) or =RiskPert(2,4,6)
The following description is for questions 6-7.

An original-equipment-manufacturer (OEM) outsources the packaging of its gaming consoles to an external assembler. The packaging at this external assembler requires a three step process. Each unit first goes through Step 1, which takes 20 seconds, then Step 2 which takes 30 seconds, then Step 3 which takes 40 seconds (all times reflect averages per worker). The manager at the external assembler decides to have one worker at Step 1, two workers at Step 2, and three workers at Step 3. All workers work concurrently and independently of each other. Assume steady state.

6. [2 points] What is the process capacity in units/min at the assembler?

The resource capacity of each step is as follows:

- Step 1: \((1 \text{ worker} / [20 \text{ secs/unit for each worker}]) * 60 \text{ secs/min} = 3 \text{ units/min}\)
- Step 2: \((2 \text{ workers} / [30 \text{ secs/unit for each worker}]) * 60 \text{ secs/min} = 4 \text{ units/min}\)
- Step 3: \((3 \text{ workers} / [40 \text{ secs/unit for each worker}]) * 60 \text{ mins/min} = 4.5 \text{ units/min}\)

The resource with the lowest capacity determines the process capacity, Step 1, thus process capacity is \(3 \text{ units/min}\).

7. [1 point] There is talk that the OEM will increase its delivery of gaming consoles to the external assembler to 7 units/min in the future, on average. Under this scenario, what is the implied resource utilization for Step 2?

The implied utilization assumes the inflow or demand rate is the throughput rate. Hence, the implied utilization for Step 2 is \((7 \text{ units/min}) / (4 \text{ units/min}) = 175\%\).
The following description is for questions 8-9.

A solar panel company’s annual sales are normally distributed with a mean of 10,000 and standard deviation of 1,500. If demand is below 8,000 units, the company can sell the product for $400 per unit. If demand is above 8,000 units, a competitor will enter the market, and the company can sell the product for only $200 per unit. The variable cost per unit has a 20% chance of being $100, a 40% chance of being $150, and a 40% chance of being $175. Annual fixed costs are $500,000. The company figures that any units leftover at the end of the year can be sold at a discount price of $125 per unit. The company plans to stock 11,000 units for the year and wants to use simulation to evaluate their annual profit.

8. [3 points] Using the screenshot of the spreadsheet below, build an @Risk model that can help evaluate the profit for the company. Clearly identify the cell you would designate as the primary output (only one). Do not worry about using “RiskName” in any cells.

![Spreadsheet screenshot](image)

B2: RiskNormal(E2,E3)
B4: RiskDiscrete(D6:D8, E6:E8)
B5: IF(B2>E10,E12,E11) or IF(B2<E10,E11,E12) or IF(E10<B2,E12,E11) or IF(E10>B2,E11,E10)
B8: Min(B1,B2) or IF(B1<B2,B1,B2) or IF(B1>B2,B2,B1) or IF(B2<B1,B2,B1) or IF(B2>B1,B1,B2)
B9: B1-B8 or max(B1-B2,0) or IF(B1>B2,B1-B2,0)
B15: B11-B12-B13 (OUTPUT)

9. [1 point] One metric of particular interest to the sales team is the average number of units sold, in cell B8. Aside from making this an Output cell, what @Risk Excel function could you use so that, after the simulation is run, the spreadsheet will display this information automatically?

We can use the class of @Risk functions for summary statistics, in this case, =RiskMean(B8).
The following description is for questions 10-12.

A service department for damaged computers is organized so that all machines first receive a diagnostic test. After this, if the computer requires a simple fix, it is then quickly addressed by an internal repair department, or, if it requires extensive work, the computer goes through additional tests and is sent to an external repair facility (i.e. after a machine is fixed or additional tests are done, the process ends). 50 computers arrive per hour at the service department, 40% of which go to the external repair facility. 30 computers are sitting and waiting for the diagnostic test. The diagnostic test takes 20 minutes. If the computer needs only a quick fix, it undergoes 5 minutes by the internal repair department. On the other hand, if a computer goes through additional tests before being sent to the external repair facility, these additional tests take 45 minutes. All numbers are averages, assume steady state.

10. [1 point] Draw a process flow diagram for this process.

```
  Arrival/Start
   `-> Queue/Waiting
        `-> Diagnostic Test
              `-> Quick Fix?
                      Yes
                        60%
                      No
                        40%
                          `-> Internal Repair Dept
                                     `-> Additional Tests
                                           `-> End

30 computers

20 mins
```

Above is one acceptable solution (you did not have to mark "Yes/No" nor put the times and number of computers, these are simply there for illustrative purposes). Other acceptable answers included ignoring the "Quick Fix" diamond (we didn't discuss decision point diamonds at length), or having two "End" nodes (one after "Internal Repair Dept" and one after "Additional Tests").

11. [1 point] On average, how many computers are receiving their diagnostic test?

Little's Law, \( I = RT \) (or \( N_s = AT_s \))

Number of Computers = Arrival Rate \( \times \) Time for Diagnostic Test

Number of Computers = 50 computers/hr \( \times \) (20mins/60mins)hrs = 16.67 computers
The following description is for questions 10-12 (REPEATED).

A service department for damaged computers is organized so that all machines first receive a diagnostic test. After this, if the computer requires a simple fix, it is then quickly addressed by an internal repair department, or, if it requires extensive work, the computer goes through additional tests and is sent to an external repair facility (i.e. after a machine is fixed or additional tests are done, the process ends). 50 computers arrive per hour at the service department, 40% of which go to the external repair facility. 30 computers are sitting and waiting for the diagnostic test. The diagnostic test takes 20 minutes. If the computer needs only a quick fix, it undergoes 5 minutes by the internal repair department. On the other hand, if a computer goes through additional tests before being sent to the external repair facility, these additional tests take 45 minutes. All numbers are averages, assume steady state.

12. [2 points] On average, how long does a computer spend in the entire system (waiting and service, in minutes)?

Use Little's Law, \( I=RT \) (or \( L=AIW \)) => \( T = \frac{I}{R} \), for each step:

- **Time in queue =** \( \frac{I}{R} = \frac{30 \text{ computers}}{50 \text{ computers/hr}} = 0.6 \text{ hours or 36 minutes.} \)
- **Time for diagnostic test =** 0.33 hours or 20 minutes (given in problem)
- **Time for internal repair and additional tests =** (60%*5mins) + (40%*45mins) = 0.35 hours or 21 minutes.

**Total time spent in process =** (0.6 + 0.33 + 0.35) = 1.28 hours or (36 + 20 + 21) = 77 minutes.
The following description is for questions 13-14.

A website provides financial advice for customers, who wait in a single (virtual) queue before chatting with a specialist (via textbox). On average, 120 customers arrive per hour and the inter-arrival time is exponentially distributed. A customer requires an average of 10 minutes service time with a standard deviation of 3 minutes. The website currently has twenty-two specialists. Assume steady state.

13. [2 points] What is the average number of customers waiting to interact with a specialist?

A single queue with twenty-two servers, so \( m = 22 \).
\[ A = 120 \text{ cust/hr} \]
\[ T_s = 10 \text{ mins}; \]
\[ S = 1/T_s = 0.10/\text{min} = 6 \text{ cust/hr} \]
\[ u = A/(m*S) = 120/(22*6) = 90.9\% \]
\[ CV_{IAT} = 1; \]
\[ \sigma_{ST} = 3 \text{ mins}; \]
\[ CV_{ST} = 3/10 = 0.30 \]
\[
L_q = \frac{u^{2(m+1)}}{1-u} \times \frac{CV_{IAT}^2 + CV_{ST}^2}{2} = \frac{0.91^{\sqrt{46}}}{1-0.91} \times \frac{1^2 + 0.3^2}{2} = 3.19 \text{ customers}
\]

14. [2 points] The director of technology operations decides to have two separate virtual queues: one for customers interested in retirement, and the other for any other inquiries. On average, 60% of all customers require retirement advice, and need an average of 12 minutes service time with a standard deviation of 2 minutes to interact with the specialist. A previous customer’s arrival time, interested in retirement, does not help predict the next customer’s arrival. How many specialists must be assigned to the retirement queue to ensure that the system is stable?

Stability requires the average service rate to exceed the average arrival rate. This is equivalent to saying that utilization must be less than 100%. The arrival rate is \( A = 60\% \times 120 = 72 \text{ cust/hr} \), and the service rate per server is \( S = 5 \text{ cust/hr} \) (12 mins per customer). Therefore:
\[ u < 1 \Rightarrow A / (m \times S) < 1 \Rightarrow m > A / S = 72 / 5 = 14.4 \Rightarrow m \geq 15 \]

There must be at least 15 specialists assigned to the retirement queue. 14 will not be sufficient.
15. [1 point] Consider a queue with a single server. Suppose that the server utilization is 40% and the average rate of arrivals doubles. How does the server utilization change?

a. Server utilization decreases.
b. Server utilization increases less than double (u>40% and u<80%).
c. Server utilization doubles (u=80%).
d. Server utilization increases exponentially, more than double, (u>80%).
e. None of the above.

16. [1 point] True/False: The maximum value that implied utilization can be is 100%.

a. True
b. False

c. [1 point] Select two operational features of Benihana which allowed the throughput time of a customer to be short, ~45 min on average, if desired.

a. They optimize the scheduling of chefs.
b. Eating and cooking occur in parallel.
c. Chefs confirm the order before cooking.
d. They implemented self-managed teams of chefs/staff.
e. Rocky withheld pay if chefs did not achieve low-throughput times.

18. [1 point] In the book “The Goal,” what was the “Zmegma” (circle one)?

a. It was the sweet ride that Bill Peach drove.
b. It was the name of the red and green color tag priority system.
c. It was Herbie’s favorite character on the Mighty Morphin’ Power Rangers.
d. It was a machine that could perform similar operations as the NCX-10 machine.
e. It was the nickname Jonah gave to Alex (“What’s up Zmegs? Let’s do some Socratic learning!”).f. It was a machine that could improve the capacity of the heat-treat department.
g. It was a book on healthy living, which reduced health insurance costs and created a more positive work environment.

There are only two legitimate answers, (d) and (f). (f) considers the heat-treat department, which was on Assignment 1, and asked how the heat-treat dept increased capacity: no answer included the Zmegma machine. We also discussed in class how Alex improved the capacity of the NCX-10 using the Zmegma.

19. [1 point] In the book “The Goal,” who annoyed you most?

a. Alex
b. Julie
c. Alex and Julie – they deserve each other!
d. Jonah
e. Who the heck are these people?

Any answer is acceptable.