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 built in the simulation
M set of ship model types that can be built
T set of timesteps to simulate optimization model (monthly basis)

Parameters

c_m^{Ship} CAPEX for ship model m
$c^{PortCapacity}$ CAPEX for port on kg basis import NH3
$c^{PortStorage}$ CAPEX for port storage on kg basis NH3

$o_m^{ShipFixed}$ Fixed OPEX 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)

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

$B_{s,m}$ whether to build ship s in simulation as model m (1-yes, 0-no) $\forall s \in S, m \in M$

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

$Y_{s,i,j,t}$ whether to activate ship s route from port i to port p at timestep t simulation (1-yes, 0
$\forall s \in S, i \in P, j \in P \setminus i, t \in T$

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

$FL_{p,r,t}^{Storage}$ flow of fuel from port p to region r at time t (can be negative which means region i
$\forall p \in P, r \in R, t \in T$

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

Optimization Model

Objective

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

where

$$CS^{Costs} = \sum_{s\in S}\sum_{m\in M}(c_m^{Ship}B_{s,m} + g_{EY}(o_m^{ShipFixed}B_{s,m}+ \\ \sum_{p\in P}\sum_{p\in P\setminus i}\sum_{t\in T}(o_m^{ShipVariable}(2\frac{l_{i,j}}{\delta})X_{s,i,j,t})) \tag{2}$$

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

S.t.

$$\sum_{m\in M} B_{s,m} \leq 1 \qquad \forall s \in S \tag{4}$$

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

$$\sum_{i \in P} \sum_{j \in P \setminus i} Y_{s,i,j,t} \leq 1 \qquad \forall s \in S, t \in T \tag{6}$$

$$X_{s,i,j,t} \leq l_{i,j} Y_{s,i,j,t} \sum_{m \in M} b_m \qquad \forall s \in S, i \in P, j \in P, t \in T \tag{7}$$

$$\sum_{s \in S} \sum_{j \in P \setminus i} (X_{s,i,j,t}) + \sum_{r \in R} i_{i,r}(FL^{Storage}_{i,r,t}) \leq FA^{Port}_{i,t} \qquad \forall i \in P, t \in T \tag{8}$$

$$\sum_{s \in S} \sum_{j \in P} (X_{s,j,i,t} + X_{s,i,j,t}) \leq C^{Transfer}_i \qquad \forall i \in P, t \in T \tag{9}$$

$$FA^{Port}_{p,t} \leq C^{Storage}_p \qquad \forall p \in P, t \in T \tag{10}$$

$$\begin{aligned} &FA^{Port}_{p,t} = FA^{Port}_{p,t-1} - \sum_{r \in R} i_{p,r}(FL^{Storage}_{p,r,t-1}) + \sum_{s \in S} \sum_{i \in P} (X_{s,i,p,t-1} - X_{s,p,i,t-1}) \\ &\forall p \in P, t \in T, FA^{Port}_{p,0} = 0 \end{aligned} \tag{11}$$

$$\sum_{p \in P} i_{p,r}(FL^{Storage}_{p,r,t}) = d_{r,t} \qquad \forall r \in R, t \in T \tag{12}$$

$$\begin{aligned} &B_{s,m}, Y_{s,i,j,t}, i^{Region}_{p,r} \in \{0,1\} \\ &\forall s \in S, m \in M, t \in T, p \in P, r \in R \end{aligned} \tag{13}$$

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 CAPEX construction costs (depends on model type) + fixed operation costs (discounted into the future) + variable operation costs (which depends on which routes served over the year and also discounted into future)
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 build definition: can only select at max 1 model to build for each ship
5. Ship built for flow requirement: you must build a ship in order to use it for flow
6. Ship port route activation definition: can only have ship go on one route per timestep
7. Ship port route limit: if you go on a route then it must be activated and connected
8. Max flow out: fuel sent out and deployed to meet demand must be less than fuel available at port
9. Port Import/Export Capacity definition: port must be large enough to handle total inflows and outflows from ships
10. Capacity Storage definition: port capacity must be large enough to contain available fuel
11. Fuel available port definition: current fuel available equal previous supply + any demand flow changes + any ship flow changes
12. Meet demand rule: fuel flowing out of or into storage must be equal to demand.
13. Bound constraints: listed decision variables are binary and all other decision variables are non negative reals