The profit maximizing liner shipping problem with flexible frequencies: logistical and environmental considerations

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The profit maximizing liner shipping problem with flexible frequencies: logistical and environmental considerations

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A synthesis of work on

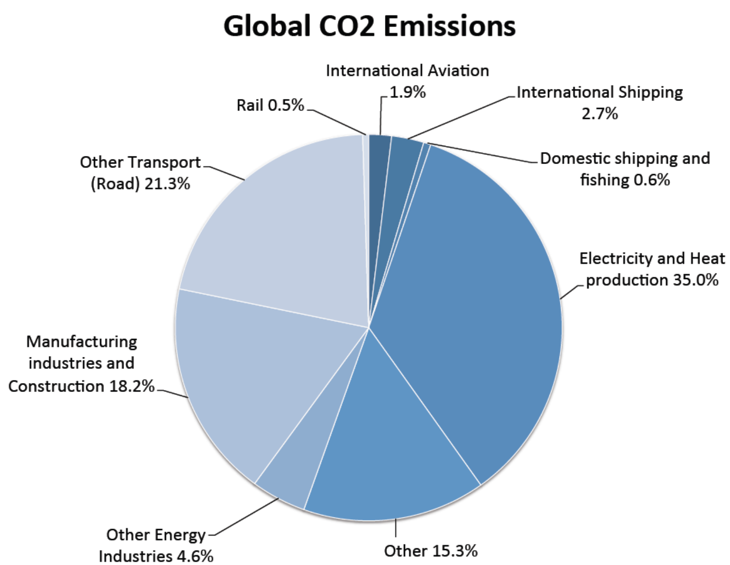
- Air emissions from ships (mainly GHGs)
- Speed optimization in maritime transport
- A recent MSc. thesis at DTU*

* Massimo Giovannini, “Speed Optimization and Environmental Effect in Container liner Shipping”, MSc. Thesis, DTU, 2017.

Global CO2 emissions

2009 IMO GHG study

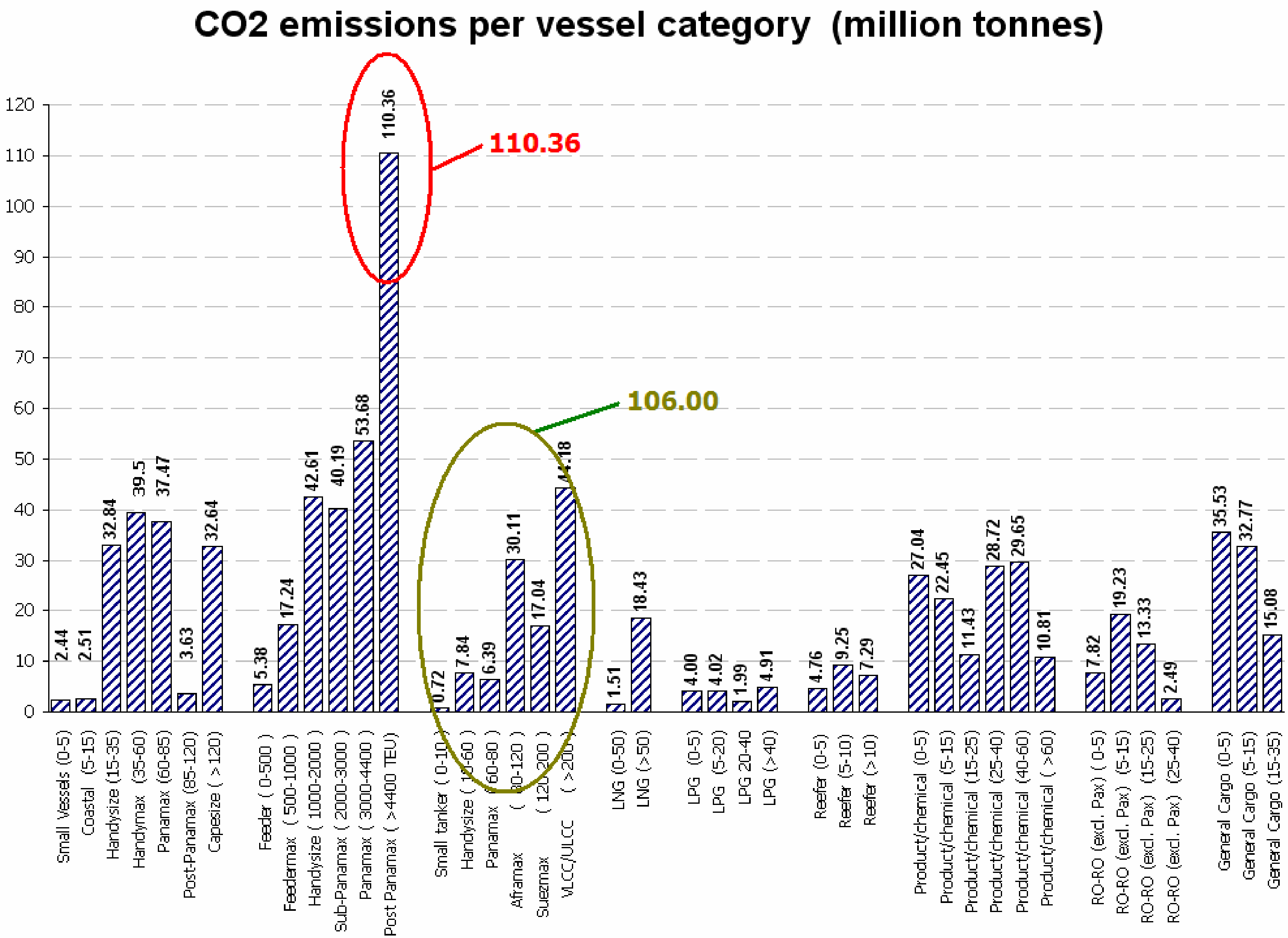
- (2007 data)



2014 IMO GHG study

- (2012 data)

- 2.7% **down** to 2.2%
- 796 million tonnes of CO_2 in 2012, **down** from 885 million tonnes in 2007
- Mainly attributed to **slow steaming** due to depressed market conditions after 2008



*Psaraftis, H.N. and C.A. Kontovas (2009), "CO2 Emissions Statistics for the World Commercial Fleet", WMU Journal of Maritime Affairs, 8:1, pp. 1-25.

Speed reduction

- An obvious way to reduce maritime emissions (and not just CO2)

- Killing 3 birds with one stone?

- Pay less for fuel
- Reduce CO2 (and other) emissions
- Help sustain a depressed market

- Looks like win- win-win?

PARENTHESIS

IMO GHG discussion

- Chile and Peru objected to ”speed reduction” as a measure.
- Argued that sending cherries to China would suffer.
- Suggested using ”speed optimization” instead

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IMO GHG discussion

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Compromise solution

- Both ”speed optimization” and ”speed reduction” were included in the text

From IMO decision

.4 consider and analyse the use of speed optimization and speed reduction as a measure, taking into account safety issues, distance travelled, distortion of the market or trade and that such measure does not impact on shipping's capability to serve remote geographic areas;

- No one really sure what is meant by ”speed optimization”

PARENTHESIS iii

- **Speed limits** have been proposed by some NGOs (CSC et al.)
- These NGOs have been lobbying for years

Side effects of speed reduction

To maintain same level of throughput, you will need:

- Either more ships
- Or bigger ships
- Or both

This will come at a cost

More side effects

- Building more ships to match demand throughput
- Implications on **safety** due to more ships sailing around
- Increasing freight rates due to a reduction in ton-mile capacity
- Increased inventory costs for the shippers (Chile & Peru’s concerns)

More side effects ii

- Cargo may shift to land-based modes, if these are available
- This may result in more CO2

- European short-sea shipping
- Even in deep-sea shipping

Speed reduction: dual targetting

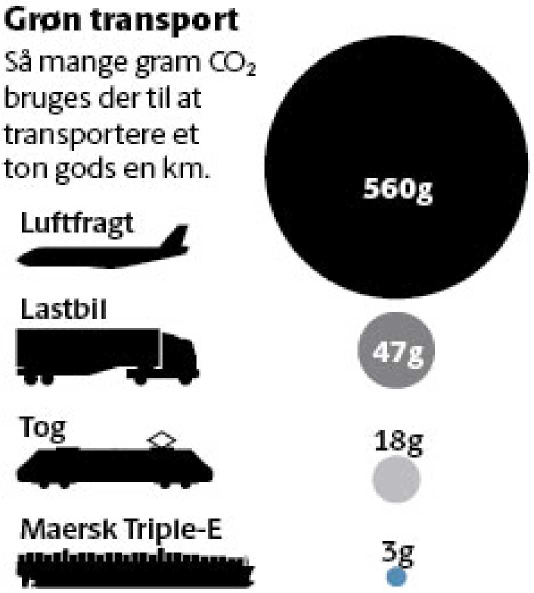
- OPERATIONAL

- Operate existing ships at reduced speed
- Derate engines
- Slow steaming kits

- STRATEGIC (DESIGN)

- Design new ships that cannot go very fast
- Use smaller engines

Mærsk Triple E



Giovannini and Psaraftis (2018)

FOCUSED ON CONTAINER SHIPPING

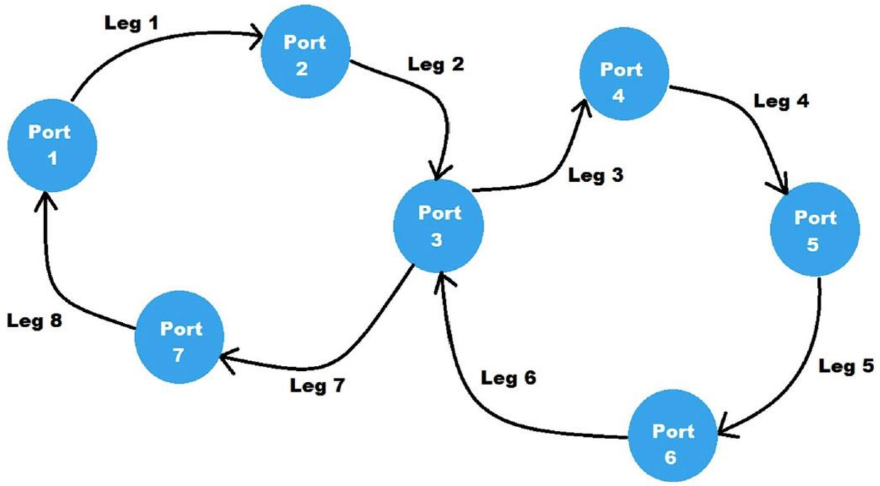
DEVELOPED A (REAL) **OPTIMIZATION MODEL** that examines:

- Effect of Freight Rate on optimal speeds and fleet size
- Effect of Bunker Price and Daily Fixed Operating Costs
- Effect of Inventory Costs (Chile’s and Peru’s concerns)
- Variable frequencies!

Optimization scenario

- The model assumes a fleet of *N* identical containerships deployed on a given fixed route.

- **WHAT IS OPTIMIZED?**
- Maximize the **average per day profit** of the carrier.



Problem inputs

- The route geometry, represented by a set of ports and a set of legs representing the route.
- The lengths of each leg of the route.
- The freight rate of transporting a TEU from a port on the route to another port on the route, for all relevant port pairs.
- The demand in TEUs from a port on the route to another port on the route, for all relevant port pairs.
- The bunker price.
- The daily operating costs of each vessel, other than fuel.
- The daily at sea fuel consumption function as a function of ship speed.
- The daily at port fuel consumption.
- The average monetary value of ship cargo on each leg of the route.
- The operator’s annual cost of capital.
- The time spent at each port.
- The cargo handling cost per TEU.
- The capacity of each vessel.
- The minimum and maximum allowable ship speeds.

Main decision variables

- The number of ships *N* deployed on the route.
- The ship speeds along each leg of the route.
- The service frequency.

NOTE: service frequency is typically assumed FIXED (and typically ONCE A WEEK)

IN OUR MODEL it is allowed TO VARY

Mathematical formulation

$$\dot{\pi} = Max_{v_i,t_0,N}\left\{\frac{1}{t_0}\left(\sum_x\sum_z F_{zx}c_{zx} - P\sum_i f(v_i)\frac{L_i}{24v_i} - PA\sum_j G_j - \sum_i \alpha_i C_i \frac{L_i}{24v_i} - H\sum_j D_j\right) - NE\right\} \tag{9}$$

subject to the following constraints:

$$v_{min} \le v_i \le v_{max} \quad i \in I \tag{10}$$

$$Nt_0 = \sum_i \frac{L_i}{24v_i} + \sum_j G_j \tag{11}$$

and

$$N \in \mathbb{N}^+. \tag{12}$$

Observation

- If frequency of service is FIXED, line has **one** degree of freedom: it can only play with N (number of ships) and speeds.
- That may restrict the line's choices and may in fact entail a cost.
- If on the other hand service frequency is FLEXIBLE, a wider set of alternatives may be available to the line
- Being restricted to a FIXED frequency generally entails a cost

Scenario examined

Mainlane East- West

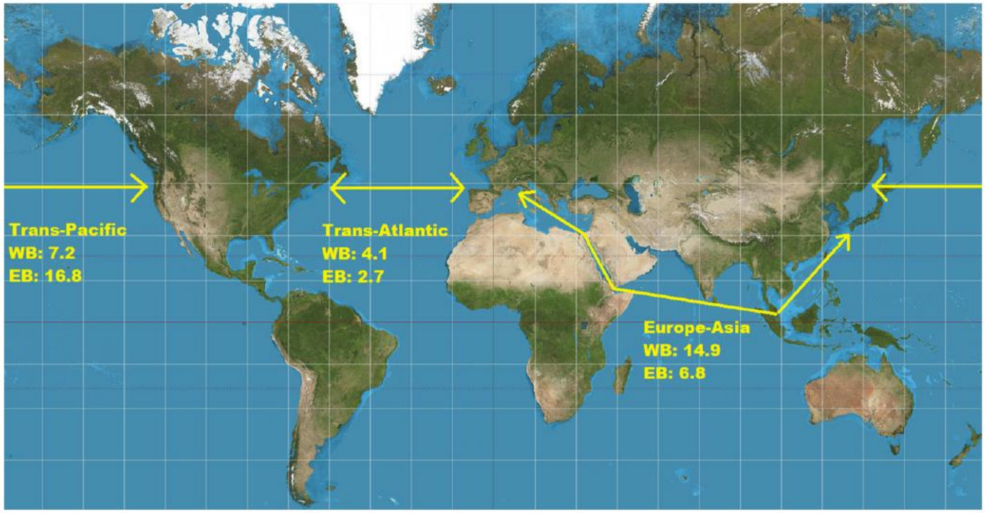
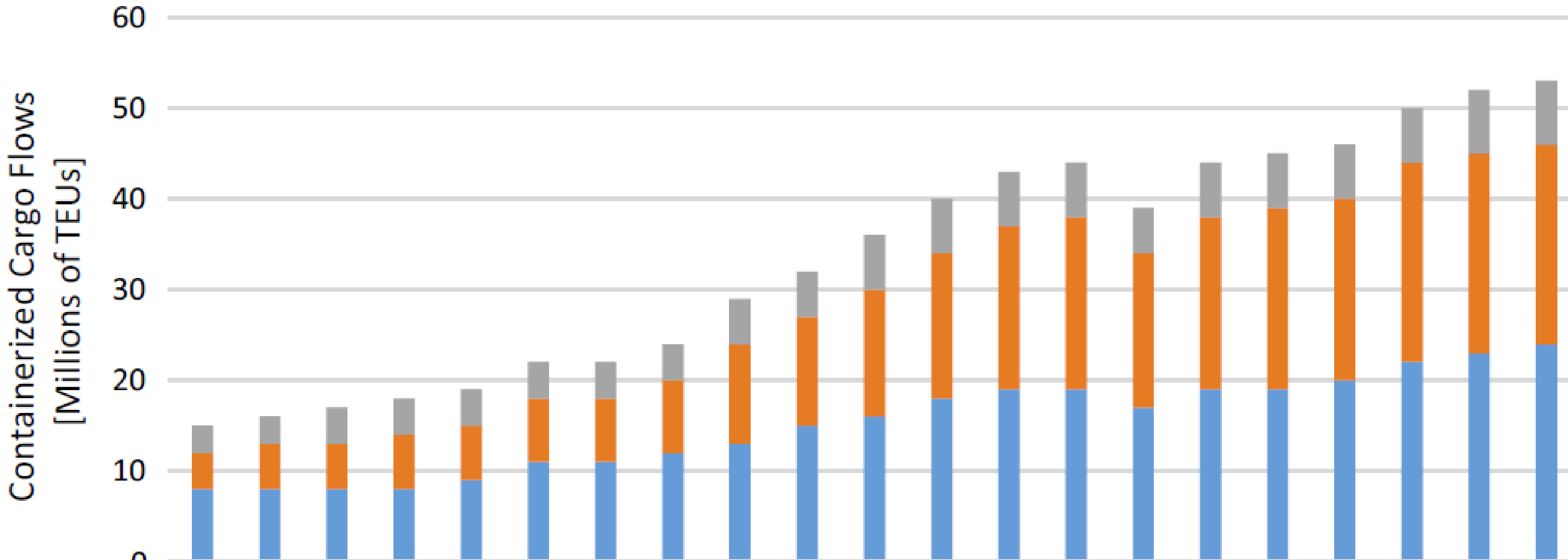


Fig. 4 Container flows on Mainlane Eas–West route [million TEUs], 2015. WB: westbound, EB: eastbound. Adapted from UNCTAD (2016), Table 1.7

3 main lanes

- Transpacific lane counts for 46% of the overall container trade on the East-West route
- Europe-Asia lane counts for 41% of the trade
- Transatlantic lane counts for 13% of the trade (UNCTAD, 2016).



	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Translatlantic	3	3	4	4	4	4	4	4	5	5	6	6	6	6	5	6	6	6	6	7	7
Europe-Asia	4	5	5	6	6	7	7	8	11	12	14	16	18	19	17	19	20	20	22	22	22
Trans-Pacific	8	8	8	8	9	11	11	12	13	15	16	18	19	19	17	19	19	20	22	23	24

Fig. 5 Containerized trade on Mainlane East-West route, 1995–2015. Adapted from UNCTAD (2016), Fig. 1.7

Imbalances i

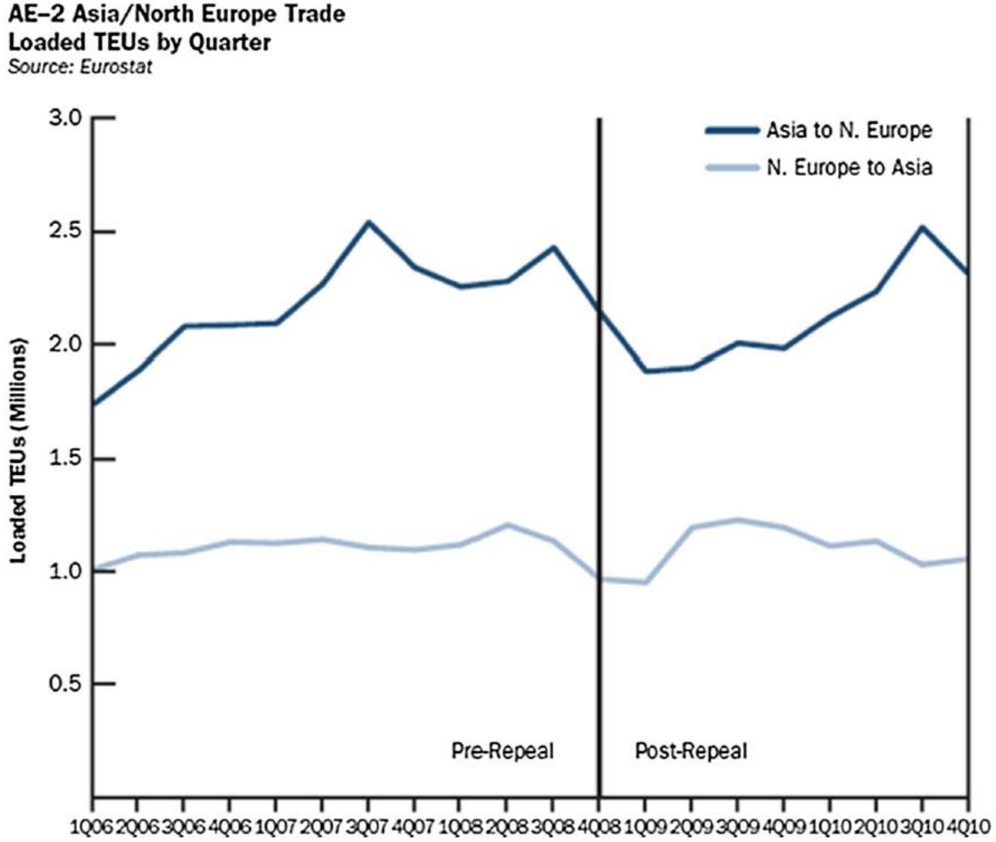


Fig. 3 Trade imbalances between Far East and Europe. The vertical line in 4Q08 is the repeal of EU Regulation 4056/86 in 2008. *Source* FMC (2012)

Imbalances ii

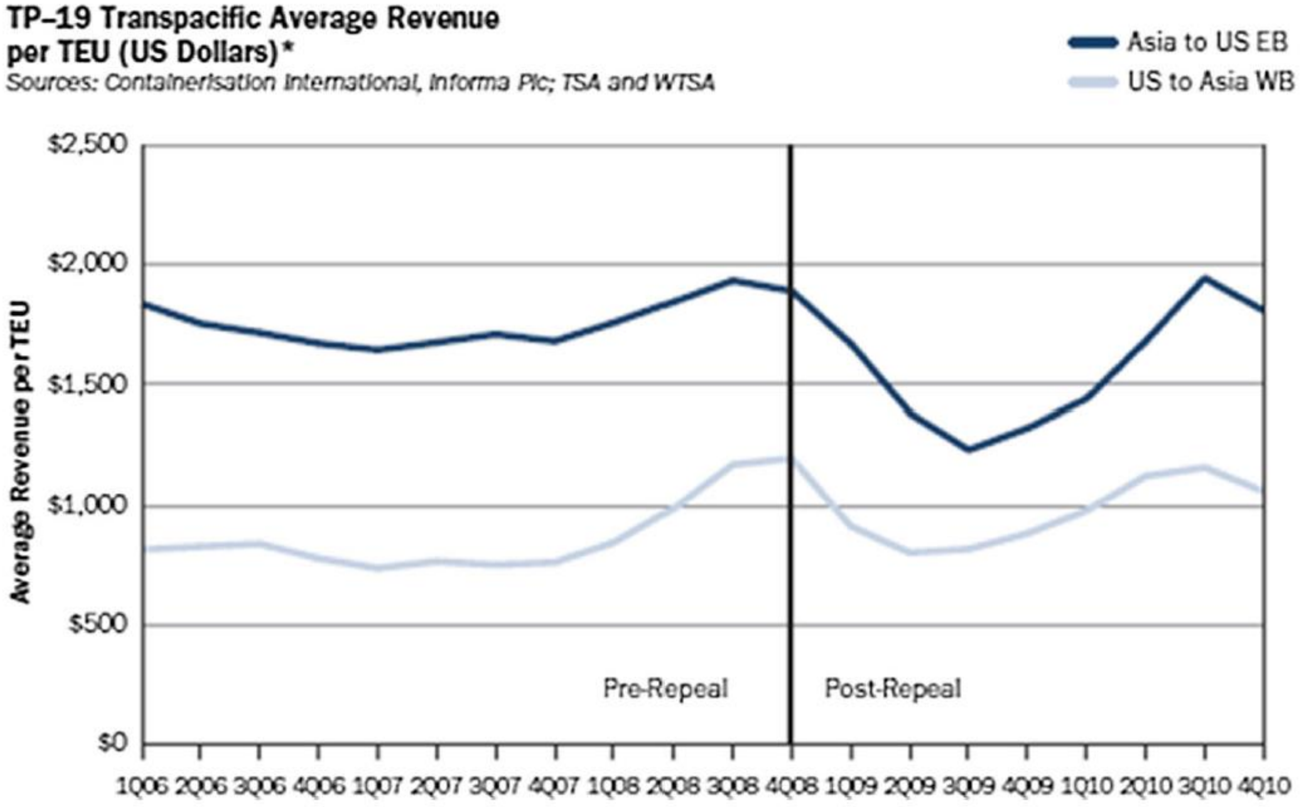


Fig. 2 Freight rate imbalances between Asia and the US. The vertical line in 4Q08 is the repeal of EU Regulation 4056/86 in 2008. *Source* FMC (2012)

Routes examined

AE2

- North Europe and Asia: such service links Asia to North Europe and is provided by Maersk. The same service is also provided by MSC under the name SWAN.

TP1

- North America (West Coast) and Asia: the route connects Asia to the West Coast of North America. Maersk offers this service. Same service is also provided by MSC and it is called EAGLE.

Routes examined ii

NEUATL1

- North Europe and North America (East Coast): the NEUATL1 lane links North Europe to the US East Coast. The service is furnished by MSC or similarly by Maersk under the name TA1.

Table 3 Ports in the routes under study

Ports					
AE2		TP1		NEUATL1	
Felixstowe	1	Vancouver	1	Antwerp	1
Antwerp	2	Seattle	2	Rotterdam	2
Wilhelmshaven	3	Yokohama	3	Bremerhaven	3
Bremerhaven	4	Busan	4	Norfolk	4
Rotterdam	5	Kaoshiung	5	Charleston	5
Colombo	6	Yantian	6	Miami	6
Singapore	7	Xiamen	7	Houston	7
Hong Kong	8	Shanghai	8	Norfolk	8
Yantian	9	Busan	9		
Xingang	10				
Qingdao	11				
Busan	12				
Shanghai	13				
Ningbo	14				
Yantian	15				
Tanjung Pelepas	16				
Algeciras	17				

Sources of data

- UNCTAD www.unctad.org for general information on liner shipping statistics
- EQUASIS (2015), database with information on the world merchant fleet in 2015
- FMC (2012) for transport demand tables, capacity utilization on various trade lanes
- Drewry (2015) for miscellaneous vessel operating cost information
- Maersk Line www.maersk.com for information on routes and schedules including port times
- https://shipandbunker.com/prices for bunker price information
- www.shipowners.dk/en/services/beregningsvaerktoejer, for the SHIP DESMO spreadsheet that calculates fuel consumption and emissions as a function of speed- developed for Danish Shipping
- www.worldfreightrates.com for freight rate information
- www.searates.com for distances among ports
- www.marinetraffic.com for information on ship deadweight, length overall and breadth
- www.containership-info.com for information on ship power.

3 scenarios

Scenario 1 The service period (or frequency) is constant and the number of ships can vary. Therefore the main decision variables in such scenario are two, the speeds and the number of deployed vessels.

Scenario 2 The number of ships is constant and the frequency can vary. Hence the main decision variables are again two, the speeds and the service period.

Scenario 3 Both the frequency and the number of ships can vary, in which case the main decision variables are three. However, in this case the number of ships will be bounded from above. This bound is imposed because otherwise the optimal number of ships may reach unrealistic values.

KEY FINDING

FREQUENCY OF ONE CALL PER WEEK NOT NECESSARILY OPTIMAL

Requiring frequency to be one call per week may (severely) restrict feasible solution space and will generally entail a cost.

Set of allowable service periods (days):

S={3.5, 4, 5, 6, 7, 8, 9, 10, 14}

Variable frequencies

- S={3.5, 4, 5, 6, 7, 8, 9, 10, 14}

Variable frequencies

- **S={3.5, 4, 5, 6, 7, 8, 9, 10, 14}**
- (weekly service)

Variable frequencies

- **S={3.5, 4, 5, 6, 7, 8, 9, 10, 14}**
- (biweekly service)

Variable frequencies

- **S={3.5, 4, 5, 6, 7, 8, 9, 10, 14}**

- (twice a week service)

Variable frequencies

- **S={3.5, 4, 5, 6, 7, 8, 9, 10, 14}**
- ???
- (this week Sunday, next week Saturday, following week Friday, etc)

Can variable frequencies work?

- As things stand today, NO!

- BUT!

- Why not?

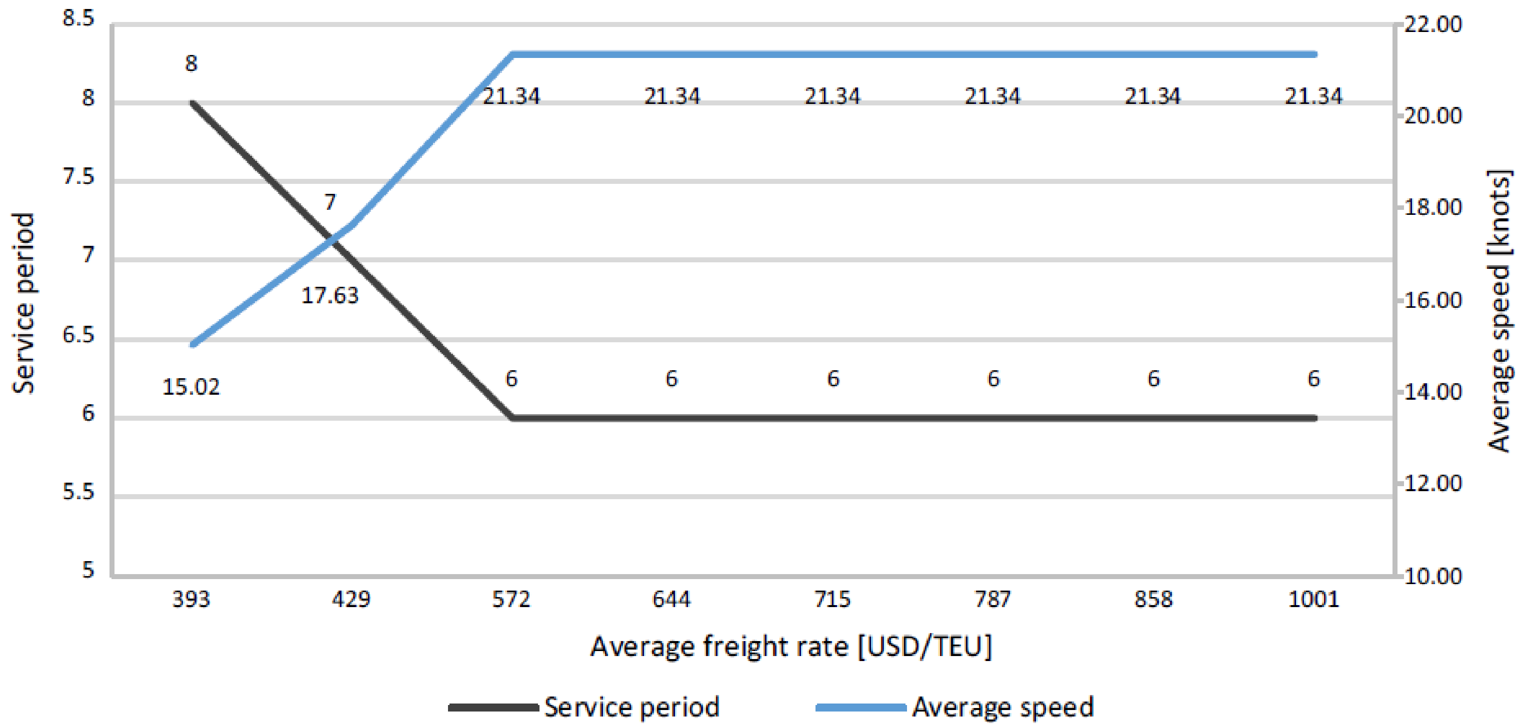


Fig. 8 Fixed number of ships scenario, optimal service period and optimal average speed at different average freight rates (route TP1)

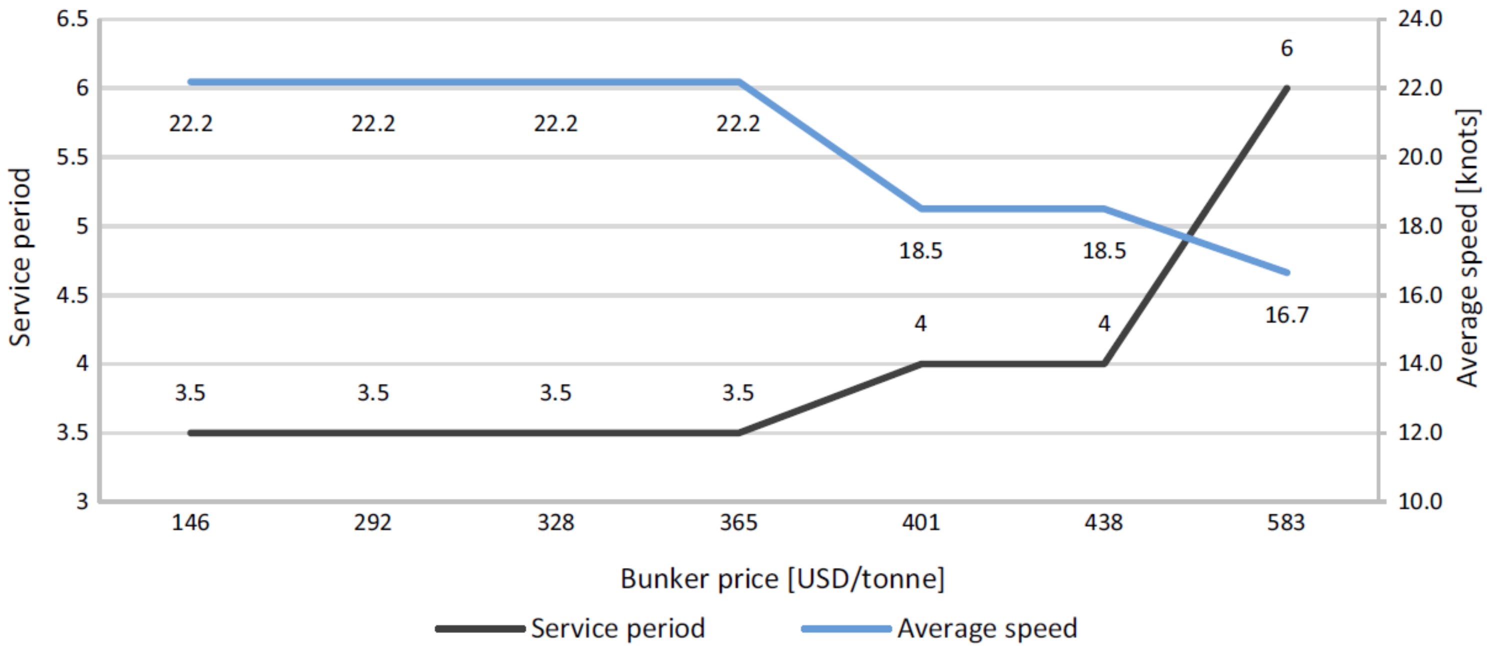


Fig. 10 Number of ships bounded above scenario, optimal service period and optimal average speed at different bunker prices (route AE2)

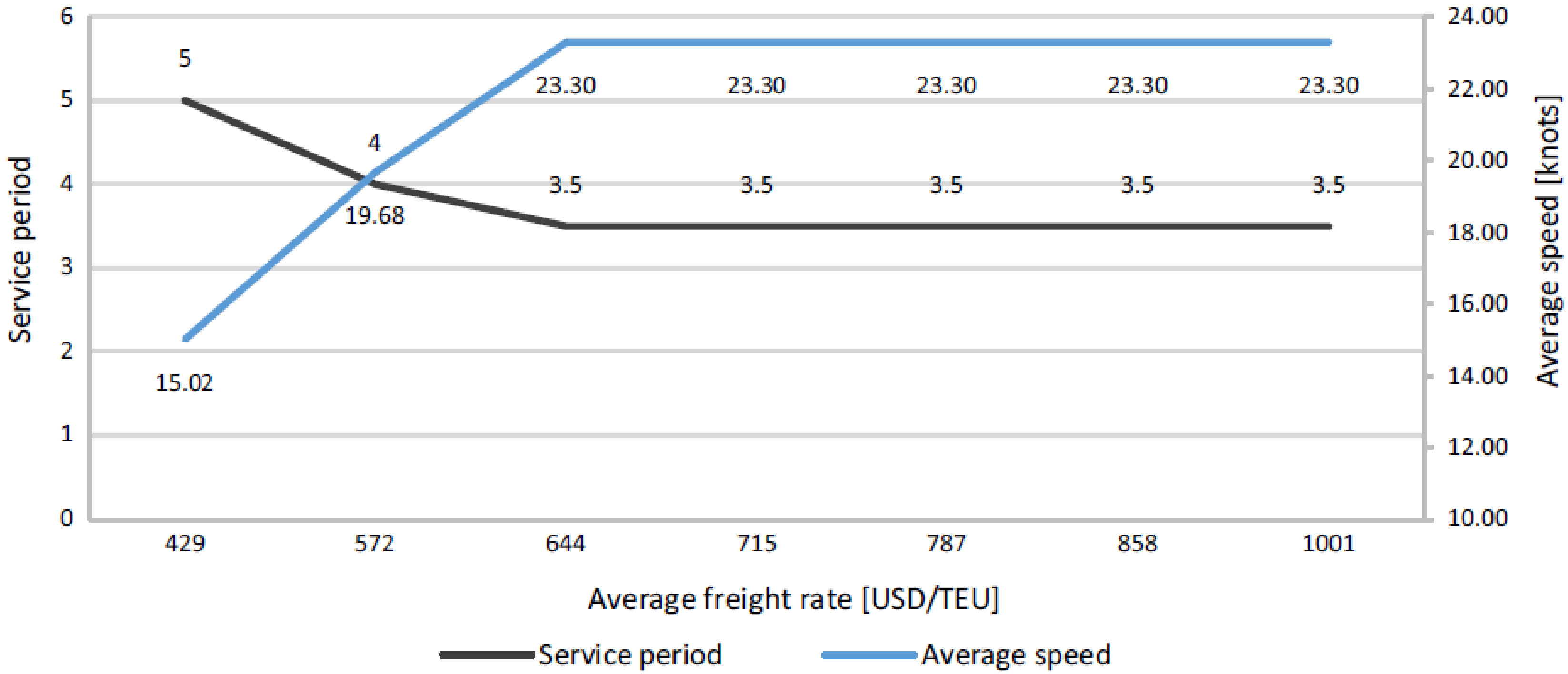


Fig. 9 Number of ships bounded above scenario, optimal service period and optimal average speed at different average freight rates (route TP1)

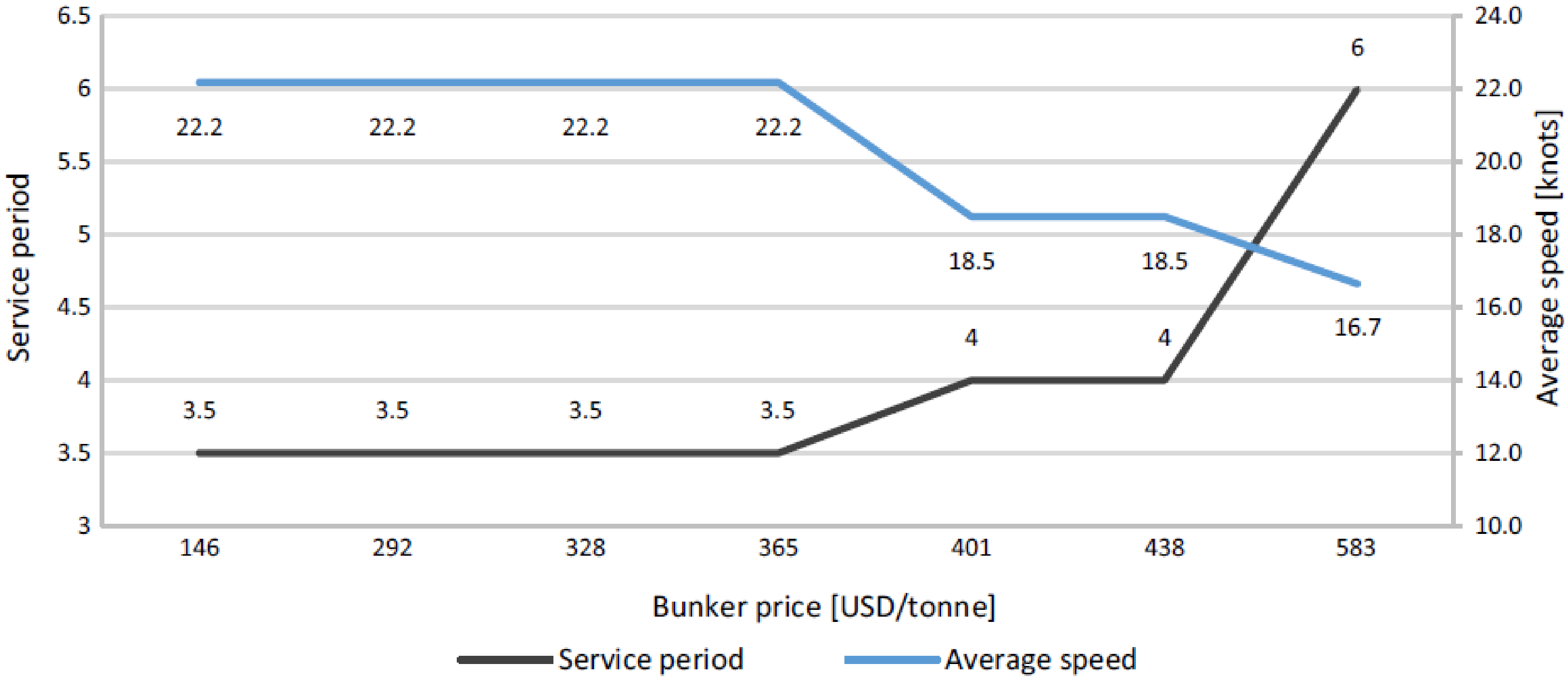


Fig. 10 Number of ships bounded above scenario, optimal service period and optimal average speed at different bunker prices (route AE2)

Cost of forcing a weekly frequency

Instance	Average freight rate (USD/TEU)	Optimal t_0 (days)	Δ (USD/day)
1	393	8	4,132
2	429	7	0
3	572	6	15,717
4	644	6	35,029
5	715	6	54,341
6	787	6	73,653
7	858	6	92,965
8	1,001	6	131,590

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Explanation

Low freight rates

- Enforcing a weekly frequency **(higher than optimal)**
  - Requires a speed higher than the optimal one
  - Increased revenue is lower than increased cost

High freight rates

- Enforcing a weekly frequency **(lower than optimal)**
  - Requires a speed lower than the optimal one
  - Reduced revenue is higher than reduced cost

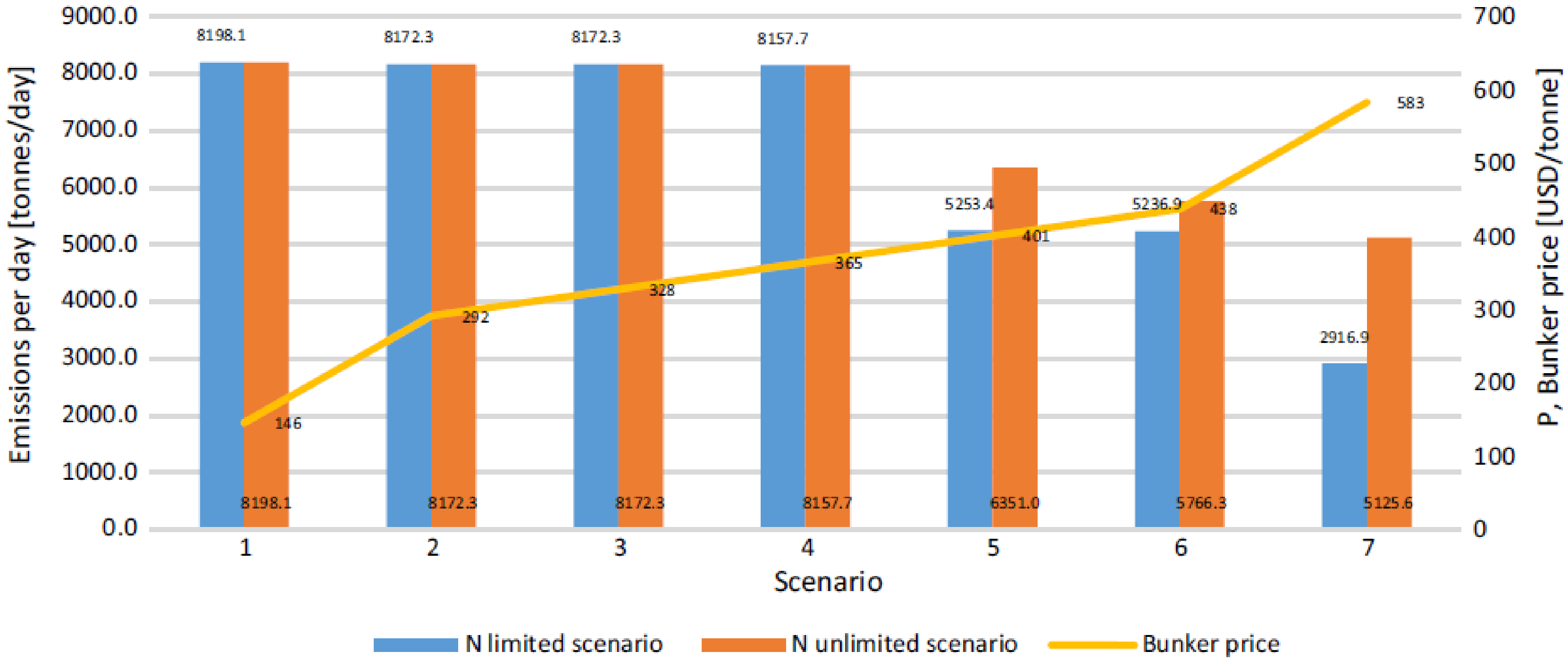


Fig. 13 Comparison between the *N* limited scenario and the *N* unlimited scenario, effect of the bunker price on the daily CO_2 emissions (route AE2)

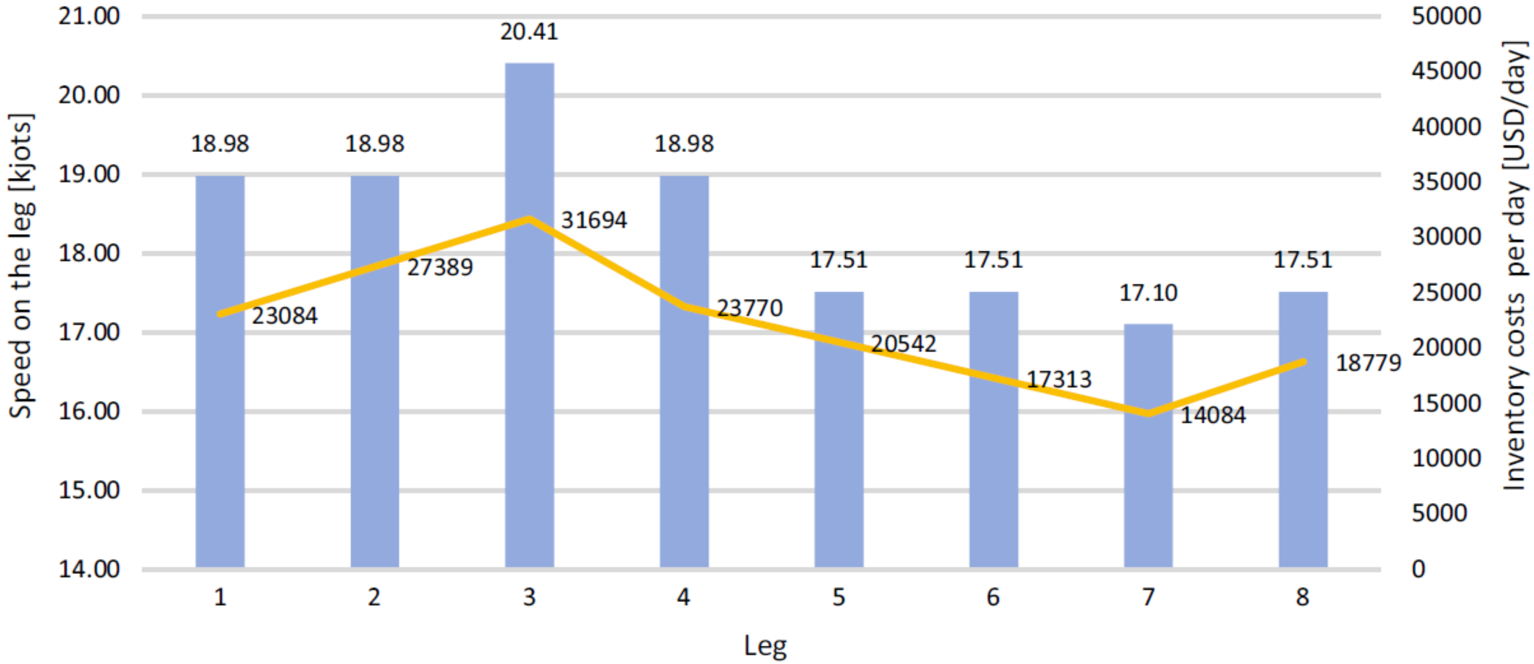
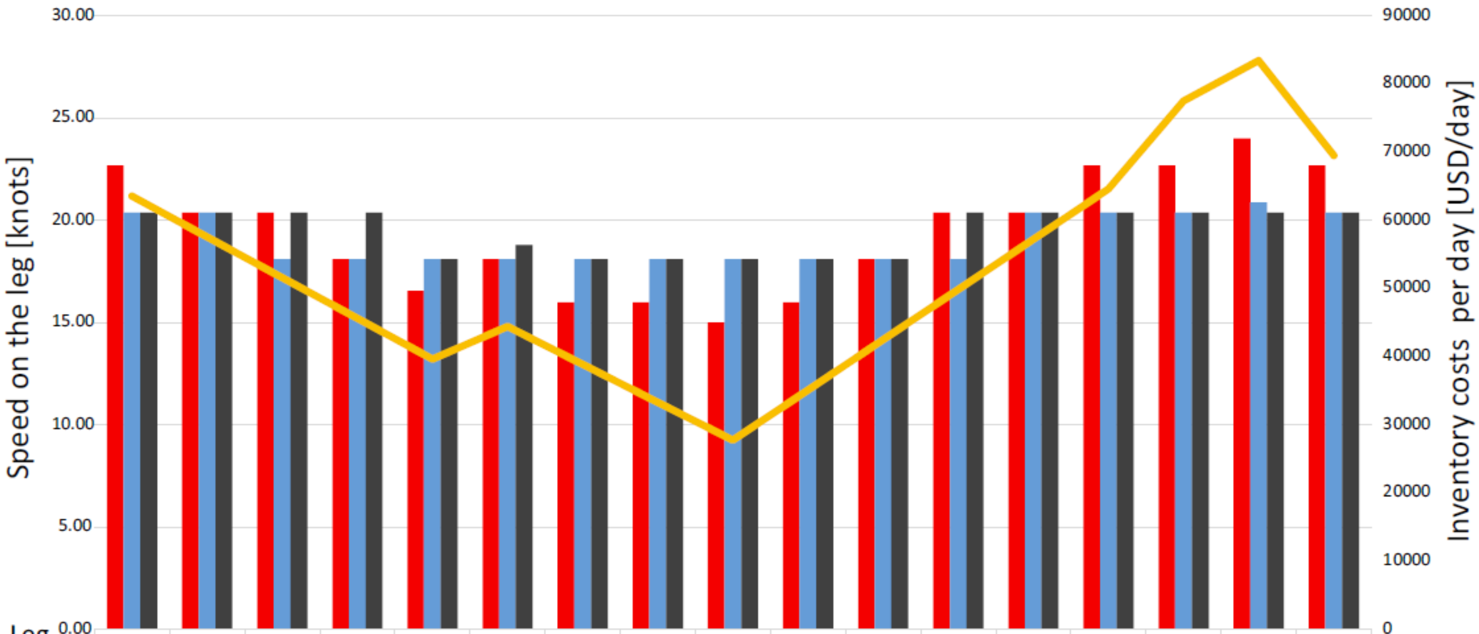


Fig. 14 Effect of inventory costs on the speeds along the legs (route NEUATL1). The figure refers to a base scenario in which $N = 5$ and $t_0 = 6$



Leg	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Scenario 1	22.68	20.38	20.38	18.10	16.55	18.10	15.99	15.99	15.00	15.99	18.10	20.38	20.38	22.68	22.68	24.00	22.68
Scenario 2-base	20.38	20.38	18.10	18.10	18.10	18.10	18.10	18.10	18.10	18.10	18.10	18.10	20.38	20.38	20.38	20.88	20.38
Scenario 3	20.38	20.38	20.38	20.38	18.10	18.80	18.10	18.10	18.10	18.10	18.10	20.38	20.38	20.38	20.38	20.38	20.38
Daily inventory costs	63533	57564	51594	45625	39655	44446	38891	33335	27779	35141	42503	49865	57226	64588	77506	83403	69503

Fig. 15 Effect of inventory costs and bunker price on the optimal speeds (route AE2). The speeds are higher on the legs on which the daily inventory costs are higher

Conclusions

- (Real) optimization of logistics services can play an important role in emissions reduction
- Under certain circumstances, win-win scenarios can be realized
- A fixed service frequency is not necessarily optimal in liner shipping
- Tools like this can be used to explore logistical measures to reduce CO2

Thank you very much!

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