Liner shipping costs and logistics: a literature survey and taxonomy of problems

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Purpose of paper

- Focus on liner shipping logistics
- Review relevant references
- Present a taxonomy of problems.

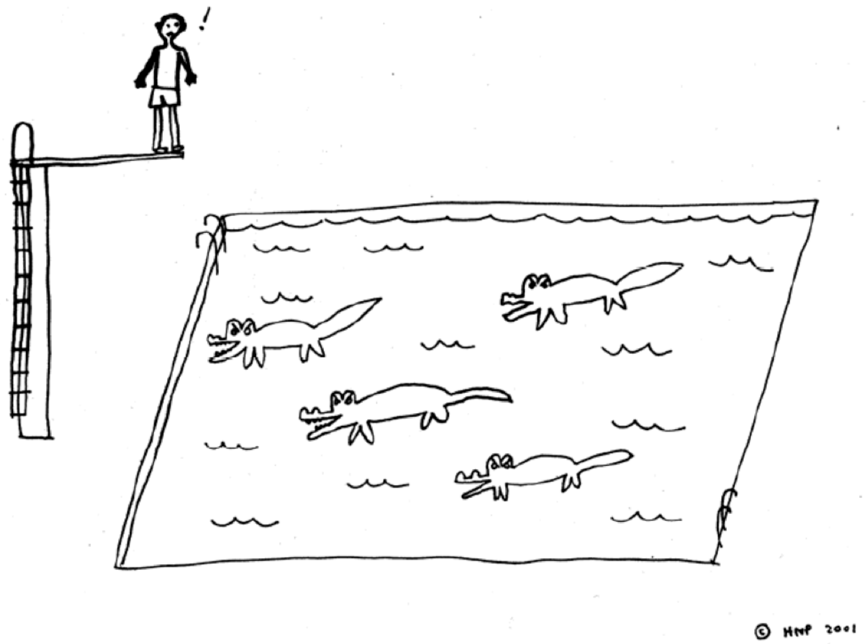
Specifically

We focus on two major areas:

- Area A: liner shipping costs
- Area B: OR/MS applications related to liner shipping logistics

From a port CEO:

“negotiating with container lines is like being thrown into a pool full of alligators”



Excluded:

- Port & terminal management problems
- Port tariff & pricing problems

(even though these problems are very much linked to those we examine!)

Connection between A & B =?

- structure of liner shipping costs impacts the modelling of OR/MS applications

- level of these costs is a function of whether and how much they are optimized

Area A: liner shipping costs

- Economies of scale suggest that as a container ship size increases:
  - ship is cheaper per ton to build
  - running costs per ton fall
  - operating costs per container-mile decrease
- Proof: mega-vessels (>20,000 TEU?)

But this is not universal

Things generally depend on

- vessel's purchase price
- average freight rate level
- average voyage lengths for the trade
- load factors
- ship specs related to
  - navigation channels along rivers
  - canals
  - port’s draft
  - port access channels
  - cargo handling facilities
- potential externalities imposed on components of the logistical supply chain, etc.

Liner cost components

- **Fixed costs**:

  independent of freight volume
  - vessel costs
  - equipment costs
  - bunker costs
  - port charges.

Estimates for a Trans-Atlantic route (Ting & Tzeng, 2003):

1. Fleet costs		**2. Container and chassis costs**	
Fleet : 5 vessels (2,000 TEU)		Hire	111,810
		Depreciation	54,493
Vessel hire (USD/day)	12,000	Insurance	3,361
Voyage days	35	Repair and maintenance	49,105
Total fleet cost per voyage	**420,000**	Container and chassis cost per voyage	**218,769**
3. Bunker costs		**4. Port charge**	
Distance (nautical miles)	11,730	Charleston	11,500
Average speed (knots)	17	Miami	11,500
Total steaming time (h)	643	Houston	11,500
Total steaming time (days)	26.8	New Orleans	11,500
A oil		Antwerp	30,000
A oil price (USD/ton)	143	Felixstowe	30,000
A oil consumption (ton/day)	3.5	Bremerhaven	38,000
A oil consumption cost (USD)	17,518	Rotterdam	30,000
C oil		Lisbon	25,000
C oil price (USD/ton)	102	Total port charge per voyage	**199,000**
C oil consumption (ton/day)	74		
C oil consumption cost	202,085		
Total bunker cost per voyage	**219,603**		
Total fix cost per voyage (1+2+3+4)		**1,057,372 USD**	

Liner cost components ii

- Variable costs: related to freight volume
  - (1) feeder costs; (2) trailer/railway costs; (3) container handling costs; (4) tally costs; (5) container management and repositioning costs; (6) terminal stowage costs.

Estimates for the same Trans-Atlantic route:

Variable cost items	East bound	West bound
Feeder costs	130	75
Trailer/railway costs	186	185
Container handling costs	160	198
Tally costs	78	82
Container management and repositioning costs	48	55
Terminal stowage costs	22	22
Another costs	4	4
Unit variable costs (USD/TEU)	628	621

Liner cost components iii

- Factors affecting liner costs (Stopford, 2004) :
  - service schedule
    - service frequency, number of port call, size of ships
  - ship costs
    - unit slot cost e.g. cost of transport for 1 TEU per day
    - operating, capital and fuel costs
  - port charges
    - vary around the world, depend on the ship's tonnage
  - container operations
    - mix of container types, container turnaround time and empty containers
  - container costs
    - daily cost, maintenance, repair, handling
  - administration costs
    - management, logistics, financial and commercial

Econo-mies of scale (applies to: service schedule, ship costs, port charges)

Economies of scale

- Economies of scale in fixed costs
  - 6,500 TEU ship
    - **fixed costs** ~ 3 times the 1,200 TEU ship fixed costs,
    - while cargo volume ~ 6 times as great
  - fixed cost component falls from 42% to 26% of total voyage cost
  - Average cost
    - 1,200 TEU ship: $771 / TEU
    - 6,500 TEU ship: $554 / TEU
  - Return (profit / total revenue):
    - 1,200 TEU ship: 2%
    - 6,500 TEU ship: 29%

- Other cost components do not especially benefit from economies of scale

Economies of scale ii

- Lim (1994) evaluates container ship size economies by examining:
  - unit earnings and unit costs for different vessel sizes
  - the performance of different size ocean container ships on different routes (over a year)
  - Indices used:
    - Freight Revenue - Variable Operation Costs (cargo related expenses + navigation expenses)
    - Fixed Costs (i.e. ship expenses + crew expenses + insurance + depreciation + overhead)

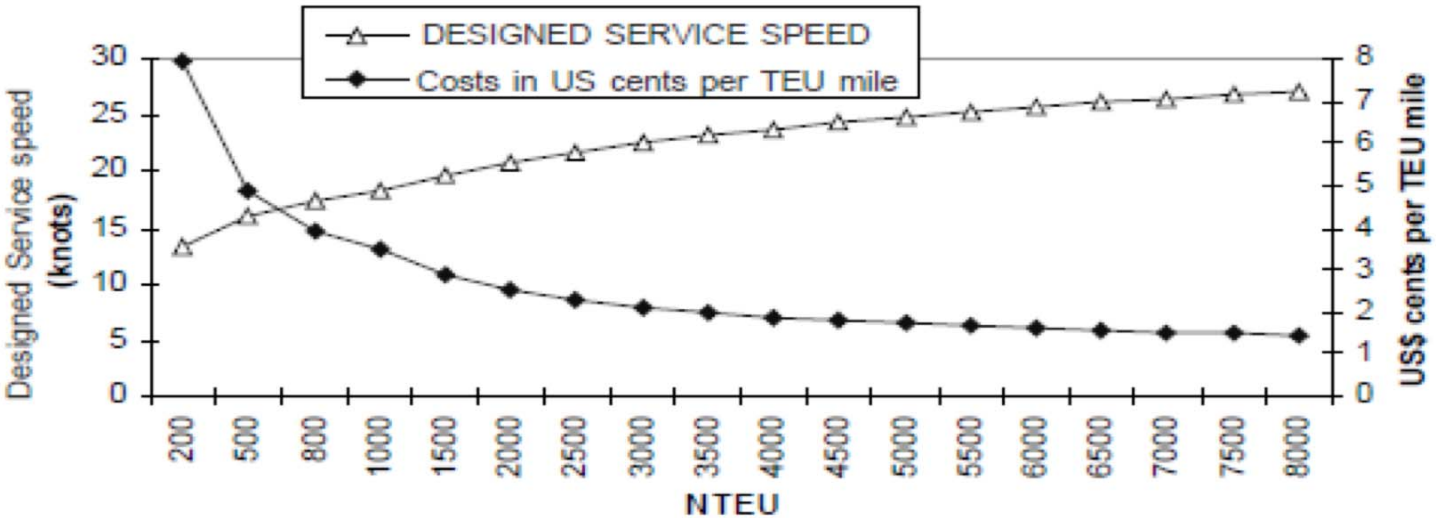
Economies of scale iii

- Data did not support the hypothesis that unit costs necessarily decrease with increments of vessel size

- Economies of container ship voyages depend on many factors unrelated to size:
  - route characteristics
  - accounting practices
  - level of freight rates
  - load factors
  - operation days
  - the shipbuilding market
  - ship's purchase price

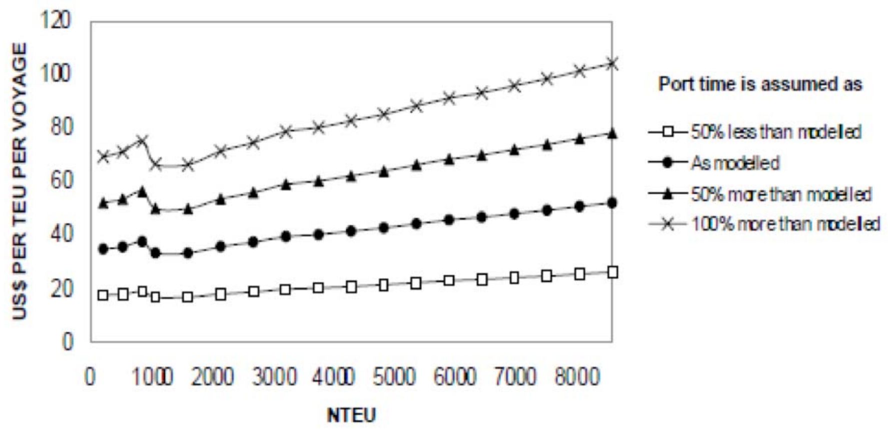
Port vs. sea time

- Cullinane & Khanna (2000): Quantify the trade-off between the positive returns earned at sea and the negative returns while in port
- Cost per TEU-Mile & ship speeds for different ship sizes



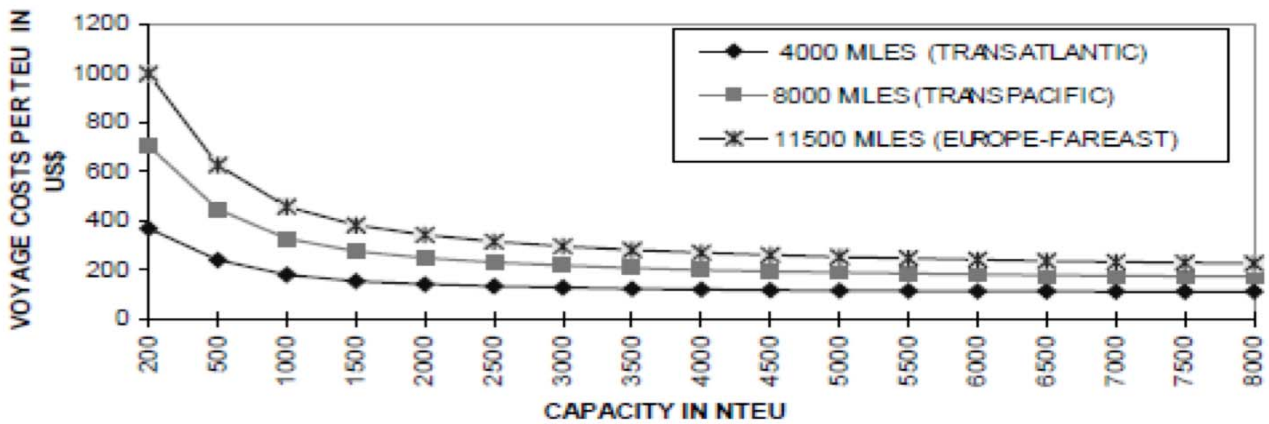
Port vs sea time ii

- Cost of time in port in USD per TEU per voyage
  - port time depends on total cargo exchange, crane density, average crane productivity, non-productive time in port, working time in port, etc.
  - Improvements in port productivity are related to a significant improvement in crane productivity in recent years.



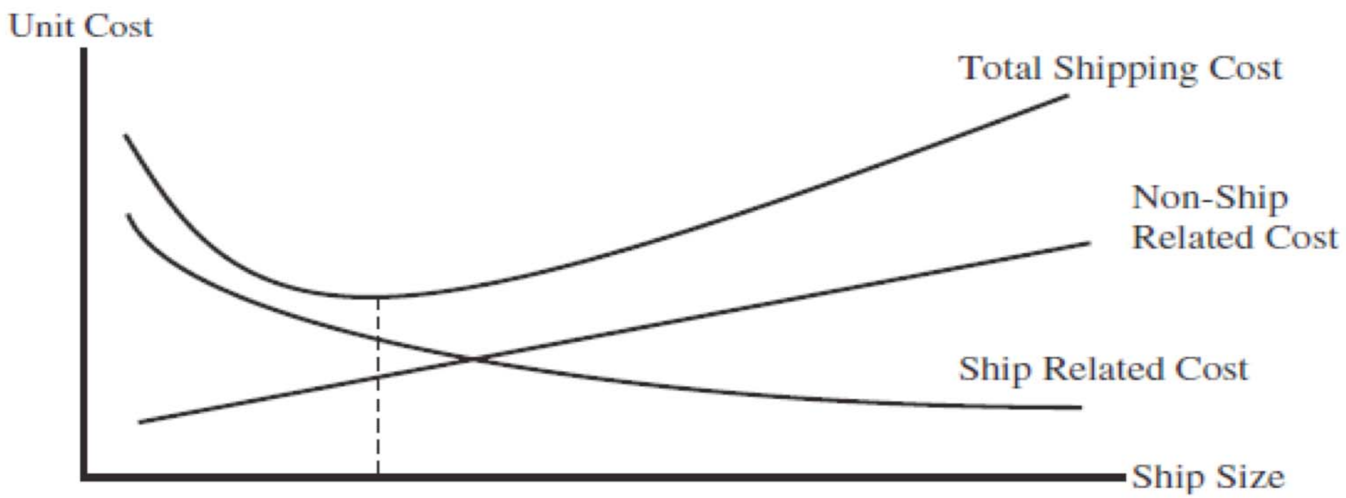
Port vs. sea time iii

- Total Shipping Cost per TEU
  - diseconomies of ship size in port are outweighed by economies of size at sea
  - benefits from scale economies in ship size decline as route lengths shorten.



Optimal ship size=?

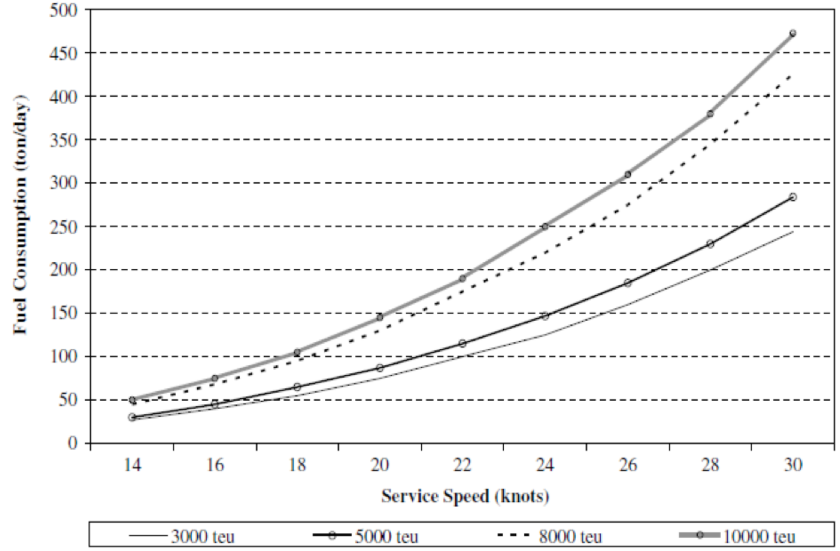
- U-shaped average cost curve, when both ship and non-ship-related costs are included in the analysis (Ng and Kee,2008).



Effect of speed

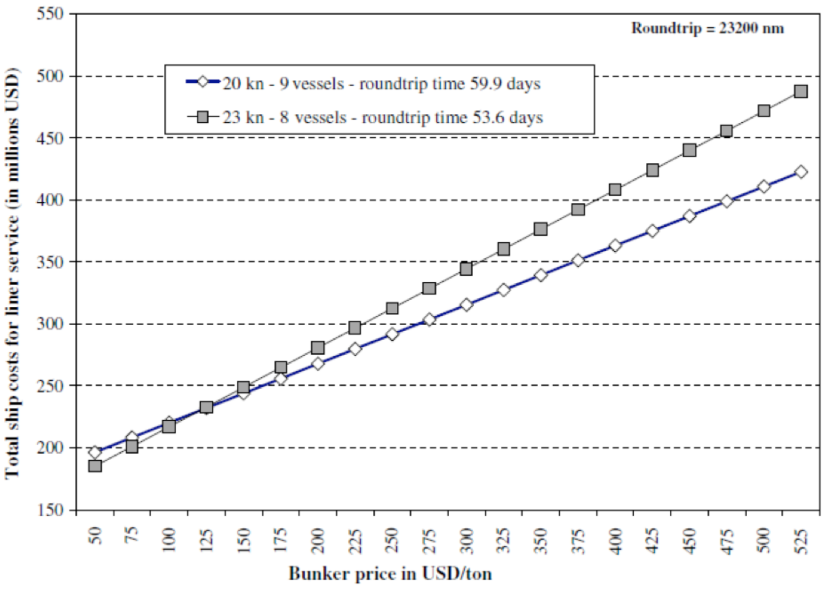
- An increase in service speed in just a couple of knots results in a dramatic increase of fuel consumption (Notteboom and Vernimmen, 2008)

- Goes the other way too!

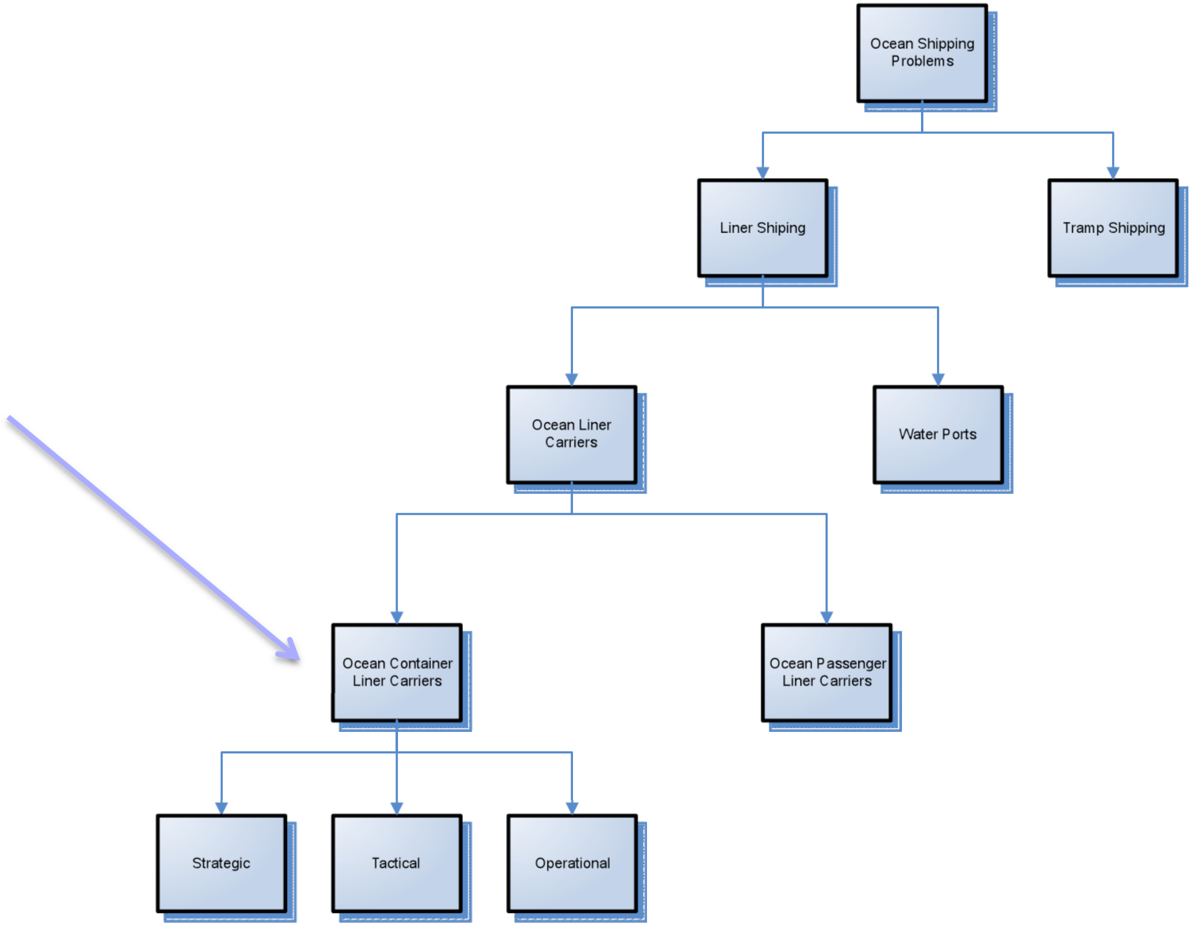


Effect of speed ii

- Example: shift from eight to nine vessels and reduce speed from 23 to 20 knots when the fuel price is higher than around USD 150 per ton (Notteboom and Vernimmen, 2008)



Area B: OR/MS applications



Ref: Tsilingiris (2007)

Hierarchy of problems

Time horizon/ stakeholder	Ocean container carrier
Strategic	• Ship design • Market & trade selection • Liner network design • Fleet size & mix • Capacity contract evaluation • Transportation services pricing
Tactical	• Fleet size & mix modifications • Fleet deployment • Distribution of empty containers • Container tracking and security
Operational	• Containership management • Containership loading/stowage planning • Service speed selection • Environmental routing • Cargo booking

Strategic problems

- Longer time horizons (>10 yrs)
- Life-cycle considerations (esp. on cost)
- Decisions hard to reverse
- Substantial uncertainties & risks

Ship Design Problem

The *Ship Design Problem* (SDP) tries to determine which is the best ship for a specific trade.

Its solution involves multiple decisions, such as ship size and other ship particulars (e.g., container handling equipment, engine selection, electrical systems, etc.)

The SDP is directly related with the Optimal Ship Size Problem (OSSP)

The SDP is a strategic problem, for a ship is a long-term investment and its operational life can extend up to 35 years.

Market & Trade Selection Problem

The *Market & Trade Selection Problem* (M&TSP) is to determine which market segments and, specifically, which routes a shipping company should aim to serve.

The M&TSP may investigate markets and trades belonging to different geographical regions

Liner Network Design Problem

Based on the forecasting of transport demand and estimations of revenue and costs of servicing a market, the shipping company must design the network served by a fleet of vessels.

The complexity of the problem increases if we include the determination of transshipment points for intermodal services.

Fleet Size and Mix Problem

Given a set of routes with a required frequency of service for each route, the planner must decide the mix of containership types to include in the fleet, their sizes, and the number of vessels of each size.

Transportation Services Pricing Problem

The *Transportation Services Pricing Problem* (TSPP) problem concerns determination of the tariffs of the carrier.

Moreover, the carrier decides the policy regarding contracts and (quantity or client) discounts.

VERY important for competitiveness of carrier vis-à-vis competitors

Tactical problems

- Moderate term time horizons (months to 1-2 years)

- Assumes strategic decisions already made
- Feedback loop from tactical to strategic level

Fleet size and mix modifications problem

The *Fleet Size & Mix Modifications Problem* (FS&MMP) is the version of the strategic FS&MP for a tactical planning horizon.

In particular, we begin from the solution of the FS&MP and then we factor in revised expectations and knowledge (e.g., service demand, what the competition does, etc) to improve the FS&MP output.

Fleet deployment problem

Given a set of routes with a required frequency of service for each route, the planner must assign vessels to specific trade routes.

The problem includes the determination of expected lay-up days (if any) for certain ships – and maybe lay-up locations!

Distribution of empty containers

The *Distribution of Empty Containers Problem* (DECP): Due to liner trade imbalances, liner operators have to reposition empty containers on their network

Operational problems

- Time horizons shorter than tactical (hours to days)
- Dynamic dimension (inputs may change as solution evolves)
- Need to reoptimize
- Need to be fast
- Link to tracking and tracing

Line between tactical-operational subjective

Cargo booking problem

The *Cargo Booking Problem* (CBP): The liner operator must decide which cargoes to accept or reject for a given voyage.

Containership management problem

The *Containership Management Problem* (CMP) addresses various topics like crew scheduling, maintenance scheduling, spare parts positioning, bunkering, etc.

(could also be a ‘tactical’ problem)

Service speed selection problem

The *Service Speed Selection Problem* (SSSP) concerns the determination of the service speeds at the various legs of a vessel's route.

In certain cases it may be profitable for a ship to operate at a slower speed than its design speed in order to reduce sailing costs

It may also be profitable to sail at a service speed slightly more than the design speed in order to align with the routes' time windows.

Connected to 'weather routing'

Containership loading problem

The *Containership Loading Problem* (CLP) investigates the optimal loading of a vessel so that total container movements (loading, unloading, shifting, etc.) are minimized, subject to ship strength and stability and other technical constraints (e.g., hatch covers type, number, and geometry, etc).

Connected to terminal management problems!

Container tracking and security problem

- The Container Tracking & Security Problem (CTSP) deals with the tracking of containers and the status of their contents.

- Tracking- tracing- security

Sample of references

Reference	Major Decision	Comments
Agarwal and Egun (2008)	FDP & NDP	Introduced a joint formulation for both problems.
Alvarez (2008)	FDP & Ship Scheduling	Introduced a joint formulation for both problems.
Bendall and Stent (2001)	Hub-n-Spoke Network Design	Several assumptions are made, such as that demand increases with the number of port calls; bi-criteria IP formulation; probably solved via standard software; afterwards, heuristics are applied to find ship schedules.
Benford (1981)	FDP	Early, simplified FDP application
Boffey et al (1979)	Route design	Early reference in the scheduling of containerships; heuristic optimization and an interactive decision-support system are proposed.
Fagerholt (1999)	FS&MP	The solution method handled only instances where the different ships that could be selected have the same speed.
Fagerholt (2004)	Route Design - FDP	The IP formulation aims to min costs; the method is route generation; the problem is tackled as a multi-trip VRP; the two-phase solution has as follows: phase 1 generates feasible routes while phase 2 solves an IP model.
Fagerholt and Lindstad (2000)	FS&MP	All the feasible routes are generated a priori and the IP model is solved by CPLEX. The model does not ensure that services for a given port pair are properly spaced during the planning horizon.

Sample of references ii

Sambracos et al. (2004)	FS&MP	Both its strategic nature and operational one (VRP) are considered.
Sigurd et al (2005)	Route design	The underlying planning problem consists of finding recurring liner routes, which fit both with the quantity and frequency demand from the given companies.
Ting and Tzeng (2003)	Liner scheduling	A DP model identifies cost items relevant to the planning of a service route, which can help planners make better scheduling decisions under berth time-window constraints as well as estimate more accurately voyage fixed costs and freight variable costs in liner service route planning.
Ting and Tzeng (2004)	Liner revenue management	A conceptual model for liner shipping revenue management is proposed and a slot allocation model is formulated through mathematical programming to maximize freight contribution.
Tsilingiris (2005)	LNDP	Uses LP, IP, DP formulations. Sequential methodology tackling: ship routing & scheduling, fleet size & mix, and a posteriori "topical" optimization of inefficiencies. Methodology works well in practice re computational time; loops connecting subproblems need enhancement; methodology testified on real and fictitious data.
Tsilingiris and Psaraftis (2006)	LNDP	Same as Tsilingiris (2005) plus a module for selective node scheduling.
Xie et al (2000)	FS&MP	Objective: min cost; method: LP and DP.

Not so much covered

- Problem integration
- Link with terminal management models
- Link with pricing models
- Link with market forecasting models
- Intermodal integration problems
- Environmental problems (eg, emissions, green logistics, etc)

Conclusions

- Area of growing importance
- Need for integration of various models
- Problems are complex, so are models
- Need for more integration with industry!

acknowledgment

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- www.martrans.org