46-893 OPERATIONS AND SUPPLY CHAIN ANALYTICS
INSTRUCTIONS FOR THE FINAL PROJECT

OVERVIEW

In this final project, you will be asked to develop an operations and supply chain management policy for an e-Commerce fulfillment center. Your policy will be applied towards a hypothetical fulfillment center operation that will be described in the following section. Your final deliverable will consist of (i) a short document stating your operations policy, and (ii) a longer document, supplemented by a set of simulation code, describing your analysis and rationale for choosing the specific operations policy.

The final project deliverables are due **October 22, 2020** at **11:59pm Eastern Time**. You will also be asked to submit own and peer evaluations on project contributions within your group by **October 23, 2020** at **5:00pm Eastern Time**.

DESCRIPTION AND SPECIFICATION OF THE FULFILLMENT CENTER OPERATION

A. Products handled

The fulfillment center handles four products: t-shirt, hoodie, sweatpants, and sneakers (assume that there is no consideration of size because everyone in this world somehow has the same physique – possibly through mass genetic engineering). The unit economics and parameters of each products are listed in Table 1.

	Gross profit per unit sold	Penalty per unit lost sales	Inventory holding cost rate per unit	Weight
T-shirt	$4	$1	$0.10/day	0.5 lbs
Hoodie	$10	$6	$0.30/day	1 lb
Sweatpants	$10	$6	$0.30/day	1 lb
Sneakers	$20	$10	$0.60/day	1.5 lb

Table 1: Unit economics and parameters of products handled by the fulfillment center

B. Facility layout and associated operations

The fulfillment center facility is divided into three major zones: inbound processing, inventory storage, and outbound processing. Within these zones, five operations take place: (1) inbound receiving, (2) inventory stowing, (3) order picking, (4) order packing, and (5) outbound shipping.

The relationship between the general facility layout and operations are summarized in Figure 1 at the very end of this document. First, products ordered from the supplier would arrive at the inbound receiving dock based on a pre-determined ordering schedule. These arriving inventories would be unloaded from the truck and sit in the inventory parking area until they are being stowed. Workers (stowers) will come pick up the inventory from the parking area and move them to the inventory storage area. There are four inventory storage areas in the facility. The inventories will be picked up by workers (pickers) from the storage areas as customer orders get processed. After picking up the items associated with a single order, the picker would send these items to the packing stations through a conveyor belt. The workers at the packing stations (packers) would then put these items into a cardboard box and send them to the outbound shipping dock where the items would get loaded onto the trucks heading out for last-mile delivery.

Sections D-K will describe the detailed rules and that must be followed at each of the five major operations, as well as various cost elements.

C. Data on past customer orders

You will be provided a .csv file containing orders placed within the last 52 weeks. This data should be used to develop your operations policy and planning. The datafile contains six columns: OrderID, OrderTimeInSec, QtyShirt, QtyHoodie, QtySweatpants, and QtySneakers. OrderID is the unique identifier of an order that must be fulfilled. OrderTimeInSec is the timestamp of the particular ID corresponding to the time when the order has been placed by the customer through the web platform. The timestamp is expressed in seconds, starting from time 0 until the end of the 52 week period. Time 0 is defined as midnight on a Thursday. The other last columns, as their name suggests, indicate the quantity of each product that must be included in the order.

We will assume no such thing as a global pandemic between the past year and this year, so the data (in aggregate) is representative of the amount of orders that need to be handled this year. We will also assume that your fulfillment center operates in a country that is situated close to the equator and that this country's culture has no concept of holiday shopping. This means that the number of incoming orders won't fluctuate too much around the year but may still fluctuate within one week. [rev2 2020-09-12: The simulation in the final reference implementation will start at midnight on Thursday.]

D. Policy on the processing of customer orders

Customer orders must be fulfilled on a first-in-first-out (FIFO) basis. We will assume that customer orders expire in exactly 72 hours. In other words, if you are unable to process the customer order (i.e., complete the order shipment) within 72 hours, then the customer will immediately cancel the order and the operation will incur a lost sales penalty for every item in the order. If the order is cancelled in the middle of an operation (e.g., middle of picking), then that particular operation must be completed but subsequent operation (e.g., packing) need not be completed. Assume that the inventory will be completely discarded upon cancellation. Customers will not cancel orders otherwise. [rev1 2020-09-11: If the order is cancelled before the start of the picking operation, the inventory will NOT be lost. However, lost sales penalty still applies.]

As a side note, e-commerce platforms like Amazon have a secret-sauce algorithm for optimizing fulfillment priorities but we will operate on a FIFO policy to simplify things.

E. Mechanics of the inbound receiving operation

The supplier will sign a 52-week contract to deliver either once a week every Monday at 9:00 am, or once every day at 9:00 am. The cost of weekly delivery is $50,000 per shipment while the cost of daily delivery is $10,000 per shipment.

The quantity delivered each shipment will be based on a pre-determined schedule decided at the beginning of the year. You will not have the chance to modify your delivery quantity during the year. The supplier will always deliver 100% of what you need and will be on time 100% of the time (amazing!). Assume that the supplier will handle unloading from the inbound receiving dock to the inventory parking area and

that this happens instantaneously (miraculous!). You will not incur additional labor expense for this operation besides the delivery cost.

[rev2 2020-09-12: Once the delivery frequency is chosen, it cannot be changed over the entire 52 week period. However, the amount delivered each day/week can vary, so it's possible to have the supplier deliver 0 units of every item for some day/week. The number of units of each item to be delivered do not need to be the same across products or across time. At the same time, you will be charged the shipment cost even if you set quantity of every item to zero (i.e., weekly schedule costs $2.6 million total and daily schedule costs $3.64 million total for the 52-week duration).

One way to organize the delivery schedule is to use a .csv file organized with each row indicating the ID corresponding to the n-th delivery during the simulation period along with the quantity to be delivered for each item.
DeliveryID,tShirt,hoodie,sweatPants,sneakers
1,1000,800,300,300,200
2,1000,3000,3000,1500
3,2000,659,893,201
...

Note that the schedule must be "static", meaning that you need to specify this before the start of the 52-week period. You cannot modify this schedule on-the-fly (or dynamically) as the simulation evolves.]

Assume that the inventory parking area has a capacity of 50,000 lbs worth of inventory. If a new shipment arrives and unloading everything would exceed the inventory parking area capacity, then one will take in the largest possible constant fraction of all items included in the new delivery to meet the maximum capacity of the inventory parking area (rounded down to whole units). The rest of the items will be rejected and sent back to the supplier, and you will incur a return shipment penalty equivalent to the cost of delivery ($50,000 if on the weekly schedule and $10,000 if on the daily schedule).

[rev1 2020-09-11: The largest constant fraction is in terms of weight, so we will take equal weight for each item, convert them to units, and round down to whole units if necessary. As an example, consider if the new delivery is 5000 units of each item (so 20,000 lbs total) but the receiving area only has room for another 10,000 lbs. One would take 1/2 of the shipments for each item. This then gets converted to 2500 units of t-shirt, 2500 units of hoodie, 2500 units of sweatpants, and 2500 units of sneakers.]

F. Mechanics of the inventory stowing operation

Each stower, provided that there are still unstowed inventories in the pooling area, will engage in stowing operation. The stowing operation will take place in the following manner:

i. At the beginning of each trip, the stower will evaluate the remaining work in the inventory parking area for each of the four products. The remaining work is defined by the # of units remaining in the parking area multiplied by the weight of each product. The stower will choose to stow the product with the most remaining work. If there are multiple products with the same remaining work,

the stower will choose one of the product with the most remaining work randomly. The stower will carry only one type of product each trip, even if the stower has remaining capacity to carry more than one type of product after taking on all of the remaining units of one type of product.

ii. The stower will carry the chosen product to the inventory storage areas and stow the product in the inventory storage areas based on either the designated storage policy or random storage policy.
    a. The designated storage policy will designate each of the inventory storage area to carry only one type of product. For convenience, we will designate area 1 to t-shirts, area 2 to hoodies, area 3 to sweatpants, and area 4 to sneakers. The stower can travel directly to the corresponding inventory storage area from the inventory parking area.
    b. The random storage policy will make the stower travel across all four storage area and store ¼ of the total units across all four storage areas. The stower will travel the storage areas in the order of 1 → 2 → 3 → 4. If the number of units carried by the stower is not evenly divisible by 4, then the number of units stowed in each area is rounded down, with the remainder being stowed in area 4.

iii. Once the product has been stowed, the stower will return to the inventory parking area and start the trip again as in step (i) if necessary.

Each stower can carry up to 12 lbs. per trip. The stower can travel directly between the inventory parking area and any of the inventory storage area. Between each inventory storage area, the stower can only travel directly to the adjacent inventory storage area. The stower cannot travel directly from inventory storage area 1 to inventory storage area 4 and the other way around.

Assume that there are no limits to the amount of products that can be stowed in any of the inventory storage area. Also assume that having a lot of stowers will not cause congestions anywhere in the facility.

The amounts of time it takes to complete individual steps in the stowing operation are listed below:

- Time to pick up items before starting the trip: 120 seconds
- Time to travel from the inventory parking area to an inventory storage area: 120 seconds
- Time to travel from an inventory storage area to an adjacent inventory storage area: 60 seconds
- Time to stow one unit of a product: 10 seconds

Assume that there are no variations in pick up, travel, or stowing time. [rev1 2020-09-11: The 120 seconds to pick up the item is NOT included in the travel time. The stower will need to prep by picking everything up (120s) + travel to the inventory storage area (120s) + travel across the inventory storage area if necessary (???s) + travel back to the inventory parking area (120s).]

G. Mechanics of the order picking operation

Each picker, if there are unfulfilled orders, will engage in picking operation. The picking operation will take place in the following manner:

i. The picker will be assigned a single order to pick (in FIFO order).
ii. The picker will travel from the picking station to the appropriate inventory storage area to pick the items included in the particular customer order.
    a. In the case of designated stowing policy, the picker will travel in the order of inventory storage area 1 → 2 → 3 → 4. However, the picker will not need to visit station 1 if there are no t-shirts for example. Once all items have been picked, the picker can return to the picking station immediately without visiting all inventory storage areas.
    b. In the case of randomized stowing policy, the picker will choose one inventory storage area at random and pick from that area. If there are not enough inventory in that inventory storage area, then the picker will choose to move to a random adjacent inventory storage area and will repeat until all items have been picked. Once all items have been picked, the picker will return to the picking station.
iii. Once the picker returns to the picking station with all items, the picker will put these items on the conveyor belt and will send to the packing station with the least amount of orders waiting to be completed. If multiple packing stations have the same amount of orders waiting to be completed, then the picker will select one randomly.

We assume that pickers can carry an unlimited number of items. The picker can travel directly between the picking station and any of the inventory storage area. Between each inventory storage area, the picker can only travel directly to the adjacent inventory storage area. The picker cannot travel from inventory storage area 1 to inventory storage area 4 and the other way around.

The amounts of time it takes to complete individual steps in the picking operation are listed below:

- Time to travel from the picking station to each inventory storage area: 120 seconds
- Time to travel from an inventory storage area to an adjacent inventory storage area: 60 seconds
- Time to pick one unit of a product: 10 seconds
- Time to send picked products from the picking station to a packing station before starting another trip: 30 seconds

Assume that there are no variations in travel, picking, or transport time.

H. Mechanics of the order packing operation

Each packer must be stationed at a packing station. If there are more packers than packing stations, then the packers remain idle (but still get paid). The packing station stores items that have been sent down from the picking station and each order is processed on a FIFO basis.

The packing operation takes 30 seconds + 10 seconds per unit of a product. Assume no variation in packing time. Once packed, the packed order will be sent for outbound shipping processing.

I. Mechanics of the outbound shipping operation

We assume that outbound shipping takes place instantaneously after packing is complete. In addition, we will assume no product returns. Therefore, we may book the gross profit per unit sold from this particular order at this point.

J. Labor policy and expenses

The fulfillment center operates on three shifts, 0:00am-8:00am, 8:00am-4:00pm and 4:00pm-0:00am. Assume no switchover costs or productivity loss between the three shifts. If a worker is in operation at the time of switchover, the worker will finish that particular task before exiting.

Each worker (stower, picker, and packer) costs $22.50/h inclusive of various administrative overhead and benefits. You will need to pay worker for all of the time that they are on duty (including the extra time that might arise during switchover). Assume that you operate an exemplary workplace and that there are no concerns of worker injuries or absenteeism.

K. Facility and inventory related costs

The fixed cost of operating the fulfillment center over the next 52 weeks will be $5 million. Each packing station that is installed in the facility will cost $50,000 for the next 52 weeks.

You will be responsible for tracking the inventory holding cost (i.e., the opportunity cost of having capital tied up in inventory) throughout the operation. The inventory holding cost rate for each product is described in Table 1. Inventory holding cost is incurred from the time the product arrives to the inventory parking area to when the product is processed at the outbound shipping dock.

[rev2 2020-09-12: We will assume the initial starting inventory of the facility to be as follows: 10000 units of t-shirt, 5000 units of hoodies, 5000 units of sweatpants, and 3333 units of sneakers. These items start off in the inventory storage areas, corresponding to the storage policy chosen.]

L. KPI

The performance metric for this e-commerce fulfillment center is the total profit over the next 52 weeks. Total profit will be calculated based on the following definition:

Gross profit
Less) Delivery expense and possible penalties
Less) Lost sales penalty
Less) Labor expense
Less) Facilities fixed cost
Less) Packing station expense
Less) Inventory holding cost
=== Total profit

DELIVERABLES AND EVALUATION

Your group will be asked to submit two documents. The first document will simply describe your operational decisions. This document will be used as the basis to benchmark the performance of your decisions against a reference simulation code and a test dataset. The second document will be a more comprehensive report on the operational problems considered and their analysis. The second document should be written in a way to properly justify your operational decisions in the first document. The second document should be supplemented with simulation codes.

The requirements for the first document are described below. You are required to decide on every one of the items described below for each of the operational steps.

The inbound receiving operation

1. Choose between (a) the weekly delivery schedule, or (b) the daily delivery schedule.
2. The delivery schedule over the next 52 weeks for each of the products managed by the fulfillment center. This can vary from shipment to shipment or it can stay constant throughout the entire 52 weeks.

The inventory stowing and the order picking operations

- Choose between (a) the designated stowing policy or (b) the randomized stowing policy.
- The weekly stowing shift schedule (i.e., the # of workers on duty each shift for every day of the week). This schedule will stay constant throughout all 52 weeks.
- The weekly picking shift schedule (i.e., the # of workers on duty each shift for every day of the week). This schedule will stay constant throughout all 52 weeks.

The order packing operation

- Choose the number of packing stations to set up (i.e., the maximum number of packers that can work at the same time).
- The weekly packing shift schedule (i.e., the # of workers on duty each shift for every day of the week). This schedule will stay constant throughout all 52 weeks.

The final project will be graded out of 40, with 10 points being allocated to each of (i) benchmarking, (ii) quality of analysis, (iii) quality of the simulation code, and (iv) own and peer evaluations.

Benchmarking

The instructor will use your operations decisions as inputs for his own e-Commerce fulfillment center operations simulation and a testing order sequence dataset. You will be evaluated against the rest of the groups in terms of the KPI performance.

Quality of analysis

The instructor will evaluate the quality of your analysis in the second document. You will need to demonstrate to the instructor that your decision is based on sound reasoning so that the policy chosen will help increase your KPI over alternatives with nearly 100% certainty. The analysis needs to be quantitative and supported with simulation code.

The instructor will mainly examine your report based on:

- The soundness of the logic and problem formulation – does your analytic framework actually help you answer the question you'd like to answer?
- Execution of the analysis – did you use the analytic framework properly to reach a reasonable conclusion?
- The ease of reading and organization of information – are there any ambiguities in your analysis and how long did it take for the instructor to wrap his head around it?

You may choose to approach this report in two ways. The first way would involve a systems-level view of the e-Commerce fulfillment center operation. You will build out a model of the fulfillment center operation in its entirety including how individual parts interact together. Analysis can then be performed on this "master" model of the operation. While successfully executing this approach would be impressive, you are not required to take this approach due to its complexity.

Another way would be to formulate a suite of smaller sub-problems involved in the fulfillment center operations and to tackle these separately. In this case, analysis and simulations may be substantially simpler for these individual sub-problems. However, the trick here would be to find an appropriate level of compartmentalization for each sub-problem and to make sure that there are minimal interactions between each components. It will be helpful to specify which approach you chose and the reasoning behind this decision at the beginning of your report.

Quality of the simulation code (or any supporting quantitative models)

The instructor will also evaluate the quality of the simulation code (or any quantitative analysis) that supplements your main analysis. The instructor will focus on the correctness of implementation in this part. This means that the instructor will ask questions along the line of…

- Does your simulation code implementation actually perform the analysis you described?
- Does your simulation code produce reasonable outputs over a range of inputs and therefore is likely bug-free?
- Are there proper documentations on how to use this simulation code so that it works completely "out-of-the-box"?

In general, you should target minimizing the time that the instructor has to spend getting the code to run or to debug the code.

Own and peer evaluation

You will be asked to submit a confidential assessment of your own and other group members' contributions to the final deliverables. The instructor will be mainly looking for large discrepancies between own evaluation and the aggregate peer evaluation.

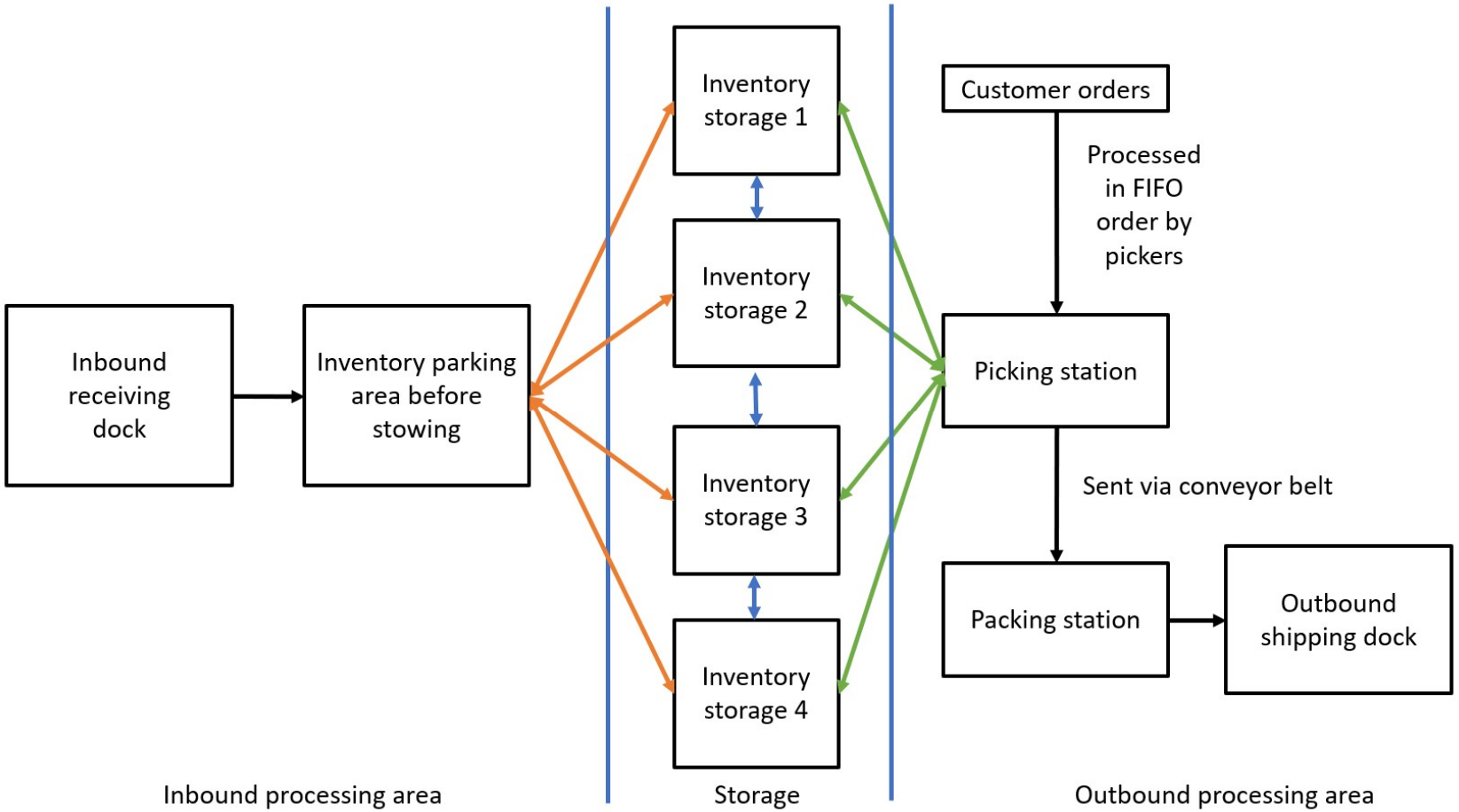

Figure 1: Overall layout of the fulfillment center facility