Casework 1.1
BotWorld's Export-to-Europe Supply Chain Design

Assessing the Value of Physical Internet Enabled Hyperconnected Logistics & Transportation

ISYE 6339 Physical Internet Engineering

Professor Benoit Montreuil
Ph.D. Candidate Ashwin Pothen

To be realized in teams of two to three students
Grading does not account for the number of students

20 Points

Due on March 5, 2026

For each task and subtask, it is important to identify the team members having actively contributed to its realization, as this is to be used for individual student grading, except if all team members explicitly and unanimously indicate that they prefer an identical grade for all team members. See course syllabus for details.

The BotWorld[1] company has had in recent years huge success in North America with its MyBot consumer-focused domestic robots. The MyBot product line includes six categories: F – Floor Care, K – Kitchen Help, L – Leisure, S – Safety & Security, W - Wall and Window Care, X – Exterior Care. MyBot products are offered in four capability levels, respectively labeled 10, 20, 30 and 50.

Building on its US momentum, BotWorld plans to launch its consumer-centric MyBot robotic product line in the European Union through online e-commerce. Its strategic market deployment roadmap is currently planned to be as follows in terms of countries:

- 2027: Belgium, Germany, Luxembourg, Netherlands,
- 2028: Denmark, Estonia, Finland, Latvia, Lithuania, Norway, Poland, Sweden
- 2029: Austria, France, Ireland, Italy, Portugal, Spain, Switzerland
- 2030: Bulgaria, Croatia, Republic of Cyprus, Czech Republic, Greece, Hungary, Malta, Romania, Slovakia, Slovenia

[1] Fictitious company created for the sole purpose of developing this academic casework

Model-focused market studies lead BotWorld to set target prices and demand expectations as follows:

Model	Demand Share			Target Market Price (Euros)
	Minimum	Most probable	Maximum	
F10	10%	17%	20%	360
K10	5%	13%	18%	360
S10	5%	10%	15%	360
W10	5%	9%	15%	360
F20	4%	8%	12%	480
K20	3%	6%	10%	480
L20	3%	5%	10%	480
S20	2%	5%	10%	480
W20	2%	4%	8%	480
X20	2%	4%	8%	480
F30	2%	3%	8%	600
K30	1%	3%	6%	600
S30	1%	3%	6%	600
W30	1%	2%	6%	600
F50	0.50%	2%	6%	720
K50	0.50%	2%	4%	720
L50	0.50%	1%	4%	720
S50	0.50%	1%	4%	720
W50	0.50%	1%	4%	720
X50	0.50%	1%	4%	720
All Models		100%		

Based on BotWorld's successful progression in America and Asia, and its European marketing studies, the company expects demand for its MyBot products in each of its targeted markets to be evolving as follows, assessed in units per year expressed as the percentage of the population in the targeted market (absolute for first year, then yearly marginal increments):

Year	Optimistic (99%)	Most Probable	Pessimistic (99%)
1	0.05%	0.025%	0.02%
2	+0.025%	+0.02%	+0.01%
3	+0.02%	+0.01%	+0.005%
4+ (yearly)	+0.01%	+0.005%	-0.002%

Consumers are expected to order any day of the week, with the following probability: Mo 12%, Tu 12%, We 23%, Th 25%, Fr 15%, Sa 10% and Su 3%. This said, the demand for MyBot products is forecast to be subject to seasonal fluctuations. The average four-week period demand share is expected to be respectively about 0.05; 0.07; 0.09; 0.09; 0.09; 0.05; 0.04; 0.06; 0.13; 0.09; 0.06; 0.07; 0.11. The first period starts on the first full week in January of the year. BotWorld estimates demand shares to be

Normally distributed around the period-specific average with a coefficient of variation of 25%, with the total periodic shares constrained to equal 100%. Beyond the four-week demand shares estimated above, the demand for MyBot products is to be boosted by peak sales in the Cyber week period from Black Friday to Cyber Monday which is expected to account for 15% of the yearly demand by itself[2]. This peak-period demand boost is to be in terms of product units, yet prices are expected to be lowered in these days by about 15% to attract buyers.

BotWorld's marketing team wants you to assume their European market to be targeting each of the metropolitan areas in each country, then consider the rest of the country as a secondary market. So, for BotWorld, think a country's market to be equal to the sum of its metropolitan markets plus the non-metro market. In this vein, it recommends for you to use the following population tables for market estimation to simplify your work in this short mandate. First, for country-level population estimates use the table at https://worldpopulationreview.com/countries, using the yearly change column for future-year projections. Second, for estimating the population of metropolitan areas, use the table at https://worldpopulationreview.com/cities/continent/europe and use the country's yearly change ratio for future-year projections. The non-metro population should be estimated by complementary computations.

BotWorld is aware that e-commerce clients have become ever more sensitive to order-to-delivery times. Even though their products are top class, they will be subject to such time sensitivity. So, its marketing team requires you to assume that all across Europe, customers desiring to acquire a MyBot will indeed do so with a probability that is function of the order-to-delivery time reliably promised by BotWorld, according the following Table.

OTD Days Promise	(Days)	0 (Same-Day)	1	2	3-4	5-7	8-15	16-30	31-60
Customer Probability	Metro	100%	95%	85%	65%	40%	20%	10%	5%
of Purchase	Non-Metro	100%	99.5%	98%	90%	70%	30%	15%	7.5%

Here is your first task set from BotWorld.

Task 1: Market Demand Forecast & Scenario Generation

1. *Based on statistics and forecasts publicly available on Internet, estimate the 2027-2034 population of targeted countries and capitals, metropolitan areas.*
2. *In line with the targeted market deployment roadmap, forecast the expected annual demand for the entire product line and for each product, in each targeted territory, in units and in euros, assuming same-day delivery offering.*
3. *Expand the annual forecasts from task 1.2 into more granular weekly and daily global and model-specific demand over the 2027-2034 horizon.*

---

[2] The expected demand shares for the 4-week periods spanning the Black Friday to Cyber Monday period do not include the demand shares of peaks days.

4. *Develop a daily demand simulator for BotWorld's expansion in Europe, in line with the uncertain forecasts from task 1.3.*
5. *Improve your simulator so that (1) it accepts as input a scenario stating the highly reliable order-to-delivery (OTD) time to be offered to every client, delineated for each metro area and non-metro region within each country in each year, (2) models customer probability of purchase given the OTD offering, and (3) transforms generated daily demand in daily sales predictions.*
6. *Use it to generate alternative scenarios of daily demand and sales for the 2027-2034 horizon with instances of daily demand and sales for each model. Contrast this set of scenarios with expected demand and sales estimates, notably leveraging heatmaps and time-series plots (e.g. boxplots).*
7. *Synthesize the key facts and insights to BotWorld derived from your analysis of market demand and sales forecasts.*

BotWorld wants you now to focus on this first operating scenario:

1. BotWorld making its Euro-regulation-adapted MyBot domestic robots in its to-be-expanded factory in Metro Atlanta in the USA, at a regular steady pace through each year.
2. BotWorld storing the MyBot robots and containerizing them in 6m or 12m dedicated containers for shipment in its to-be-acquired export deployment center in the export-import distribution center park in Savannah, Georgia
3. BotWorld shipping the containerized MyBots through the Savannah port to the Rotterdam port in the Netherlands, then directly to one of four BotWorld's European deployment centers to be put in operation intime for each of the four market expansion phases
4. BotWorld shipping each consumer-ordered MyBot to the appropriate hub of the delivery service provider responsible for last-mile delivery to the consumer's residence within the consumer's metro area or non-metro region within the customer's country.
    a. Metro service providers promise 99% of deliveries to clients within 24, 12, and 8 hours of receiving the packages at their hub, respectively in metro areas with population of [1M,+], [250K-1M), and of [-, 250K).
    b. Non-metro service providers promise 99% of deliveries to clients within 24, 48, and 72 hours of receiving the packages at their hub, respectively in within-country non-metro regions within 250 km, 500 km, and beyond, from their hub (assume they have hubs near every metro area and near the country borders along the main roads).

Task 2: European Deployment Center Network & Reachable Market Demand Estimation

Accounting for the facts that (1) each Euro DC will be fed directly from containers shipped from Savannah, Ga, USA, through the Port of Rotterdam, (2) one DC will be added each year from 2026 to 2029, (3) each metro and non-metro market will be assigned to a specific DC each year, (4) direct truck-based shipment of customer orders with an 11-hour max driving limit per 24h, concurrently perform the following sub-tasks:

1. *Propose a location for each European deployment center, justifying rigorously your (heuristically) optimized propositions*
2. *Estimate the robustly achievable OTD times WorldBot can promise to each metro & non-metro market, and the induced reachable demand in each market*
3. *Use your simulator to generate realizable demand scenarios and contrast with the results of task 1.*

Hereafter are described sets of technical information that you are to work with while addressing this scenario.

First, here is more about the product dimensions while traveling across the supply chain from factory to customers. Once assembled, BotWorld factory is to pack its MyBots in packages, and then over-protect them by packing them in shipping boxes. material. The packages and boxes are not planned to be reusable, yet they are to be recyclable. The volumetric dimensions of the packages and boxes are listed in the following Table for each MyBot, as well as their total weight including the product and packaging.

When palletized, MyBot boxes are planned to be placed, stacked two-high max, on single-MyBot-model pallets having one of the following ISO-standard sizes:

- Wooden pallet – 3 runner: [1200 x 1200 x 154] mm^3
- Perimeter wooden pallet: [1200 x 1000 x 154] mm^3

Two pallets may be stacked above each other in a container, trailer, or truck cargo space during inter-site transportation as long as:

1. The container/carrier space allows forklift handling
2. The loaded pallet heights do not exceed the available height
3. The lower pallet is made of layers with products having all the same height
4. Each of the layers of the lower pallet is mostly fully filling the pallet's horizontal space.

MyBot		Packaged dimensions				Shipping box dimensions			
Category	Model	Length (cm)	Width (cm)	Height (cm)	Weight (kg)	Length (cm)	Width (cm)	Height (cm)	Weight (kg)
Floor Care	F10	40	40	30	15	55	55	50	19
	F20	40	40	30	15	55	55	50	19
	F30	48	40	30	20	65	55	50	25
	F50	53	44	30	25	70	60	50	32
Kitchen Help	K10	32	25	28	8	50	40	50	12
	K20	32	25	28	8	50	40	50	12
	K30	36	28	28	10	55	45	50	15
	K50	42	30	28	12	60	45	50	18
Leisure	L20	45	23	30	12	60	40	50	18
	L50	45	33	30	16	60	50	50	20
Safety & Security	S10	56	26	33	18	70	40	55	22
	S20	56	26	33	18	70	40	55	22
	S30	56	32	33	20	70	45	55	25
	S50	56	38	33	23	70	55	55	29
Wall & Window Care	W10	30	30	25	8	45	45	45	12
	W20	30	30	25	8	45	45	45	12
	W30	40	30	25	9	55	45	45	14
	W50	40	40	25	11	55	55	45	16
Exterior Care	X20	50	55	40	35	65	70	60	43
	X50	60	65	45	50	75	80	65	60

Second, production wise, BotWorld aims in this scenario to expand the capacity of its Metro Atlanta factory so that it may assemble all the Euro-market MyBots. As it is doing for its US market, BotWorld plans to smooth overall production to a steady daily quantity of all MyBots produced from each of two clusters of MyBot categories:

1. Floor Care, Kitchen Help, Leisure
2. Safety & Security, Wall & Window Care, and Exterior Care

For example, this means that BotWorld wants to freeze the assembled quantity of MyBots from Cluster 1 assembled in every workday of a year. Mix variability is accepted between MyBot categories within a cluster, as they will share the same capacity, assembled in the same center. This induces the need to store finished MyBots to prevent stockouts in high-demand periods.

Workdays are seven days a week all year long, except for official US Holidays, so as to optimize use of factory assets.

European MyBot products are not to be stocked in the Atlanta factory. In fact, they will be palletized with MyBots of a single model per pallet, then daily shipped by truck or tractor-trailer. Operationally, once assembled a MyBot is immediately palletized, then as soon as the pallet is full, it is put in the truck or trailer, and as soon as the truck or trailer is full, it is shipped to the Savannah Export Deployment Center. This pattern keeps on repeating every day along the planning horizon.

Each deployment center is currently planned to use pallet racks capable of holding N<6 pallet high, with picking of MyBot packages from pallets allowed only on ground-level pallets in the racks. You are given degrees of freedom on their overall high-level design.

Third, appendix A provides technical details about the types of trucks and tractor-trailers privileged by BotWorld in the USA and in Europe.

Four, appendix B provides multiple cost estimates.

Task 3: US-Based Production, Inventory, and Transport Flow Projections

Note: Autonomy of d-days at r%-robustness denotes that the available inventory can satisfy all upcoming demand for d-days with r% probability, under demand and supply uncertainties.

1. *Building on your results from task 2, estimate the 99%-robust steady daily production rate and capacity to be planned for each category cluster as well as how many days ahead in the previous year should production of a given year's products be started to keep a steady rate once assembly is launched while avoiding stockout, if pertinent, assuming BotWorld wants to maintain a target autonomy of 12 weeks at 99% for each of its products globally over the entire downstream supply chain.*
2. *Enhance your simulator to enable validating the feasibility of your projections above, working only with the overall inventory of each product in the network without yet modeling how many units will be in each day, assuming the inventory would be deployed smartly.*
3. *Estimate how many units of each specific product can be put on a pallet layer, depicting the loaded pallet layer layout. Then estimate how many units of each specific product can be put on a single-product pallet, respecting height considerations, again depicting layouts to validate feasibility.*
4. *Enhance your simulator to enable computing how much volume and weight of each product-specific packages, boxes, and pallets are to be shipped every day out of the factory, and how large a fleet of trucks and/or tractor-trailers (as described in Appendix A) will be necessary to support these daily flows between the Atlanta factory and the Savannah DC. Cross-validate these estimations with rough-cut analytical estimations.*

The logic guiding the dynamic deployment of MyBots across the network is as follows. First, stock will reside for a significant time only at (1) the Savannah DC, (2) in-transit between Savannah and Rotterdam ports, (3) at each of the regional Euro DCs (the number expanding from 1 to 4 in the first four years and then stabilizing).

Daily input into the Savannah DC for each of the four clusters is globally pushed by the factory. Its mix is to be pulled by Savannah DC based on the current deviation of its inventory of each product from autonomy target for each product. The output from Savannah DC to the port is pulled by each of the regional Euro DCs, based again on product-specific deviation from their target autonomy, with agglomerated sets of MyBot units fitting as full as possible in a 6m or 12m container.

Assume that (1) the end-to-end journey time from arrival at Savannah port to exiting Rotterdam port is in average 17 days, optimistically 13 days and pessimistically 21 days; (2) the frequency of ship departures from Savannah to Rotterdam is about once every 2 to 4 days; and (3) the journey cost for a 6m container has a median of 2500$, with a range between 2000$ and 4000$. Further assume that containers arriving at the Savannah port will be loaded in the next arriving ship aiming toward the Port of Rotterdam.

Assume that truck-based journey times from the Port of Rotterdam to a Euro DC as well as those from an Euro DC to a metro or non-metro hub, are stochastic, approximated by a triangular distribution with the minimum, mode, and maximum are respectively 90%, 125%, and 200% of the travel time at speed-limit bounded at 100km/h max; to which should be added rest time-s if travel time exceeds 11 hours.

Autonomy setting protects about uncertainty and disruptions due to demand, supply, operations, environment, etc. There is an interplay between the autonomy targets of the Euro DCs, the Savannah DC, and the overall network. The individual DC targets must jointly balance. For example, if the network autonomy target is 90 days at 99% then WorldBot will always be aiming to have enough inventory in the network to meet this target, the inventory being spread among the four DCs. If each Euro DC targets only 30-day 99% autonomy, this means then that the Savannah DC will inherently end up with high realized autonomy and inventory. If alternatively, each Euro DC targets a 200-day 99% autonomy, then this could bounce up the realized network autonomy. Beyond the effects of interlacing autonomy targets on global inventory and each DC's inventory, the smoothed production requirements may get the network inventory high before peak periods and induce the realized network autonomy to be higher than targeted in some periods.

Task 4: Sales, Flows, Inventory, and Fleet Size Projections

1. *Based on your realized demand estimations from your simulations in tasks 2 and 3, estimate the flow of product-filled containers to shipped from the Savannah DC to each of the Euro DCs, with the expected mix distribution of products in these containers. From this flow estimation, estimate:*
    a. *The flow of MyBot-containers and MyBot-container-carrying ships departing from the Savannah ports daily/weekly*
    b. *The dedicated fleet size of tractors and chassis (container carrying trailers) robustly required to ship containers from the Savannah DC to the Savannah Port.*
    c. *The dedicated fleet size of tractors and chassis robustly required to ship containers from the Savannah Port to the Euro DCs.*
2. *Propose and justify a set of reasonable lower and upper bounds on the potential autonomy targets for the entire network and for each Euro DC, each in terms of days and robustness %. Then propose a specific autonomy target for the network and each Euro DC.*
3. *Extend your simulator to notably model for each day:*
    a. *The MyBots sales to clients as well as lost sales in each metro and non-metro market*

b. The ordered-MyBot shipments to metro and non-metro hubs from each Euro DC
c. The client-ordered-MyBots sales to clients and shipments to metro and non-metro hubs from each Euro DC
d. The replenishment requests (in containers, specifying how many of each MyBot models in each container) from each Euro DC to the Savannah DC
e. The loading of Euro-DC-requested MyBot-containers at the Savannah DC
f. The shipment of Euro-DC-requested MyBot-containers from the Savannah DC to the Savannah Port by dedicated tractors pulling the container-carrying chassis
g. The flow of empty dedicated tractors-chassis from the Savannah port to the Savannah DC.
h. The arrival of ships at Savannah Port that are heading toward the Rotterdam Port.
i. The loading of MyBot containers into specific ships at Savannah Port
j. The departure of ships from Savannah Port and their arrival at Rotterdam Port.
k. The unloading of MyBot containers from specific ships at Rotterdam Port
l. The arrival of empty dedicated trucks-chassis at Rotterdam Port
m. The loading of MyBot containers in specific dedicated trucks-chassis at Rotterdam Port
n. The Rotterdam-Port departure, transit, rest (as pertinent), and arrival Euro DC times for dedicated trucks-chassis
o. The replenishment arrivals of containers with a specific mix at each Euro DC
p. The inventory of each MyBot model at each Euro DC & the Savannah DC
q. The realized autonomy in terms of days for the targeted robustness % of each MyBot model at each Euro DC & the Savannah DC
r. The active trucker, truck, and chassis fleet size in Georgia
s. The active trucker, truck, and chassis fleet size in Europe

4. *Use your proposed autonomy targets from task 4.2 to test your simulator and to proceed to a thorough validation.*
5. *Assess for each year the dedicated fleet requirements in each continent, the storage and throughput requirements at each Euro DC and the Savannah DC. Proceed to an approximate design, sizing, and costing of each DC, specifying their main centers, processing activities and resources (e.g. number of racks of each height, number of dock doors, and number of workers).*
6. *Estimate the overall expected demand, revenues, and costs (capital and operating costs), and resulting expected marginal profitability. Use Appendix B for cost metrics. Any additional assumptions must be justified, providing your method and sources.*
7. *Assuming internal combustion engines for the trucks, estimate the energy consumption and greenhouse gas emissions.*

You must now assume that BotWorld is in a world where Physical Internet enabled hyperconnected transportation and logistic capabilities are now available. This has multiple impacts on its vision moving forward, leading to a new overall scenario. First, in this scenario, BotWorld is to be using Physical Internet modular reusable packaging containers (π-packs) with standardized side dimensions of 20, 30, 40, and 60 cm. These π-packs do not require supplementary packing/filling/protecting materials into boxes, contrary to what was assumed earlier. Furthermore, they do not require using pallets for consolidation as they can be snapped to each other to form consolidated composite pack containers, and their connectors allow grabbing and moving them without having ground clearance normally offered by pallets.

MyBot		Modular reusable PI-pack dimensions			
Category	**Model**	**Length (cm)**	**Width (cm)**	**Height (cm)**	**Weight (kg)**
Floor Care	F10	40	40	30	18
	F20	40	40	30	18
	F30	60	40	30	23
	F50	60	40	30	28
Kitchen Help	K10	30	30	30	10
	K20	30	30	30	10
	K30	40	30	30	12
	K50	40	30	30	15
Leisure	L20	60	20	30	15
	L50	60	30	30	18
Safety & Security	S10	60	30	30	20
	S20	60	30	30	20
	S30	60	30	30	22
	S50	60	40	30	26
Wall & Window Care	W10	30	30	30	10
	W20	30	30	30	10
	W30	40	30	30	12
	W50	40	40	30	14
Exterior Care	X20	60	60	40	40
	X50	60	60	60	55

Maritime transport containers (π-pods) have internal width of 2.33-2.35m, length 5.89 or 12m, and height of 2.38m, so BotWorld aims to ship composite π-boxes of 1.1 m or 2.2m in width and length, and height with modular stacked layers of the same dimensions or smaller values of 30, 40, 60, 80, or 90cm. Similar principles apply for long-haul truck/trailer transport.

Second, Europe and North America are both served by an open multi-tier network of logistic hubs spanning their entire territory and multimodal transport service providers flowing modular containers from origin to entre hub, between hubs, and from exit hub to destination. Even though the network is multimodal, within Georgia and Europe, BotWorld aims to privilege truck-based transportation. Botworld leverages π-hubs for directional consolidation modular containers and relay routing maximizing multi-shipper utilization of cargo space and decoupling truckers' rest time regulations from near-continuous flow of π-container transportation. For this study, BotWorld wants you to assume that the dwell time at each visited hub is one hour if only relay service is required and two hours if π-container consolidation is required.

Third, BotWorld aims to leverage combinations of the following containerized shipping options for its transportation of MyBots from Savannah to European DCs:

1. Ship MyBot π-packs encapsulated in a BotWorld-contracted PI transport container (π-pod).
   - In this option, Botworld loads the MyBot π-packs directly in the π-pod at its Savannah DC. Once filled and sealed, the π-pod is loaded on a tractor-pulled chassis and transported to the Savannah port by a contracted drayage transport service provider, then loaded in the prescribed ship to Rotterdam, subsequently unloaded from the ship in Rotterdam port and finally loaded on a tractor-pulled chassis for delivery to the Euro DC by a contracted hinterland transport service provider.
2. Ship MyBot π-packs grouped in composite PI handling containers (π-boxes) loaded in a shared π-pod.
   - With this option, BotWorld encapsulates MyBot π-packs in Euro-DC-specific π-boxes at its Savannah DC and loads these π-boxes, then get them shipped to the π-box transload center at the Savannah Port using π-box drayage services that span the Savannah territory. At the port's π-transload center, BotWorld's are custom-vetted then loaded in the next shared π-pod departing toward Rotterdam. In Rotterdam, the inverse process is performed at their π-transload center, reconsolidating them with other π-boxes directionally heading toward the π-hub near the Euro DC destination.

Fourth, in this PI enabled world, BotWorld is to deal for final delivery with metro and non-metro delivery service providers that have access to many more openly accessible tiered hubs as well as inter-hub transport and last-mile delivery options. Their OTD velocity is much better than in the original scenario:

1. Metro service providers promise 99% of deliveries to clients within 4, 2, and 1 hour-s of receiving the MyBot π-packs at their peri-urban hub, respectively in metro areas with population of [1M,+], [250K-1M), and [-, 250K).
2. Non-metro service providers promise 99% of deliveries to clients within 8, 16, and 32 hours of receiving the MyBot π-packs at their hub, respectively in within-country non-metro regions within 250 km, 500 km, and beyond, from their hub, assuming they have hubs near every metro and urban area and near the country borders along the main roads.

Fifth, as inter-DC mobility is facilitated by the hyperconnected transport and logistic network, BotWorld now allows inventory transfers between Euro DCs, resulting in lower autonomy requirements at each of these facilities.

Task 5: Hyperconnected Transportation

1. *Design and justify a network of open hubs and roadways that could be exploited by BotWorld to transport its MyBot products in Europe from port to its Euro DCs, between Euro DCs, and from Euro DCs to hubs at the periphery of each to-be-served metropolis and near country boundaries. The open hubs are to be assumed as already existing, serving other clients and having capacity to serve BotWorld. The network should facilitate relay transportation, daily shipments without requiring full truck loads, consolidation of transport with other shippers, and fast origin-destination travel without excessive extra distance.*

   Do not aim to design the full hyperconnected multi-tier logistic network at as fine granularity as illustrated in class for the US Southeast. Concentrate of ensuring the flows required for serving well Botworld's operations.

   Provide your proposed roadmap for the exploitation of the hyperconnected network, notably drawing the network hubs and inter-hub lanes to be leveraged in each year.

   You do not have to size hubs nor to estimate flows between hubs. This said, you must explain your reasoning and approach for designing the hyperconnected logistic network. You must also demonstrate clearly whether your design achieves the goals stated above.

2. *Estimate the space saving impact of using the π-packs and π-boxes instead of the original packages, shipping boxes, and pallets, in the different settings of this scenario. For example, how many MyBots can be loaded in a 6-meter transport container (π-pod)? Discuss your results.*

3. *Demonstrate whether, and if so how and how much, the designed European hyperconnected network reduce the transport times from Rotterdam port to each of the Euro DC, and from each Euro DC and the hubs used to connect with its served markets.*

4. *Demonstrate how a joint shipment including MyBots of different types and having NyBots destined to all Euro DCs would arrive at the Port of Rotterdam and then leverage the hyperconnected network to get all MyBots to their destination. Provide a very clear and specific illustrative example. Contrast with the original non-PI way. You may want to illustrate a few alternative ways depending on how they have been containerized in Savannah.*

5. *Estimate the robustly achievable customer-bound OTD to each metro and non-metro market from its preferred/nearest Euro DC, then estimate the demand that can be realized in each market through the 2027-2034 horizon.*

6. *Propose and justify a set of reasonable lower and upper bounds on the potential autonomy targets for the entire network and for each Euro DC, each in terms of days and robustness %. Then propose a specific autonomy target for the*

network and each Euro DC. Contrast with your recommendations for the non-PI scenario.

7. *Adapt your simulator developed for the non-PI scenario to model adequately the dynamic day-to-day impact of leveraging PI-enabled hyperconnected transportation over the 2027-2034 horizon. The simulator can be leveraged in providing answers to task 5.1 to 5.4 and 5.6.*
8. *Use your proposed autonomy targets from task 5.5 to test your simulator and to proceed to a thorough validation.*
9. *Assess for each year the total number of requested shipments and used trucks, the total distance traveled in the USA, on the Atlantic, and in Europe, as well as the induced transportation and logistics costs.*
10. *Assess for each year the storage and throughput requirements at each Euro DC and the Savannah DC. Proceed to an approximate design, sizing, and costing of each DC, specifying their main centers, processing activities and resources (e.g. number of racks of each height, number of dock doors, and number of workers).*
11. *Estimate the load on the transload centers in Savannah and Rotterdam, and the induced costs.*
12. *Estimate the overall expected demand, revenues, and costs (capital and operating costs), and resulting expected marginal profitability. Note that you are responsible for estimating any cost not explicitly mentioned in the casework description, providing your method and sources.*
13. *Assuming internal combustion engines for the trucks, estimate the energy consumption and greenhouse gas emissions.*
14. *Contrast your results from 5.9 to 5.13 for the PI scenario with those from task 4 for the Non-PI scenario. Discuss your key findings.*
15. *As all European ports are equipped to leverage the Physical Internet, would BotWorld benefit by backing away from imposing all transatlantic shipments to land at the Port of Rotterdam? Justify your answer.*

Task 6: Synthesis

1. *Provide an executive summary of your key findings and recommendations to WorldBot (2-page maximum)*
2. *Discuss your key learnings from realizing this casework (2-page maximum)*

We hope this casework will prove to be a highly valuable learning experience.

Advice:
Start early and work smartly as a team,
concurrently addressing tasks,
leveraging the capabilities of each team member,
and calibrating approaches and answers for the available time window.

Professor Benoit Montreuil and PhD candidate Ashwin Pothen

Appendix A: Ground Transportation Options

To standardize analysis and avoid unnecessary engineering complexity, you must use the following three generic truck archetypes (S, M, L) for Europe and the United States. These reference vehicles represent typical urban, regional, and long-haul freight equipment.

Europe

Truck Type	S - Small Urban Van	M - Medium Rigid	L - Articulated
Overall Length (m)	6	8.5–9.5	16.5
Cargo Volume (m^3)	10–14	35–45	85–100
Payload (t)	1.2–1.6	4–6	20–25
Fuel / Energy Use	9–11 L / 100 km	18–24 L / 100 km	28–33 L / 100 km
CO_2 Emissions	240–290 g / km	500–650 g / km	800–950 g / km
Expected Cost	€0.45 / km	€0.75 / km	€1.15 / km
Reference Image			

United States

Truck Type	S - Small Box / Van	M - Medium Straight	L - Tractor-Trailer
Overall Length	22–25 ft	28–33 ft	70 ft
Cargo Volume (m^3)	12–18	35–50	100–110
Payload (tons)	1.5–2.5	5–9	20–25
Fuel Economy	10–14 mpg	7–9 mpg	6–7 mpg
CO_2 Emissions	500–700 g / mile	900–1,200 g / mile	1,500–1,800 g / mile
Expected Cost	$0.60 / mile	$1.05 / mile	$1.75 / mile
Reference Image			

Appendix B: Cost and Financial Assumptions

This appendix defines all cost parameters to be used consistently by all teams when estimating revenues, costs, and operational profitability. Unless explicitly stated, all costs are operating costs (not accounting for depreciation).

1. **Revenue assumptions**
   Unit selling prices by MyBot model are provided in the main case description (page 2). Any demand that cannot be fulfilled due to customers' order-to-delivery time sensitivity, inventory, or capacity limitations is treated as lost sales, resulting in a complete loss of the associated revenue. Backorders are not permitted.
2. **Production Costs (Metro Atlanta Factory)**
   Assembly costs are modeled as a constant unit cost and are differentiated by product cluster. For MyBots belonging to Cluster 1 (Floor Care, Kitchen Help, and Leisure), the assembly cost is assumed to be 25% of selling price per unit. For MyBots belonging to Cluster 2 (Safety & Security, Wall & Window Care, and Exterior Care), the assembly cost is assumed to be 30% of selling price per unit. These costs include direct labor, factory utilities, quality control, and routine maintenance, but exclude packaging, transportation, and inventory holding costs.
   In addition to assembly, each MyBot incurs a packaging and protection cost of €15 per unit. This cost covers individual product packaging, overboxing for international shipment, and protective materials. Packaging is assumed to be non-reusable but recyclable and is applied uniformly across all products.
3. **Inventory Holding Costs**
   Inventory holding costs apply to all inventory present anywhere in the network, including the Savannah Export Deployment Center, in-transit inventory between Savannah and Rotterdam, and inventory stored at European Deployment Centers. Inventory holding costs are modeled using an annual holding rate of 20% applied to the unit production value of the product. This rate is intended to capture the cost of capital, insurance, shrinkage, obsolescence risk, and handling inefficiencies associated with holding inventory over time. Holding costs should be computed based on the average inventory level observed over the relevant period.
4. **Transportation Costs**
   All ground transportation costs within the United States and Europe must be computed using the generic truck archetypes and expected per-distance cost parameters provided in Appendix A. These costs are assumed to include fuel, drivers, routine maintenance, insurance, tolls, and regulatory compliance. Teams are responsible for selecting appropriate truck types (S, M, or L) based on payload, volume, and operational context, and for computing ground transportation costs as the product of distance traveled and the applicable per-mile (United States) or per-kilometer (Europe) cost. Delivery from

European deployment centers to delivery service providers hubs must be modeled as ground transportation as well.

Ocean transportation between the Port of Savannah and the Port of Rotterdam is performed using dedicated containers. Utilize the average shipping cost for a 6-meter container to be within a plausible cost range between $2,000 and $4,000 per container with a median at $2,500 per container, inclusive of port handling at both origin and destination. In-transit inventory during ocean transportation is subject to inventory holding costs.

In the PI scenario, transportation costs must be allocated to BotWorld proportionally to the share of container, vehicle, or modular transport capacity utilized by its shipments, reflecting shared consolidation with other shippers rather than dedicated full-load movements.

5. **Customer Delivery Costs from Delivery Service Provider Hubs**

   Last-mile delivery costs are modeled as constant per delivered unit, differentiated by metro size and non-metro distance tier. These per-unit costs are assumed identical in the Non-PI and PI scenarios, as the Physical Internet primarily affects upstream consolidation and transit times rather than doorstep delivery economics.

   Teams must apply the following per-unit delivery costs:
   a. Metro areas with population ≥ 1 million: €8 per delivered unit
   b. Metro areas with population 250 thousand to 1 million: €10 per delivered unit
   c. Metro areas with population < 250 thousand: €12 per delivered unit
   d. Non-metro regions within 250 km of the serving hub: €14 per delivered unit
   e. Non-metro regions within 500 km: €18 per delivered unit
   f. Non-metro regions beyond 500 km: €24 per delivered unit

   These costs include parcel handling, sorting, local transportation, and final doorstep delivery.

6. **Deployment Center Operating Costs**

   Deployment center operating costs apply to both the Savannah Export Deployment Center and all European Deployment Centers. Storage costs are modeled as a cost of €110 per pallet position per year, regardless of pallet height or rack configuration. This storage cost includes facility rent, racking infrastructure, and basic utilities.

   Each deployment center incurs a throughput capacity (setup) cost proportional to the maximum daily pallet throughput processed by the facility. This cost captures the standing resources required to sustain a given throughput (dock/yard capacity, material-handling equipment availability, labor scheduling readiness, systems capacity, and operational overhead associated with peak processing). Teams must compute pallet throughput capacity as the maximum daily total number of inbound pallets received plus outbound pallets shipped by the deployment center. The throughput capacity cost is €25 per pallet-throughput per year, applied to this pallet throughput capacity.

Handling costs are assessed on a per-activity basis. Each inbound pallet handled at a distribution center incurs a cost of €4, each outbound pallet incurs a cost of €5, and each unit picked for customer order fulfillment incurs a cost of €3 per unit. These handling costs represent labor and equipment usage associated with routine warehouse operations.

In addition to variable storage and handling costs, each deployment center incurs a fixed annual operating overhead. The Savannah Export Deployment Center has a fixed operating cost of €0.9 million per year, while each European Deployment Center incurs a fixed operating cost of €0.6 million per year. These fixed costs include site management, IT systems, security, maintenance, and administrative support.

7. **Fleet Costs (Dedicated Equipment)**

   For explicitly sizing and operating a dedicated transportation fleet, annual vehicle ownership/leasing costs must be accounted for separately and must be differentiated by truck size. Use the following annual fixed costs per vehicle:

   United States: Small (S) €18,000/year, Medium (M) €35,000/year, Large tractor-trailer (L) €95,000/year for the tractor plus €35,000/year per trailer/chassis.

   Europe: Small (S) €16,000/year, Medium (M) €32,000/year, Large articulated (L) €90,000/year for the tractor unit plus €30,000/year per trailer.

   If a fleet is not dedicated (i.e., transportation is fully contracted), teams should not add fleet fixed costs and should rely only on the per-distance costs of Appendix A. These costs include leasing, insurance, and maintenance. Driver costs are already embedded in the per-distance transportation costs and should not be double-counted.

8. **PI Scenario – Additional Packaging, Transload, and Hub Handling Costs**

   In the PI scenario, BotWorld uses reusable modular π-packs and may consolidate them into composite π-boxes and ship them in π-pods. To account for the cost of reusable packaging, assume each MyBot shipped in a π-pack incurs a packaging usage cost of €2.0 per unit shipped, capturing amortized container cost, cleaning, repositioning, and losses. The π-pack usage cost replaces the traditional €15 packaging cost defined for the non-PI scenario and must not be added to it. No supplementary shipping boxes, fillers, or pallets are used in the PI scenario.

   In the PI scenario, if BotWorld uses port transload centers (Savannah and Rotterdam) for π-box / π-pod crossdocking and directional consolidation, assume a transload handling cost of €1.5 per unit handled per transload center visited (i.e., a unit transloaded in Savannah and Rotterdam incurs €3.0 total).

   For hub relay and consolidation services in the hyperconnected network, assume an additional logistics service cost of €0.20 per unit per hub visited for relay-only and €0.40 per unit per hub visited when consolidation is required.

9. **Penalty and Opportunity Costs**
   Lost sales result in the full loss of the associated contribution margin, as no backordering or deferred fulfillment is allowed. Orders that are not placed due to excessive promised order-to-delivery times are treated as reduced demand and are already accounted for upstream in demand modeling. No additional penalty costs are applied beyond lost revenue, which is a key performance metric that must be carefully computed and optimized for.

10. **Energy/Fuel Consumption and Greenhouse Gas Emissions**
    Teams must estimate fuel consumption and CO_2 emissions using the truck archetype based on distance traveled, using the parameters in Appendix A.

11. **Operational Profit Definition**
    Teams must compute operational profit as total realized revenue minus all applicable production, packaging, transportation, inventory holding, distribution center operating, and fleet costs. In the PI scenario, operational profit must additionally include π-pack usage, transload handling, and hub relay/consolidation logistics costs defined in Section 8. Only costs explicitly defined in this appendix should be included. All analyses should clearly document assumptions and intermediate calculations.