ISYE 6202 Supply Chain Facilities

Casework 2

HelpBots Supply Chain Facility Network Analysis, Planning, and Simulation

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- *The casework is meant to be realized in self-organized teams of up to 3 students, yet may be realized solo, with the number of students in the team having no influence on the grading.*
- *The HelpBots company at the core of this casework does not exist, that all stated facts are fictitious, and that all data has been synthetically generated.*
- *The casework to be completed by October 21st is shaped around two equally weighted (50%) main phases, each with a set of mandatory tasks having a significant grading weight, purposefully not revealed to the class.*
- *For each task, you must rigorously describe your methodology, present your results, analyze them, and discuss them relative to the current task and, when pertinent, relative to previous tasks.*
- *For computational algorithms and simulations, exploitation of Python and linked tools is preferred. Using spreadsheets such as Microsoft Excel/VBA is tolerated. All developed codes are to be provided.*
- *For maps and visualizations, exploitation of Python libraries or Tableau (or similar business analytics softwares) are recommended.*
- *Phase 1 must be completed at the very latest by October 4th at 23h59, with all its task 1-10 deliverables submitted online.*
- *Upon completion of phase 1, at any time before or on October 4th, each team will be provided with a simulator and a user guide to be leveraged for realizing the tasks of phase 2.*
- *In phase 2, the simulator-based team experience comprises nine levels, with successive level access and documentation released once the team completes the previous level by submitting its proposed solution. Phase 2 must be completed by October 21st at 23h59 with all simulation level solutions submitted and all task deliverables also submitted online.*
- *Starting in phase 1, then within the levels of phase2, it is strongly encouraged to read the available casework documentation to identify early the types of tasks to be realized and the potential for proactive concurrent preparation. This is crucial for teams to plan and not simply react, to leverage the potential and availability of each team member, to avoid a lengthy linear single-thread realization of the casework tasks, and to rather achieve concurrent-engineering-style task realization.*

Introduction to the Simulator Used in this Casework

Imagine stepping into the role of a COO at a multinational retail giant, managing an intricate supply chain system. Your team's responsibilities span from daily production planning at the factory to optimizing inventory levels across a multi-echelon warehouse network, all towards maximizing customer satisfaction and your firm's profitability. As a hands-on leader, you would interact regularly with key decision-makers and be required to have a broad vision and understanding of the impact of various strategic, tactical, and operational decisions. On a more detailed level, you need to make decisions about demand planning, production planning, inventory management, transportation and shipment management. While these tasks may seem daunting, a sophisticated simulator will give you the tools to operate like a true supply chain leader.

This Simulator, developed by Georgia Tech's Physical Internet Center (led by Prof. Montreuil), allows you to effortlessly set key parameters of a complex supply chain system, such as inventory targets, delivery modes, and production capacities, through an intuitive set of interactive tools (Figure 1). It then simulates daily demand to evaluate the effectiveness of your current supply chain system. The simulator vividly displays all order statuses and inventory levels on an interactive map, while also tracking your revenue and costs. Additionally, it offers a range of other exciting features and visualizations for you to explore! What would typically take a team of analysts' weeks to evaluate can now be simulated in just minutes.

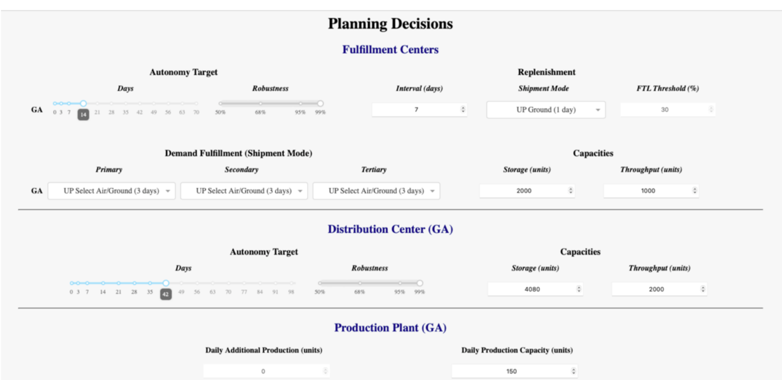

Figure 1: Interactive interface for setting various decision parameters in the simulator

To give you an idea of what you'll experience:

- **Dynamic Demand Simulation and Forecasting:** The engine simulates customer demand from various locations in the USA, and dynamically utilizes the fulfillment network to satisfy the demand. It also refreshes demand forecasts on a daily basis, based on the historical information up to the previous day, utilizing a sophisticated algorithm considering the various seasonalities and trends.

- **Dynamic Inventory Planning:** With the daily-updated demand forecasts, the simulator dynamically adjusts production plans and inventory levels at each node of the network by just specifying your inventory targets (say you want to maintain 4 weeks of stock in the network with 99% confidence that no demand is lost during these four weeks). It enables for example to visualize the evolving current state of the inventory levels and flow of goods through the network (Figure 2).

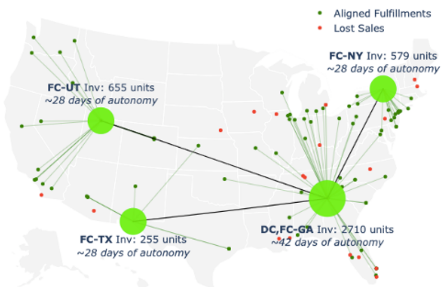

Figure 2: Inventory level and flow of goods through the network

- **Advanced Analytics and Visualizations:** Utilize the simulator's analytical tools to monitor key performance indicators, such as market penetration, demand fulfillment, and profit indicators, displayed on the top bar. Further, many plots are included to enable you to visualize the impact of your decisions on the various aspects of the complex network.

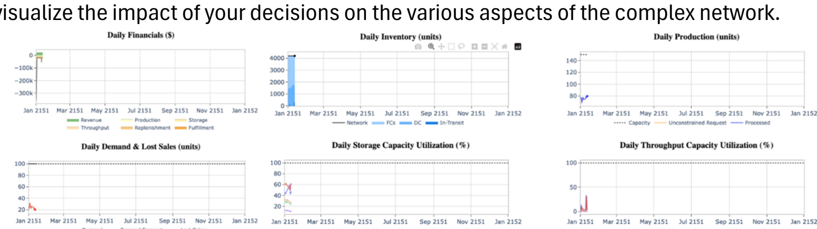

Figure 3: Visualizations embedded in the simulator

- **Scenario Testing:** Experiment with different demand scenarios and transportation modes to observe their impact on customer satisfaction and cost efficiency. The simulator allows you to adjust parameters to find the optimal balance between the various tradeoffs, and manage the intricacies of this complexity with a thoroughly researched analytical background.

Overall, we have developed the simulator for you – to enable you to perceive, understand, and appropriately react to the various aspects in a real-world-inspired supply chain. We envision this to be an aid for you, as you prepare for a journey towards becoming supply chain leaders of the future.

Overall Case Introduction

The HelpBots Company is an established yet small player in the design, engineering, manufacturing, commercialization, and distribution of domestic collaborative robots. It has an excellent portfolio of products with four families ranging from smaller to larger capability and capacity. HelpBots has decided early on to be fully e-commerce based. It has grown slightly in the last 10 years to reach a current 1.8% market share of an annual estimated continental-USA market of 2,000,000 product units for its types of collaborative robots.

The company has recently been purchased by a corporation that has sensed that the company could reach much higher market shares and attain operational excellence with a combination of (1) improved business leadership, (2) better alignment of demand and supply throughout its network through coordination and collaboration, and (4) leveraging data-driven daily forecasting and AI-based decisional models.

The new management has carefully studied the overall market. It has interviewed facility managers, current and potential customers, as well as third-party storage and logistics providers and experts from the industry. It has also purchased market databases and analyzed data relative to multiple key market drivers. Combining all this, it has made a set of discoveries and hypotheses.

Your role as a supply chain consultant to HelpBots is help analytically model, validate, and visualize the hypotheses through tasks and simulations to enable the leadership to take the right actions about its network of supply chain facilities, towards overall operational excellence and growth.

Your work helping HelpBots throughout this casework is structured in two major phases. First is the preparatory analysis and planning phase 1, performed without access to the interactive simulator. This phase focuses on systematically tackling HelpBots' five key sets of discoveries and hypotheses respectively relative to market demand, fulfillment network, delivery time sensitivity, robust autonomy targeting, and network replenishment.

Upon phase 1 completion, second is the simulation-based holistic analysis and planning phase 2. This phase integrates tackling all HelpBots's discoveries and hypotheses in light of the learnings from phase 1, leveraging an iterative multi-level game-like approach.

Phase 1: Preparatory analysis and planning

Discoveries and Hypothesis Set 1: Market Demand

- The overall market in the USA is to grow by about 7.5% over the next year, with conservative and optimistic scenarios at 4% and 12% yearly.
- HelpBots' market share is planned to grow yearly by a minimum of 15%, a median of 20%, and a maximum of 25% from its current 1.8% market share.
- The overall market has been categorized into three market types. HelpBots has identified its primary markets are 100 miles radius around the center of key Metropolitan Statistical Areas (MSAs) across the USA, as in *HelpBots msa.csv*; secondary market as 300 miles radius around

MSAs, beyond the primary markets; and tertiary markets as all other US territories. The corresponding market type for each 3-digit ZIP in the USA is provided in *HelpBots zip3_market.csv*. (Figure 4)

- Based on historical information and market analysis, demand for HelpBots products is subject to seasonal effects. Expectations of week-of-year and day-of-week seasonalities are provided in *HelpBots demand_seasonalities.csv*. Respectively assume 20% and 15% coefficient of variation on these estimates.
- The expected probability mass function (PMF) for geomarket demand share at each 3-digit ZIP in USA can be approximated to remain stable over the next five years, as provided in *HelpBots zip3_pmf.csv*. Assume a 15% coefficient of variation on these estimates.
- The average price ($), weight (lbs) and volume (width*height*length ft^3) of packaged HelpBots products are to be on the order of 300$, 60lbs, and 1.5*2*2 ft^3.

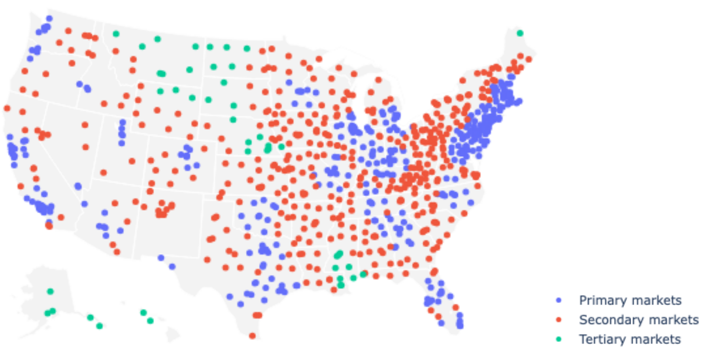

Figure 4: Market Type Map (points represent 3-digit ZIPs)

Task 1

Assuming no demand uncertainty and no demand seasonality, compute the estimated overall market demand (for HelpBots and its competitors) over 1-year planning horizon for the various combinations of the three aggregation threads below:

- *Temporal: (1) Yearly, (2) monthly, (3) daily*
- *Spatial: (A) USA territory, (B)Market Type, (C) State, and (C) 3-digit ZIP*
- *Measure: ($) dollars, (#) units, (V) volume, (W) weight*

An example of combination is 3-B-$ corresponding to daily demand in $, segregated by market type. Provide visual displays of your results, analyze your results, and provide key insights. Explore the various combinations, identify the key visualizations, and provide actionable insights.

Task 2

Repeat task 1 now accounting for demand seasonality and uncertainty. Instead of deterministic numbers as in task 1, the demand estimates take the shape of statistical distributions and their X%-min, mode, mean, X%-max values. Consider 68% (1σ), 95% (2σ), and 99% (2.5σ) for X.

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If the demand follows a standard normal distribution, the mode and mean are 0. The 1σ min and max are ±1, the 2σ min and max are ±2, and the 2.5σ min and max are ±2.5.
Hint: *You could run a Monte Carlo simulation using the demand's statistical distribution, incorporating seasonality adjustments, to generate a large set of demand values. Then, calculate the desired percentiles (68%, 95%, 99%), mean, and mode from the simulated data to obtain the results.*

Discovery and Hypothesis Set 2: Fulfillment Network

- Facilities are identified by their type, state, and 3-digit zip code.
- HelpBots has a single assembly factory (AF-GA-303), located in Georgia within zip code 303.
- HelpBots has a single distribution center (DC-GA-303) fed by AF-GA-303 and feeding all fulfillment centers (FCs) in its fulfillment network.
- HelpBots is considering three alternative fulfillment networks:
  1. Single-FC Network, centralizing all fulfillment operations at FC-GA-303.
  2. Four-FC Network, relying on FCs in Georgia (FC-GA-303), New York (FC-NY-134), Texas (FC-TX-799), and Utah (FC-UT-841), as displayed in Figure 5.
  3. 15-FC Network, relying on the following FCs, as displayed in Figure 6:

1. FC-AZ-852	4. FC-CO-802	7. FC-IL-606	10. FC-NC-275	13. FC-TX-770
2. FC-CA-900	5. FC-FL-331	8. FC-MA-021	11. FC-NJ-070	14. FC-UT-841
3. FC-CA-945	6. FC-GA-303	9. FC-MI-481	12. FC-TX-750	15. FC-WA-980

Important: HelpBots requests the realization of all subsequent tasks for each network to contrast them. For each task, it is mandatory to analyze results for each network and contrast them, and to provide key insights.

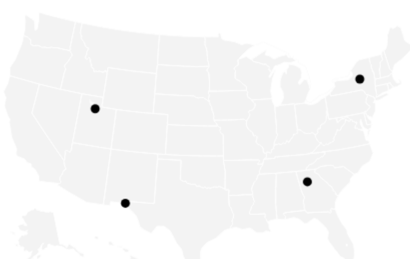

Figure 5: 4-FC Fulfillment Network

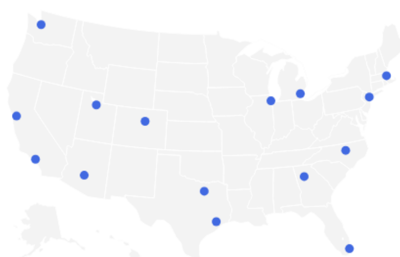

Figure 6: 15-FC Fulfillment Network

Task 3

Based on location proximity, estimate target regions for each FC, where all the 3-digit ZIP codes are strictly served by the closest FC. This yields clusters of 3-digit ZIPs with the same preferred FC.

a) Provide a geographical plot coloring the various 3-digit-zipcode clusters.

b) Estimate the aggregated demand share for each FC, and for each FC and market type combination.

c) Estimate the demand distribution for each market type, over the following shipping distance buckets in miles:

<50, 51-150, 151-300, 301-600, 601-1000, 1001-1400, 1401-1800, >1800

Distance from FC locations to all 3-digit ZIPs is provided in HelpBots fc_zip3_distance.csv.

Task 4

HelpBots is keen on ensuring resilience through multi-source fulfillment, so it allows to ship customer orders from a farther FC than the preferred one to avoid losing a sale when the closest FC is stocked out or disrupted. With a goal to minimize lost sales, identify for each 3-digit ZIP the set of FCs that can serve as fulfillment centers within the same distance bucket as the closest FC, or just the next higher one. This enables to create fulfillment clusters, each including the set of 3-digit ZIP with the same set of FCs.

a. *Provide a geographical plot coloring the generated fulfillment clusters.*
b. *Provide a geographical plot coloring the various clusters based on the number of FCs that can serve the cluster, in a red (lowest) – yellow – green (highest) color scheme.*
c. *Estimate the proportion of demand that can only be served by a single FC.*
d. *Estimate the variation in demand distribution over the shipping distance buckets, assuming 90% demand satisfaction by closest FC, and the remaining 10% split equally among the other FCs serving the cluster.*

Discovery and Hypothesis Set 3: Delivery Time Sensitivity

- In this era of shrinking order-to-delivery lead times promises by e-commerce retailers and induced e-customer expectations, the proportion of customers willing to place orders with HelpBots depends on promised Order-to-Delivery (OTD) lead times and this proportion differs per market type. Table 1 shows for example that in all primary markets, it is expected that only 60% of the demand can be converted into sales if the promised OTD time is four days.

	Promised Order-To-Delivery Lead Time (days)					
Market	1	2	3	4	5	5+
Primary	100%	90%	75%	60%	40%	30%
Secondary	100%	100%	95%	75%	60%	40%
Tertiary	100%	100%	100%	95%	80%	60%

Table 1: OTD Time and Market Type Sensitive Expected Demand Conversion Rates

- All markets must be covered through white-glove online-based sales experience with corporate-led fulfillment and service, while delivery is to be leveraging third-party shipment delivery service providers. The product shipment costs per unit from FCs to customer location depends on the promised Order-To-Delivery duration and shipment distance zones, as denoted in Table 2.

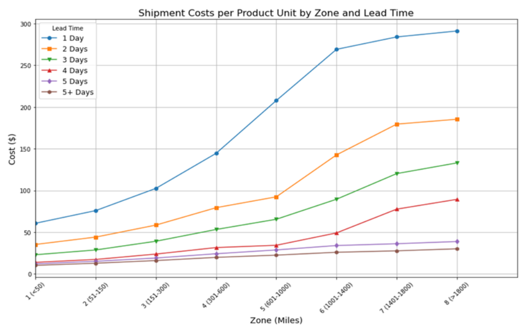

Figure 7: Shipment cost by zone and promised OTD Lead Time

	Promised Order-To-Delivery Lead Time (days)					
Zone (*miles*)	1	2	3	4	5	5+
1 (*<50*)	$60.71	$35.30	$22.97	$13.86	$12.07	$10.25
2 (*51-150*)	$75.89	$44.13	$28.71	$17.33	$15.09	$12.81
3 (*151-300*)	$102.53	$58.52	$39.15	$23.77	$19.05	$15.97
4 (*301-600*)	$144.55	$79.37	$53.25	$31.57	$24.15	$19.81
5 (*601-1000*)	$207.84	$92.39	$65.49	$34.31	$28.73	$22.49
6 (*1001-1400*)	$269.21	$142.65	$89.50	$49.12	$34.00	$25.92
7 (*1401-1800*)	$284.08	$179.54	$120.24	$77.63	$36.17	$27.65
8 (*>1800*)	$291.21	$185.41	$133.04	$89.36	$38.81	$30.07

Table 2: Shipment Costs (per product unit)

Task 5

Based on the provided information and the proposed solution for task 3, estimate the maximum achievable demand conversion rate in each market given the FCs assigned to it, for each potential OTD time promise options (from 1 to 5+ days). For each market and each option, estimate the induced total revenue assuming that the average selling price of a product unit is $300, the total shipping cost, the net revenue (revenue – shipping cost), and the gross operating profit (net revenue – cost of goods sold (COGS) excluding AF-DC-FC capacity costs and DC & FC replenishment costs) assuming a COGS of $75 per unit including the cost of raw materials and production. Plot and discuss your results.

Task 6

Propose an optimized OTD time promise for each market, with aim to maximize expected overall gross operating profit. Document and justify your optimization model or heuristic algorithm. Compute the resulting expected revenue, shipping cost, net revenue, and gross operating profit in each market and overall. Contrast with the two extreme solutions corresponding to offering 1-day service to all and offering 5+-day service to all.

Discovery and Hypothesis Set 4: Robust Autonomy Targeting

- HelpBots aims for each FC to maintain a 4-week-99% target autonomy stock. This signifies that it aims to have at least enough inventory at all times to robustly cover without replenishment the 99% optimistic forecasted demand over the next 4 weeks, aiming not to have more stock than required by this target. This automony target, expressed in time (weeks) at a given robustness (%), implies a target inventory that dynamically evolves on a daily basis depending expected seasonality, growth, and uncertainty.
- HelpBots aims to maintain a 6-week-99% target autonomy stock in its overall fulfillment and distribution network (FCs+DC), adjusted dynamically on a daily basis. Given the above bullet, the complementary inventory is intended to be held at the DC.

Task 7

Estimate the stock to be maintained in each FC in the fulfillment network for each day in the planning horizon given the 4-week-99% target autonomy, building on the results from the previous tasks. Compute the estimated maximum inventory over the planning horizon induced by the target autonomy policy at each FC and over the fulfillment network.

Estimate the stock to be maintained in the overall fulfillment and distribution network for each day in the planning horizon given the 6-week-99% target autonomy. Accounting for the stock expected to be maintained in each of the FCs according to their autonomy policy, estimate the stock to be maintained in the DC for each day in the planning horizon to ensure there is enough inventory in the network to respect the 6-week-99% target autonomy.

Contrast these results with those induced by an autonomy robustness of 50, 68%, and 95% rather than 99%. Discuss your results.

Task 8

Given the results of task 7, estimate the daily production capacity requirements at the assembly factory if it is to feed the DC with additional products daily to ensure that it reaches the stock level enabling respect of the 6-week-99% autonomy target. Estimate the maximal daily production capacity required over the planning horizon.

As an alternative, consider the case where HelpBots aims to have a steady production rate at the AF over the year. This will cause HelpBots to inject in the DC inventory beyond what is required by the robust 6-week-99% network-wide autonomy target policy, so as to absorb the smoothing induced anticipatory production.

Compare the AF production and DC storage capacity requirements under these two production strategy alternatives.

Discovery and Hypothesis Set 5: Network Replenishment

- HelpBots is considering utilizing a third-party logistics service provider (LSP) to manage replenishment of the fulfillment network. This enables HelpBots to not be constrained by its fleet of trucks, rather utilizing the LSP's network and gain consolidation benefits. HelpBots and the LSP have reached an agreement on the shipment costs, with the condition that a minimum 10% of a full-truck-load (FTL) (*32 product units, based on product and trailer dimensions*) must be shipped. The replenishment shipping costs per unit are provided in the following Table 3.

Zone *(miles)*	**Replenishment Shipment Cost**
1 *(<50)*	$4.83
2 *(51-150)*	$6.04
3 *(151-300)*	$7.62
4 *(301-600)*	$9.66

Zone *(miles)*	**Replenishment Shipment Cost**
5 *(601-1000)*	$11.49
6 *(1001-1400)*	$13.60
7 *(1401-1800)*	$14.47
8 *(>1800)*	$15.52

Table 3: FC Replenishment Shipment Cost (per product unit)

- The LSP, through its network of truckers, is able to swap drivers and/or trailers to achieve faster shipment durations, respecting the daily driving limit for truckers in the US. For simplicity, consider that shipments progress at a velocity of 500 miles/day, and an additional number of hours for consolidation and distribution. For your ease, Table 4 provides the time at which replenishments have arrived and are available to fulfill customer demand.

FC ID	Value
FC-GA-303	T
FC-NY-134	T+2
FC-TX-799	T+3
FC-UT-841	T+4

FC ID	Value
FC-AZ-852	T+4
FC-CA-900	T+4
FC-CA-945	T+5
FC-CO-802	T+3
FC-FL-331	T+2

FC ID	Value
FC-IL-606	T+2
FC-MA-021	T+2
FC-MI-481	T+2
FC-NC-275	T+1

FC ID	Value
FC-NJ-070	T+2
FC-TX-750	T+2
FC-TX-770	T+2
FC-WA-980	T+5

Table 4: FC Replenishment Durations
(Value denotes day on which replenishments are available in FC, when shipped from DC-GA-303 on day T)

- To respect the FC autonomy targets and to avoid any potential stock-out situations, while minimizing overstock situations, HelpBots proposes an FC replenishment algorithm using a combination of replenishment interval and robust autonomy threshold, in line with the previous hypotheses and tasks. Its essence is hereafter described through an example. Consider an FC with a 7-day replenishment interval and 14-day minimum robust autonomy threshold. The algorithm tracks the current robust autonomy days of the FC on a daily basis, i.e. the number of days till the FC will stock-out considering its pipeline inventory (on-hand inventory + replenishments enroute if any) and the upper 99% demand forecast over the forthcoming days, assuming no more replenishments are provided to the FC. When the robust autonomy days fall below 14 days, a replenishment is triggered which is the maximum of (4-week-99% autonomy target inventory – pipeline inventory) and 10% FTL (32 units). If the minimum robust autonomy days threshold is not breached on any given day during the

7-day replenishment interval, a replenishment decision is triggered on the 7th day from last shipment following similar replenishment quantity logic as described above (leading or not to a replenishment).

Task 9

Based on the solution of your tasks so far, and considering a 7-day replenishment interval and 14-day minimum robust autonomy threshold, estimate the profile of daily replenishment quantities over the planning horizon for each FC.

Then, estimate the throughput capacity required for each FC and the DC. The throughput capacity is defined as the maximum capacity to handle both inbound and outbound movement in a single day. Estimate the throughput capacity required at each FC and DC to robustly support replenishments and customer order fulfillment, in product units, over a 1-year planning horizon. For the inbound DC throughput capacity, contrast the requirements for the two production strategy alternatives.

Task 10

Based on the replenishment shipment durations, estimate the replenishment parameters (replenishment interval, minimum robust autonomy days threshold) for each FC. The idea is to model parameters such that the replenishment quantities are not frequently bumped up to 10% FTL, yet ensuring stock-out probability is not compromised.

Submission of tasks 1 to 10 deliverables enables access to the simulator and documentation necessary to engage in Phase 2.

Phase 2: Simulation-Based Holistic Analysis and Planning

The details of the nine simulation-based experiential levels of this second phase will be revealed gradually as each team progresses from level to level, in online gaming fashion. This is why this phase's tasks 11 to 13 are hereafter expressed in a succinct way.

Task 11
Complete the various levels in the simulator, being mindful of the level-specific deadlines, and allowing enough time to test various strategies and conducting sensitivity analysis. It is worth testing for various robust inventory autonomy targets, and adjusting the decisional parameters as outlined in above tasks.
Utilize the simulator to test your initial solutions for the above tasks, and contrast with Investigate the various plots in the simulator, and provide your interpretation of the information displayed. Discuss how this information enabled you as the decision-makers to adjust the various decisional parameters.

Task 12
Investigate the various dashboards (including tables, plots, and maps) in the simulator in detail, and provide your interpretation of the information displayed. Discuss how this information enabled you as the decision-maker to identify the best set of decisional parameters.

Task 13
Synthesize your key learnings from realizing this casework and provide a detailed feedback and recommendations on the simulator leveraged in this casework.

We hope this casework proves to be a challenging, stimulating, and worthwhile learning experience.

Benoit Montreuil, Ashwin Pothen and Xiao Huang

Appendix 1. Basic Financial information

- *Revenue - $300 for each unit of product demand fulfilled*

- *Production*
  - *Cost of raw materials: $60 per unit produced*
  - *Cost of production equipment utilization: $15 per unit produced*

- *Production Capacity*
  - *Operation and maintenance cost of contracted capacity: $10 per unit per day*
  - *One-time capacity setup or increase - $140 per unit increase, $0 when decreased*

- *Storage Capacity*
  - *Operation and maintenance cost of contracted capacity: $0.66 per unit per day*
  - *One-time capacity setup or increase - $4.62 per unit increase, $0 when decreased*

- *Throughput Capacity*
  - *Operational cost of handling throughput movement - $2.5 per unit of utilized capacity*
  - *Operation and maintenance cost of contracted capacity: $0.36 per unit per day*
  - *One-time capacity setup or increase - $2.52 per unit increase, $0 when decreased*