1. (12 points) Which of the following is most characteristic of a Forward-pick area? Which of a Reserve (bulk-storage area)? Which is most characteristic of Both? Which is characteristic of Neither? Write F, R, B, or N, to indicate your answer and explain.

(a) (2 points) Dedicated storage (“reserved parking”)

Solution: F: Dedicated storage is typically used to further speed picking in that area of the warehouse in which labor is concentrated.

(b) (2 points) Random storage (“open parking”)

Solution: R: Random storage is used to increase space utilization in the largest area of the warehouse.

(c) (2 points) Consumes most of the space in the warehouse

Solution: R: Recall the photos of bulk storage, with lots of pallet rack.

(d) (2 points) Responsible for most of the labor in the warehouse

Solution: F: Concentrates picking in a small region.

(e) (2 points) Holds most of the SKUs in the warehouse

Solution: R: Typically, a small percentage of SKUs qualifies for forward space.

(f) (2 points) Most likely to use accelerative technologies like pick-to-light

Solution: F: Such technologies will have the greatest impact here.
2. (10 points) Consider a forward-pick area where cases are picked from pallets (and all full-pallet picks are from reserve storage and may be ignored). Storing a SKU in the fast-pick area realizes a savings of 1 minute per pick; but each restock requires about 3 minutes. Because of volatility of purchasing, management is unable to specify a reasonable upper bound on how many pallets of each SKU may be expected in the warehouse. Consider the following SKUs, for each of which a minimum number of pallets has been determined to avoid stockout while waiting for replenishment.

<table>
<thead>
<tr>
<th>SKU</th>
<th>Case picks</th>
<th>Case-pick demand (pallets)</th>
<th>Min. forward pallets</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>600</td>
<td>100</td>
<td>2</td>
</tr>
<tr>
<td>B</td>
<td>1000</td>
<td>350</td>
<td>3</td>
</tr>
<tr>
<td>C</td>
<td>200</td>
<td>2</td>
<td>1</td>
</tr>
</tbody>
</table>

(a) (5 points) Which of the SKUS has greatest claim to storage in the forward-pick area that consists of single-deep floor positions?

**Solution:**

<table>
<thead>
<tr>
<th>SKU</th>
<th>bang-for-buck</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>( \frac{(1)(600) - (3)(100)}{2} = 150 \text{ min/location} )</td>
</tr>
<tr>
<td>B</td>
<td>( \frac{(1)(1000) - (3)(350)}{3} \approx -16.6 \text{ min/location} )</td>
</tr>
<tr>
<td>C</td>
<td>( \frac{(1)(200) - (3)(2)}{1} = 194 \text{ min/location} )</td>
</tr>
</tbody>
</table>

SKU C would have the strongest claim to forward space.

(b) (5 points) How would your answer change if the forward area is double deep pallet flow rack?

**Solution:** Now there are two pallets per location.

<table>
<thead>
<tr>
<th>SKU</th>
<th>bang-for-buck</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>( \frac{(1)(600) - (3)(100)}{1} = 300 \text{ min/location} )</td>
</tr>
<tr>
<td>B</td>
<td>( \frac{(1)(1000) - (3)(350)}{2} \approx -25 \text{ min/location} )</td>
</tr>
<tr>
<td>C</td>
<td>( \frac{(1)(200) - (3)(2)}{1} = 194 \text{ min/location} )</td>
</tr>
</tbody>
</table>

SKU A would have the strongest claim to forward space.
3. (10 points) Recall that we analyzed a model that helped us evaluate the benefit of a forward pick area. What is the likely effect on the value of a forward pick area of . . .

(a) (5 points) An advertising campaign to win new customers by convincing them to change from a competitor? (Explain your answer.)

Solution: It will increase both picks and demand. If these are in about the same proportion as for current customers, then the bang-for-buck of each SKU will increase and so will the value of the forward pick area.

(b) (5 points) An advertising campaign to get current customers to purchase and consume greater quantities of each SKU?

Solution: The increase in quantity will increase the required number of restocks but without necessarily increasing the picks. Therefore the bang-for-buck of each SKU may be expected to decrease and so will the value of the forward-pick area.
4. (10 points) Suppose your customers move to a more “just-in-time” purchasing pattern and now order twice as often but half as much with each order.

(a) (5 points) Does this make your forward carton-pick-from-pallet area less valuable, more valuable, or does it have no effect? Explain.

**Solution:** More valuable because doubling the picks without increasing the restocks means the net-benefit per unit-space for every SKU will strictly increase.

(b) (5 points) Could this change your selection of which SKUs to store forward? Explain.

**Solution:** Yes, it could. A very popular SKU that also had high demand and so was relatively unattractive, could become much more attractive. Example: a SKU with forecast pick-savings of 100 and restock costs of 99 would be less attractive than one with values of 3 and 1 respectively (100 − 99 < 3 − 1), but the opposite would be true if picks doubled while restocks remained the same.
5. (10 points) Pick-path optimization
   (a) (5 points) Which warehouse is more likely to get value from optimizing pick-paths? Explain your answer.
      - One with extremely high pick-density?
      - One with extremely low pick-density?
      - One with moderate pick-density?
      - It is impossible to tell without more information.

      **Solution:** One with moderate pick-density, because there are many alternative pick-paths (unlike when there is very high or very low pick density).

   (b) (5 points) What computational technology was used to find the shortest pick-path? Choose the best answer.
      - Linear programming
      - Integer-programming
      - A shortest-path algorithm
      - A maximum flow algorithm
      - A network-cycling algorithm
      - A minimum cost algorithm

      **Solution:** A shortest-path algorithm
6. (21 points) You are setting up a flow line of nine successive work stations to produce widgets. The task times, which vary insignificantly from item to item, are as follows:

<table>
<thead>
<tr>
<th>Station</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minutes</td>
<td>1</td>
<td>5</td>
<td>3</td>
<td>2</td>
<td>4</td>
<td>5</td>
<td>2</td>
<td>4</td>
<td>1</td>
</tr>
</tbody>
</table>

Assume there is a buffer of capacity 3 after station 1.

(a) (4 points) What is the maximum rate of production of this line and what limits it to this rate?

**Solution:** There are two bottlenecks, stations 2 and 6, which have the most work and so the slowest rate of production: one widget every 5 minutes.

(b) (5 points) Can the maximum production rate be improved by removing the buffer after station 1? If so, what would be the new production rate? Could it be improved by moving the buffer to a new location between two other stations? If so, where and what would be the new production rate?

**Solution:** No; wherever the buffers are located, the long term production rate would be unaffected after the buffers filled.

(c) (4 points) What is the flow time of a widget through this line?

**Solution:** Station 2 is the bottleneck station farthest upstream and it has 5 minutes of work, so the flow time would be \((5)(5) + 3 + 2 + 4 + 5 + 2 + 4 + 1 = 46\) minutes. (Note that eventually each widget will spend 5 minutes at the first station and then 5 minutes at each of the three buffer stations, and then 5 minutes at the second station.)

(d) (8 points) What would be the effect on maximum production rate and on flow time of swapping the positions of stations 1 and 2? Stations 3 and 4? Stations 5 and 6? Stations 7 and 8? (Consider all swaps — interchanges — independently, not cumulatively.)

<table>
<thead>
<tr>
<th>Stations</th>
<th>Max production rate</th>
<th>Flow time</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 and 2</td>
<td>No change</td>
<td>Decreases to 27</td>
</tr>
<tr>
<td>3 and 4</td>
<td>No change</td>
<td>No change</td>
</tr>
<tr>
<td>5 and 6</td>
<td>No change</td>
<td>No change</td>
</tr>
<tr>
<td>7 and 8</td>
<td>No change</td>
<td>No change</td>
</tr>
</tbody>
</table>

**Solution:**
7. (15 points) Variable task times
   
   (a) (5 points) Suppose the task times are variable (that is, the task can require different amounts of time at each execution even when done by the same person). If the times given in the previous problem are the average task times, how does your estimation of the production rate change?
   
   - The realized production rate will probably be greater than predicted above.
   - The realized production rate will probably be lower than predicted above.
   - The realized production rate will probably be the same as predicted above.
   - It is impossible to say.

   **Solution:** The realized production rate will probably be lower because when task times vary, the bottleneck station can move, which creates many more opportunities for blocking and starving.

   

   (b) (6 points) Draw the typical distribution of task times. What accounts for the fact that it is not a normal distribution?

   **Solution:** The typical distribution resembles a lognormal distribution. One of its distinctive features is that it is truncated on the left, reflecting the fact that most processes have a lower bound on time required, generally because of innate human limitations. Another distinctive feature is that it is positively skewed, reflecting the fact that disruptions sometimes occur.

   

   (c) (4 points) Why are neither the normal nor the exponential distributions good choices for modeling work-content in a manufacturing or assembly operation?

   **Solution:** The normal distribution displays neither of the features described above. The exponential distribution is memoryless, which suggests that work-in-process cannot “remember” work invested in it.
8. (12 points) Miscellaneous
   
   (a) (4 points) Why are bucket brigades really not practical for either of our clients?

   **Solution:** There is not enough pick-density to determine a clear, common pick-path and so it is not clear how a worker could efficiently walk back to take over work of another.

   (b) (4 points) What technology did our guest speaker employ to improve the processes and so the rate of production for her client? Choose the best answer.

   - Time-motion studies
   - Video
   - Bucket brigades
   - Automation
   - Lean six-sigma

   **Solution:** Video, from which workers could easily recognized best practices

   (c) (4 points) For our model of selecting SKUs for forward storage in a carton-pick-from-pallet area what are the dimensions (that is, units of measure, like \(m/sec^2\)) of the expression for “bang-for-buck”?

   **Solution:** Person-hours per storage location.