Simplified Downstream (Mesoscopic)

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Sets

P set of ports that can import or export the fuel
R set of regions in the simulation
S set of ships that can be chartered in the simulation
M set of ship model types that can be chartered
T set of timesteps to simulate optimization model (monthly basis)

Parameters

$c^{PortCapacity}$ CAPEX for port on kg basis import NH3
$c^{PortStorage}$ CAPEX for port storage on kg basis NH3

$o_m^{ShipFixed}$ berthing fee for ship type m
$o^{PortCapacityFixed}$ Fixed OPEX for port on kg basis NH3
$o^{PortStorageFixed}$ Fixed OPEX for port storage on kg basis NH3

$o_m^{ShipVariable}$ Variable OPEX for ship type m (fuel costs and chartering costs per day)

b_m bulk size of ship model m (how much ammonia can it carry)

$d_{r,t}$ demand for fuel in region r at timestep t (positive for supply and negative for demand)

$l_{i,j}$ length (or distance) from port i to port j $\forall i \in P, j \in P \setminus i$

$i_{p,r}^{Region}$ indicator parameter on whether port p is in region r. If it is, value is 1, else, value is 0

δ speed of ships (assume all ship speeds are similar and constant)

n lifetime of ships (years to run simulation for)

i discount rate

g_{EY} equivalent lifetime of ship or port at NPV terms
(includes the discount rate and lifetime of ship/port).
$g_{EY} = \frac{(1+i)^n - 1}{i(1+i)^n}$

Decision Variables

$X_{s,i,j,t}$ amount of fuel to send on ship s from port i to port p at timestep t simulation
$\forall s \in S, i \in P, j \in P \setminus i, t \in T$

$Y_{s,m,i,j,t}$ whether to activate ship s as model m for route from port i to port p
at timestep t simulation (1-yes, 0-no)
$\forall s \in S, m \in M, i \in P, j \in P \setminus i, t \in T$

$FA^{Port}_{p,t}$ amount of fuel available at port p at time t
$\forall p \in P, t \in T$

$FL^{Storage}_{p,r,t}$ flow of fuel from port p to region r at time t
(can be negative which means region is supplying fuel to port,
or positive which mean the region has a demand for fuel)
$\forall p \in P, r \in R, t \in T$

$C^{Storage}_{p}$ capacity storage for port p (how much fuel can be held at the port) $\forall p \in P$
$C^{Transfer}_{p}$ capacity for import export of port p
(how much fuel can be moved through the port in a given timestep) $\forall p \in P$

Optimization Model

Objective

$$\min \quad CS^{Costs} + PS^{Costs} \tag{1}$$

where

$$CS^{Costs} = g_{EY} \sum_{s \in S} \sum_{m \in M} \sum_{t \in T} \sum_{i \in P} \sum_{j \in P \setminus i} (Y_{s,m,i,j,t}((2 * o^{ShipFixed}_{m} + (o^{ShipVariable}_{m}(\frac{l_{i,j}}{\delta})))) \tag{2}$$

$$\begin{aligned} PS^{Costs} = \sum_{p \in P} (C^{Storage}_{p}(c^{PortCapacity} + g_{EY} o^{PortCapacityFixed}) + \\ C^{Transfer}_{p}(c^{PortStorage} + g_{EY} o^{PortStorageFixed})) \end{aligned} \tag{3}$$

S.t.

$$\sum_{m \in M} \sum_{i \in P} \sum_{j \in P \setminus i} Y_{s,m,i,j,t} \leq 1 \qquad \forall s \in S, t \in T \tag{4}$$

$$X_{s,i,j,t} \leq \sum_{m \in M} l_{i,j} Y_{s,m,i,j,t} b_m \qquad \forall s \in S, i \in P, j \in P, t \in T \tag{5}$$

$$\sum_{s \in S} \sum_{j \in P \setminus i} (X_{s,i,j,t}) \leq FA^{Port}_{i,t} \qquad \forall i \in P, t \in T \tag{6}$$

$$\sum_{r \in R} (i^{Region}_{i,r} FL^{Storage}_{i,r,t}) \leq FA^{Port}_{i,t} \qquad \forall i \in P, t \in T \tag{7}$$

$$\sum_{s \in S} \sum_{j \in P} (X_{s,j,i,t} + X_{s,i,j,t}) \leq C^{Transfer}_{i} \qquad \forall i \in P, t \in T \tag{8}$$

$$FA^{Port}_{p,t} \leq C^{Storage}_{p} \qquad \forall p \in P, t \in T \tag{9}$$

$$FA^{Port}_{p,t} = FA^{Port}_{p,t-1} - \sum_{r \in R} i^{Region}_{p,r} (FL^{Storage}_{p,r,t-1}) + \sum_{s \in S} \sum_{i \in P} (X_{s,i,p,t-1} - X_{s,p,i,t-1})$$
$$\forall p \in P, t \in T, FA^{Port}_{p,0} = 0 \tag{10}$$

$$\sum_{p \in P} i^{Region}_{p,r} (FL^{Storage}_{p,r,t}) = d_{r,t} \qquad \forall r \in R, t \in T \tag{11}$$

$$Y_{s,m,i,j,t} \in \{0, 1\} \qquad \forall s \in S, m \in M, i, j \in P, t \in T \tag{12}$$

All other decision variables are non negative reals

Objective and Constraint Explanations

1. Minimize cargo ship costs and port costs

2. Ship costs are equal to fixed operation costs (both at home port and destination port-thus the 2*) + variable operation costs (which is really fuel and chartering cost and depends on the route served by length divided by speed of ship-number of days). All costs discounted into the future as it is represented as one model year

3. Port costs are equal to CAPEX constructions costs (port capacity costs) + fixed operation costs (for both capacity and storage segments-discounted into future)

4. Ship charter definition: can only select at max 1 model to charter for each ship across all routes at a timestep

5. Ship charter for flow requirement: the flow from one port to another via ship s can only occur if the two ports are connected by an edge, you put a ship on that route for the specific model and have some upper capacity (for that model).

6. Max ship flow: must have enough fuel at start of month to send out on ships

7. Max port flow: must have enough fuel at start of month to deploy from storage and meet demand

8. Port Import/Export Capacity definition: port must be large enough to handle total inflows and outflows from ships

9. Capacity Storage definition: port capacity must be large enough to contain available fuel

10. Fuel available port definition: current fuel available equal previous supply + any demand flow changes + any ship flow changes

11. Meet demand rule: fuel flowing out of or into storage must be equal to demand.

12. Bound constraints: listed decision variables are binary and all other decision variables are non negative reals