

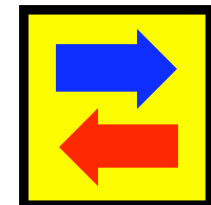
Green Maritime Logistics

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Laboratory for Maritime Transport

National Technical University of Athens

Greece





Outline

- Background: ship air emissions
- Measures to reduce emissions
- Logistics: issues and tradeoffs
- Some simple models and examples
- Conclusions

Background

Drive for greener shipping:

- very high on IMO agenda
- very high on agendas of individual coastal countries
- Reduction of ship emissions: top priority



Types of emissions



- Green House Gases- GHGs (mainly CO₂, but also CH₄ and others)
- Non-GHG (mainly SO₂, but also NO_x and others)
- P.M., etc



Kyoto Protocol

- United Nations Framework Convention on Climate Change -UNFCCC (1997)
- Urgent measures to reduce CO₂ emissions are necessary to curb the projected growth of GHGs worldwide
- Shipping has thus far escaped being included in the Kyoto global emissions reduction target for CO₂ and other GHGs
- Some regulation exists for SO₂, NO_x



Era of GHG non-regulation:

- Rapidly approaching its end!
- Measures to curb future CO₂ growth are being sought with a high sense of urgency.
- As CO₂ is the most prevalent of these GHGs, any set of measures to reduce the latter should primarily focus on CO₂.



Next UNCCC

- Copenhagen, Dec. 2009
- IMO may not have reached a decision on how to curb GHGs
- Serious disagreement still exists
 - mainly between developed and developing nations
- **Message of EC to IMO: Act now, or we shall act instead!**



Measures contemplated

■ Technological

- More efficient (energy-saving) engines
- More efficient ship hulls
- More efficient propulsion
- “Cold ironing” in ports
- Cleaner fuels (low sulphur content)
- Alternative fuels (fuel cells, biofuels, etc)
- Devices to trap exhaust emissions (scrubbers, etc)

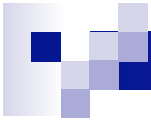
■ Market-based instruments

- Emissions Trading Scheme (ETS)
- Carbon Levy- International Fund Scheme

■ Operational

- Speed reduction
- Optimized routing
- Other, logistics-related





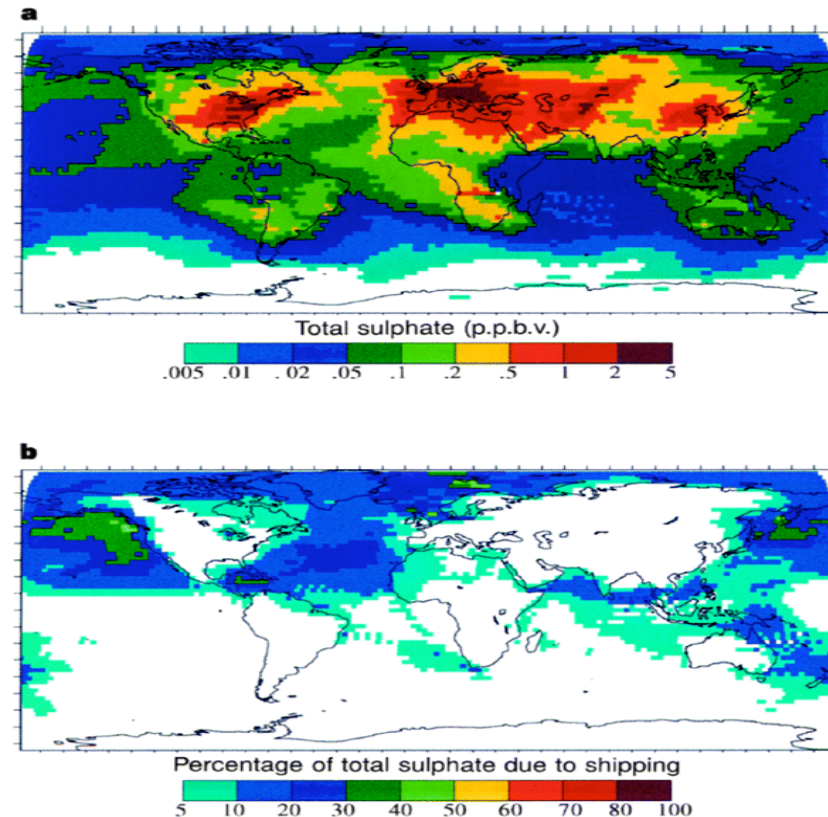


Green maritime logistics problems

- Optimal ship speed
 - Optimal ship size
 - Routing and scheduling
 - Fleet deployment
 - Fleet size and mix
 - Weather routing
 - Intermodal network design
 - Modal split
 - Transshipment
 - Queueing at ports
 - Terminal management
 - Berth allocation
 - Supply chain management
- Optimize with respect to environmental criteria
 - Optimize with respect to both environmental and traditional criteria
 - Try to find 'win-win' solutions

Emissions literature: vast

- R&D and studies on:
- Estimation of emissions
 - Impact of emissions on world climate
 - Technological means to reduce emissions



Remarks

- Even estimates of marine bunker sales are difficult to make
- Most global emissions estimates are based on modelling
- Not much on logistical dimension!





GHG emissions estimates

- IMO latest update of GHG study

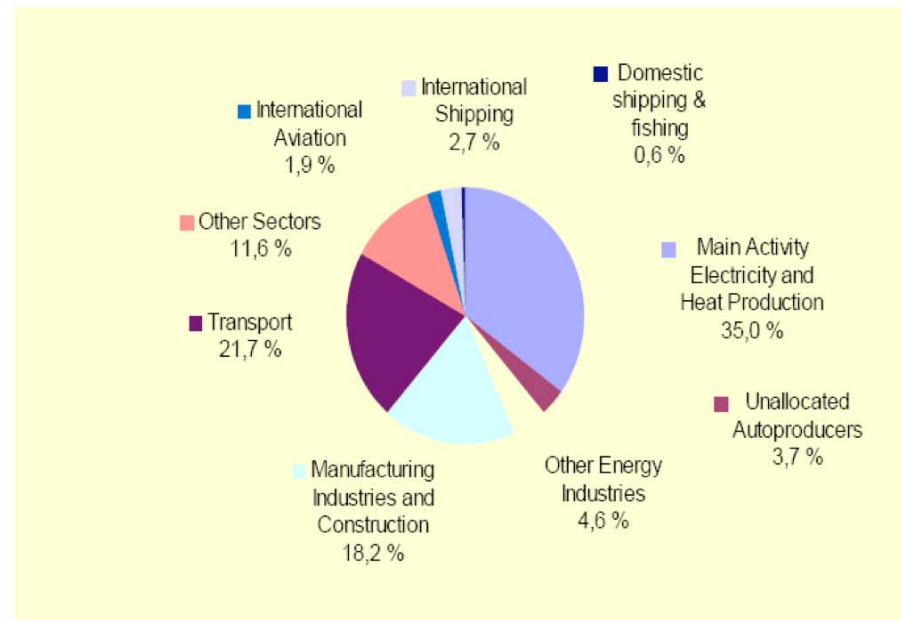
Table 1: Consensus estimate 2007 CO₂ emissions (million tonnes CO₂). Source: Buhaug et al (2008)

	Low bound	Consensus estimate	High bound	Consensus estimate % Global CO₂ emissions
Total ship emissions ¹	854	1019	1224	3.3
International shipping ²	685	843	1039	2.7

¹ Activity based estimate including domestic shipping and fishing, but excluding military vessels.

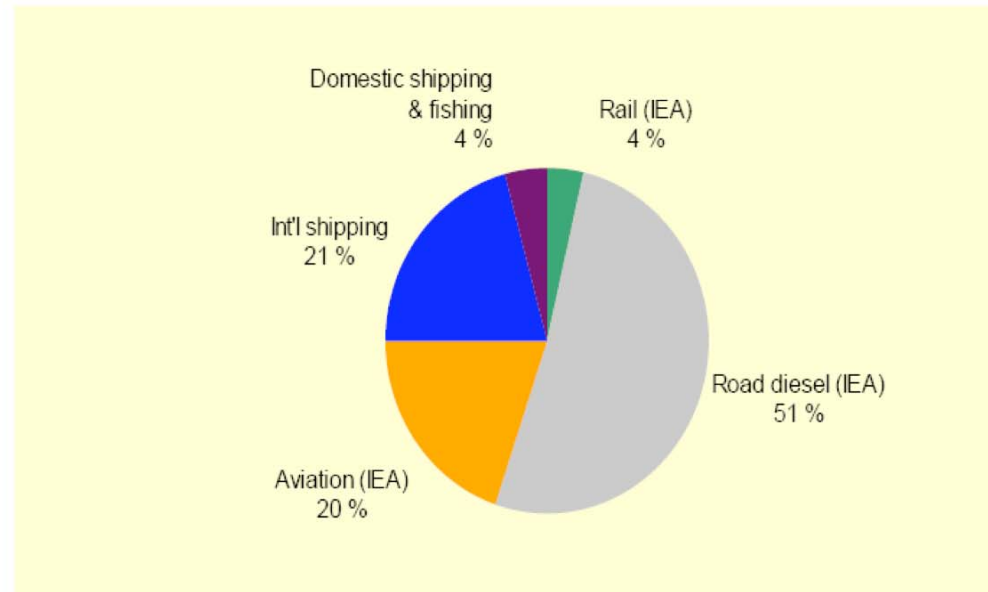
² Calculated by subtracting domestic emissions estimated from fuel statistics from the activity based total excluding fishing vessels.

Share of global emissions



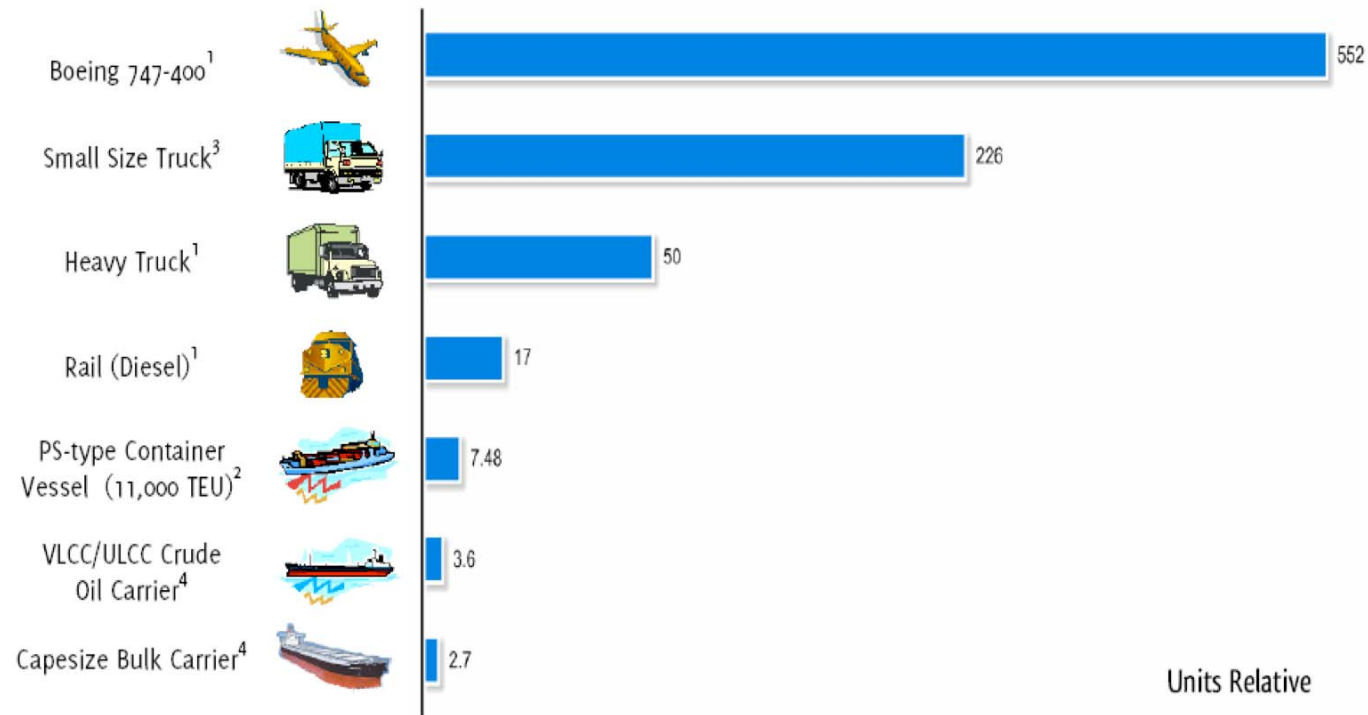
Data: International Shipping: This study. Other IEA. Reference year: 2005

Comparison with other modes (2005)



Data: International Shipping: This study. Other IEA. Reference year: 2005

COMPARISON OF CO₂ EMISSIONS AMONG TRANSPORT MODES (grams per tonne-kilometer)



Sources:

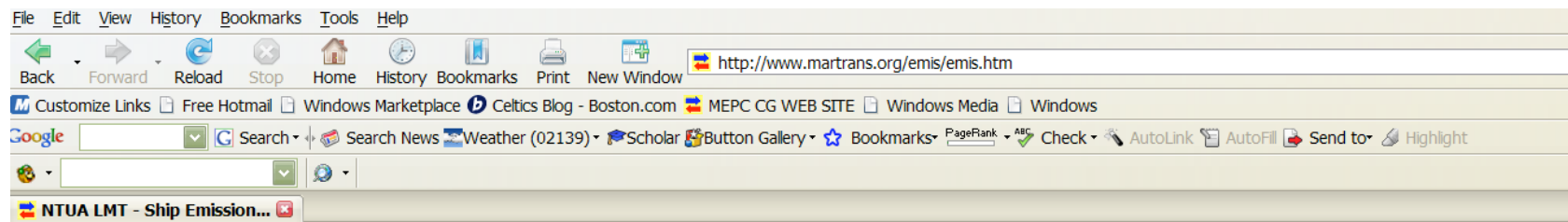
- 1 Swedish Network for Transport and the Environment (NTM)
- 2 Maersk Line
- 3 Man B&W Diesel
- 4 National Technical University of Athens (NTUA)



Produced by
NTUA Laboratory for Maritime Transport
www.martrans.org

NTUA ship emissions study

www.martrans.org/emis/emis.htm



Ship Emissions Study

➡ [Download Ship Emissions Study](#) (pdf format - 1.1 Mbytes)

Psaraftis, H.N., Kontovas, C.A., (2008), "Ship Emissions Study", National Technical University of Athens, report to Hellenic Chamber of Shipping, May

➡ [Emissions Calculator \(web tool\)](#)



Ship Emissions Calculator

VESSEL DETAILS

SELECT SHIP TYPE

Dry Bulk Carrier

SELECT SHIP SIZE

Handysize BC

Slow Speed Eni

ROUTE

Tubarao-Rotterdam

TRIP DISTANCE

4974 nm

9232 km

PAYLOAD (tonnes)

25000

DWT (tonnes)

27000

OPERATIONAL DETAILS

STATE

TIME
(days)

SPEED (knots)

FUEL OIL

S % Consumption
(tonnes/day)

DIESEL OIL

S % Consumption
(tonnes/day)

SEA LADEN

15.94

13

3.5

24

1.5

0

SEA BALLAST

15.94

13

3.5

24

1.5

0

PORT (loading, discharging)

4

3.5

4.5

1.5

0

EMISSIONS

	CO2	SO2	NOx
ROUNDTRIP EMISSIONS KG PER tonne TRANSPORTED	99.31	2.19	2.73
ROUNDTRIP EMISSIONS GRAMS PER LADEN tonne-MILE	19.97	0.44	0.55
ROUNDTRIP EMISSIONS GRAMS PER LADEN tonne-KM	10.76	0.24	0.30

SHOW/HIDE DETAILED RESULTS

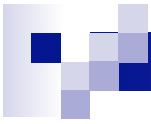
CALCULATE

HELP

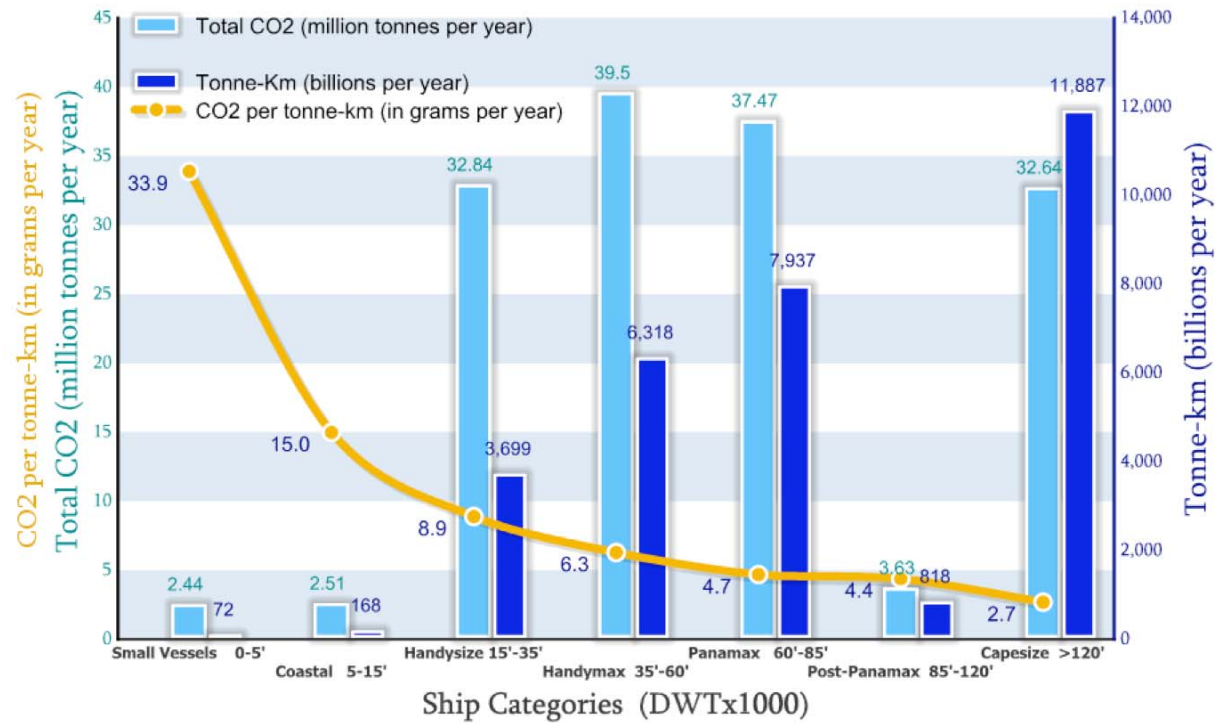
ABOUT

DETAILED RESULTS

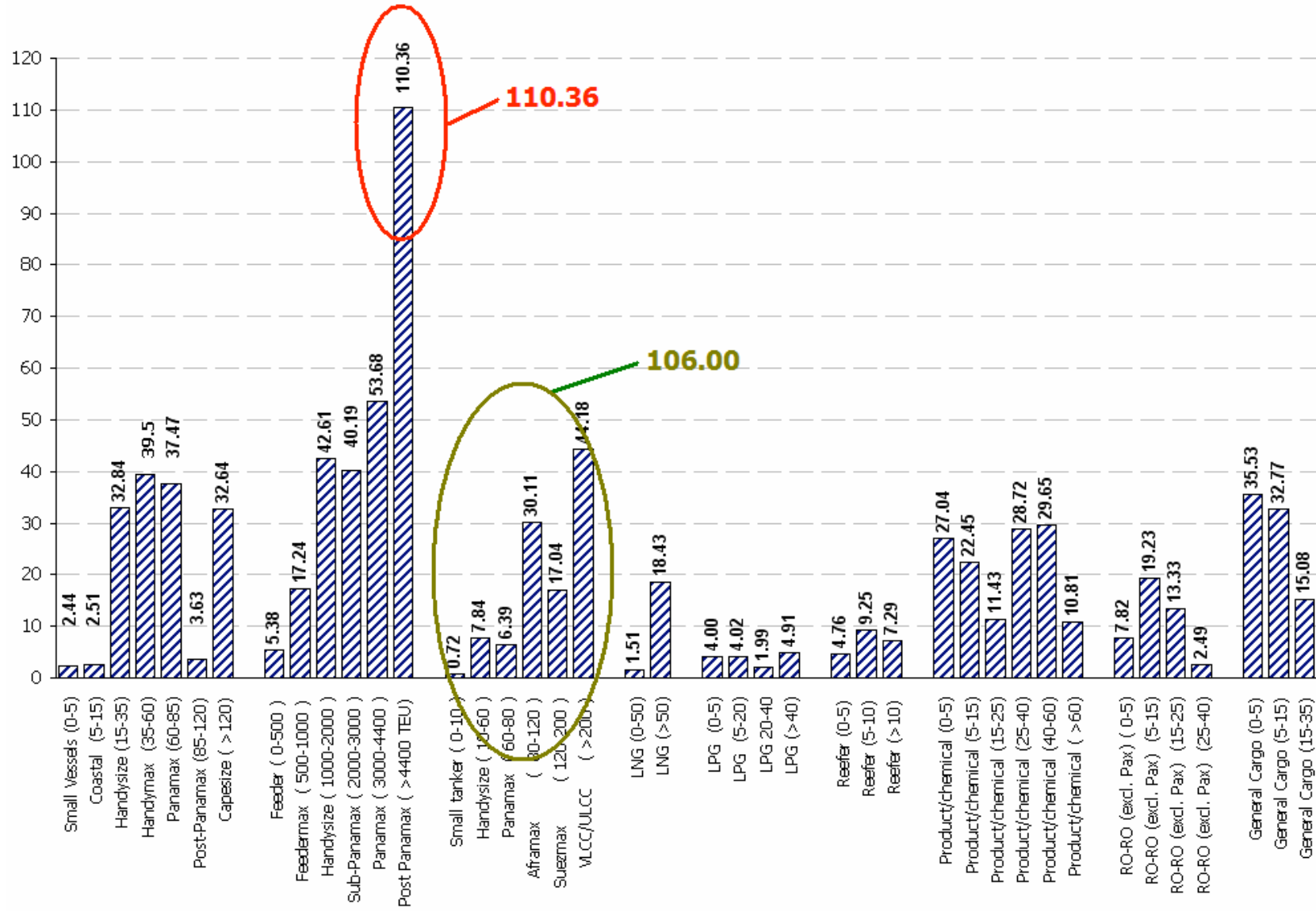
TOTAL BALLAST-LADEN DISTANCE		nm	9,948.00			
LADEN tonne-MILES		tonne*nm	124,350,000.00			
TIME IN PORT		days	4.00			
TRIP DURATION	SEA-LADEN	days	15.94	EMISSIONS		
TRIP DURATION	SEA-BALLAST	days	15.94	CO2	SO2	NOx
TOTAL RTRIP DURATION		days	35.88	tonnes	tonnes	tonnes
CONSUMPTION FO	SEA LADEN	tonnes	382.62	1,212.89	26.78	33.29
CONSUMPTION DO		tonnes	0.00	0.00	0.00	0.00



Dry Bulk Carriers



CO2 emissions per vessel category (million tonnes)





Logistics trade-offs

- Operational measures to reduce emissions may have **ramifications** as regards the **logistical supply chain**
- Measures such as **speed reduction** or others will generally entail costs, such as **in-transit inventory** and others (eg, more ships to carry the same cargo).

Boomerang effect?

- Cleaner, low-sulphur fuel may make maritime transport (and in particular short-sea shipping) more expensive and induce shippers to use **land-based alternatives** (mainly road)
- That might increase overall GHG emissions!





Some basics

ONE tonne of marine bunker produces:

- 3.17 tonnes of CO₂ (indep. of fuel type, engine type)
- $0.02 \cdot S$ tonnes of SO₂, where S is the % of sulphur content in fuel ($0.5 \leq S \leq 4.5$)
- 0.057-0.087 tonnes of NO_x (engine-dependent)



Simple model

- Fleet of N identical ships, each of capacity (payload) W .
- Go back and forth between 2 ports A and B
- Full in one direction, on ballast in the other
- Investigate impact of speed reduction
- Reduce speed, but **add more ships to maintain same demand throughput**



Fuel consumptions

- In port: f (tonnes per day)
- At sea: F (tonnes per day)
- Effect of speed change on fuel consumption:
assumed **cubic** for same ship, ie

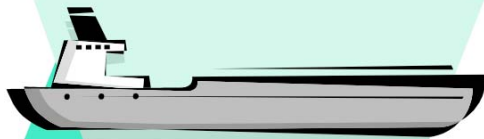
- $F_{\text{new}} / F = (V_{\text{new}} / V)^3$



Basic question

- If all ships reduce speed uniformly, but number of ships is increased to match demand throughput, does this lead to a lower fuel bill? (and hence to reduced emissions?)

- Answer: **YES**



VESSEL DETAILS

AFRAMAX TANKER
modern D/H - 106,000 DWT
Payload : 80,000

Laden Leg

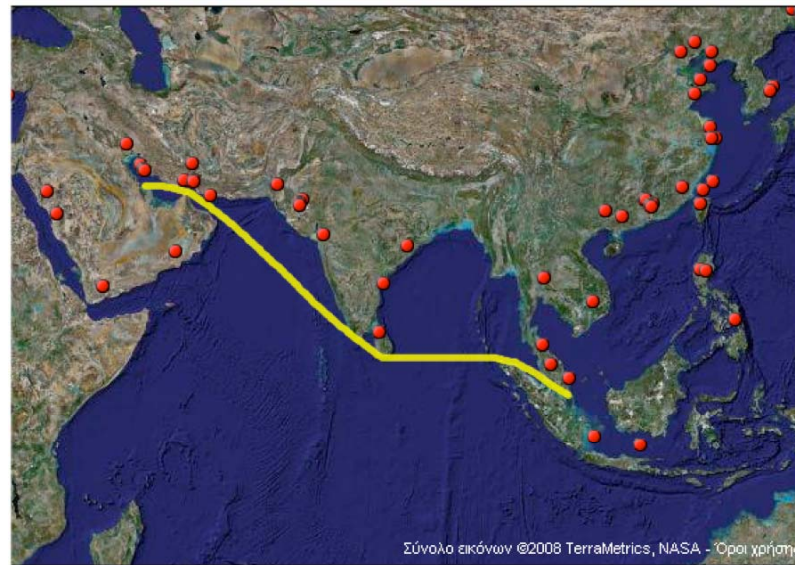
Speed : 14.5 Kn
Consumption : 49 tn/day

Ballast Leg

Speed : 14.5 Kn
Consumption : 40 tn/day

At port

Consumption : 116 tn/day



ROUTE DETAILS

Ras Tanura – Singapore

Distance : 3,702 nm

Voyage Time:

Sea Time : 21.3 days
Port Time : 4.0 days

no canal transit time
no port waiting

Scenario:

One fleet of one ten (10) aframax tankers
12 trips per year (oper. Days = 303,6 days)

	Bunkers (tonnes)	Cost (\$) 583.2 \$/tonne	CO2 emissions emis. Factor 3.17
1 Aframax tanker - Per trip	1,410.78	822,766.90	4,472.17
Fleet of 10 ships	169,293.60	98,732,027.52	536,660.71

To satisfy the same demand i.e constant total payload within the same period of operation we need a number of additional ships. In this case we need 0,627 more ships thus we need one more ship.

For a fleet of 11 identical aframax vessels sailing with a reduced by 1 knot speed we obtain the following results :

	Bunkers (tonnes)	Cost (\$) 583.2 \$/tonne	CO2 emissions emis. Factor 3.17
1 Aframax tanker - Per trip	1,284.72	749.284.70	4,472.17
Fleet of 11 ships	159,607.57	93,083,133.11	505,955.99

We see that we have a reduction in fuel consumption and, thus, in CO2 emissions

NET REDUCTION	Bunkers (tonnes)	Cost (\$) 583.2 \$/tonne	CO2 emissions emis. Factor 3.17
	9,686.03	5,648,894.41	30,704.72



However!

- STILL HAVE TO INCLUDE:
- Costs to charter more ships
- Cargo in-transit inventory costs

- So final answer depends on the above



In-transit inventory costs

- Hauling cargo at a reduced speed will entail additional **in-transit inventory** costs for the shipper.
- Such inventory cost is incurred during the time the cargo is in transit, and is equal to a factor of **IC** (\$/tonne/day), times the transit time, times the amount of cargo.
- **$IC = P * R / 365$** , where P is the CIF price of the cargo, and R is the cargo owner's cost of capital.



Containership example

- String of $N=100$ (identical) container ships
- Payload $W= 50,000$ tonnes
- Base speed $V= 21$ knots
- Fuel Consumption at 21 knots = 115 tonnes/day
- Assume fuel price $p= \$600/\text{tonne}$
- Fuel bill = $\$69,000/\text{day}/\text{ship}$

- Reduced speed $v= 20$ knots
- FC at 20 knots = 99.34 tonnes/day (cube law vs. 21 knots)
- Fuel bill = $\$60,500/\text{day}/\text{ship}$

For simplicity assume that

- These 100 ships go back and forth 2,100 miles full in one direction, empty in the other.
 - (if this is relaxed, analysis will be more involved, but will lead to similar results)
- Assume also zero loading and unloading times
 - (if non-zero, analysis will be more involved, but will lead to similar results).



100 SHIPS GOING 21 KNOTS (case A)

- Transit time (one way) = 100 hrs = 4.17 days
- Round trip = 8.33 days
- Number of round trips per year (assuming 365 days operation): 43.8
- Tonnes carried each year (per ship): $43.8 \times 50,000 = 2,190,000$.
- Times 100 ships = 219,000,000.
- Total fuel burned/year/ship: $115 \text{ tonnes/day} \times 365 = 41,975 \text{ tonnes}$
- Times 100 ships = 4,197,500 tonnes
- Total fuel cost (x\$600) = **\$2,518,500,000**.

105 SHIPS GOING 20 KNOTS (case B)

- Transit time (one way) = 105 hrs = 4.375 days
- Round trip = 8.75 days
- Number of round trips per year (assuming 365 days operation): 41.714
- Tonnes carried each year (per ship): $41.714 \times 50,000 = 2,085,714$.
- Times 105 ships = 219,000,000 tonnes.
- Total fuel burned/year/ship: $100 \text{ tonnes/day} \times 365 = 36,259 \text{ tonnes}$
- Times 105 ships = 3,807,256 tonnes
- Total fuel cost (x\$600) = **\$2,284,353,741, REDUCED**.



A or B better?

- B reduces CO₂ emissions by 1,237,073 tonnes per year (versus A)
- Fuel cost difference: \$128,299 per additional ship per day
- If sum of additional cargo inventory costs plus other additional operational costs of these ships (including the time charter) is less than \$128,299 a day, then case B is overall cheaper.



Case of expensive cargo, high fuel prices, high charter rates (2007)

- If $P = \$20,000/\text{tonne}$ (price of cargo)
- $P = \$600/\text{tonne}$ (price of fuel)
- $OC = \$20,000/\text{day}$ (charter rate for Panamax ship)

- Then $\Delta(\text{inventory costs}) = \$200,000,000/\text{yr}$
- $\Delta(\text{charter costs}) = \$45,625,000/\text{yr}$
- Then case B is more expensive!



Cost to avert one tonne of CO₂

- **BASIC QUESTION: HOW MUCH DOES IT COST TO AVERT ONE TONNE OF CO₂?**

(here 'speed reduction' is the measure, but question may be posed for any other measure)



CATC: how to compute it?

CATC =

- Total extra cost caused by speed reduction
 - (>0 , <0 , $=0$)

divided by

- Tonnes of CO₂ averted



Formula for CATC



$$\text{CATC} = \frac{I_c \text{WD} + \frac{2O_c}{D}}{F_{\text{CO}_2} V(V - \Delta V)(2V - \Delta V)(k_1 + k_2)} - \frac{p}{F_{\text{CO}_2}}$$

Cost to avert one tonne of CO₂

(\$/tonne of CO₂ averted)

p= fuel price
 P= Value of cargo at destination
 (CIF)
 OC: cost of chartering 1 more ship

Scenario	CATC (\$/tonne CO ₂)
p=\$600/tonne P=\$20,000/tonne OC=\$25,000/day	9.28
p=\$600/tonne P=\$10,000/tonne OC=\$25,000/day	-71.56
p=\$250/tonne P=\$20,000/tonne OC=\$15,000/day	104.94
p=\$250/tonne P=\$10,000/tonne OC=\$15,000/day	24.10



How to use CATC criterion?

- If $CATC < \text{threshold}$, then speed reduction recommended
- What is an appropriate threshold?
- Connected to price of CO₂ in a possible Emissions Trading Scheme



[Market-based instruments

2 basic ideas on the table (IMO)

- Emissions Trading Scheme
- Carbon Levy (or International Fund) Scheme
- No decision as of yet]



Effect of bigger ships operating at slower speed

- Base scenario: Fleet of N ships and capacity W , operating at speed V .
- Alternate scenario: Fleet of M bigger ships, of capacity U ($>W$), operating at speed v ($<V$).
- Both fleets achieve same throughput per year:
 - $M=N(VW/vU)$

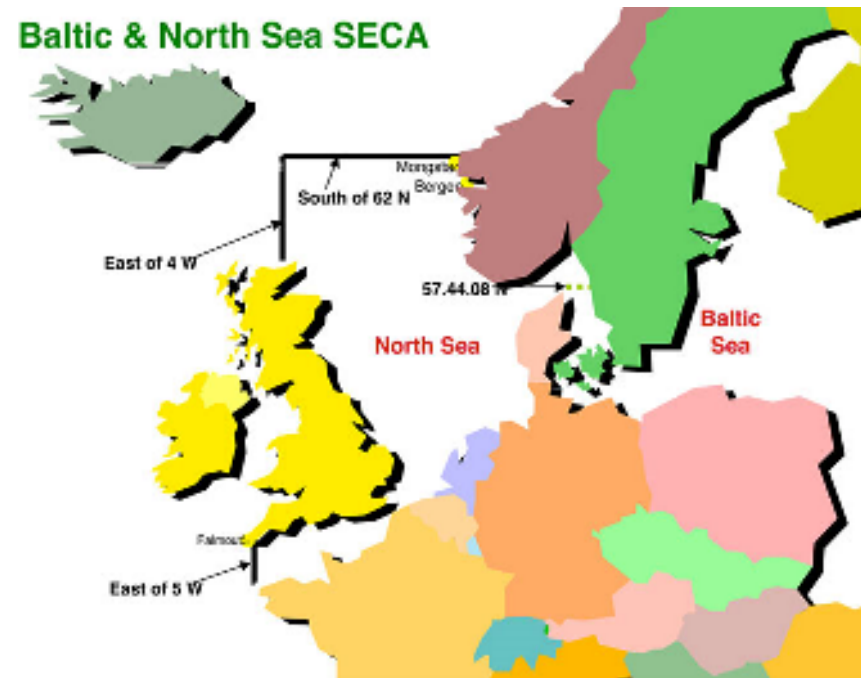


Basic result ($M=N$)

- **Substituting a string of ships with a string of bigger ships of same number, going at a slower speed so that total throughput remains the same, will reduce total fuel bill, hence total emissions.**
- Conjecture result also holds for $M < N$.

Sulphur Emissions Control Areas: SECAs

- SO₂ reduction: high on IMO agenda
- Regional policies
- Big question: how to limit SO₂ emissions
- Various measures (cleaner fuel, scrubbers)





How about speed reduction?

- Can **speed reduction** at SECAs work, as a measure to reduce SO₂ emissions?
- An easy question, for which the answer is not so easy.



Scenario

- A ship that goes from A to B, distance L .
- At beginning or end of trip, there is a SECA, of distance d ($<L$).

2 options:

- A. go all trip at a constant speed of V .
- B. reduce speed to v ($<V$) within SECA, but go at a higher speed of V^* ($>V$) outside SECA, so that total transit time is the same.



Example

- $L = 2000$ nmiles
- $d = 200$ (SECA)
- $V = 20$ (knots)
- $v = 18$ within SECA

- $V^* = 1800 / (2000/20 - 200/18) = 20.25$ knots outside SECA.

- Then $R = (1800)^3 / 2000 * (2000 - 200 * 20 / 18)^2 + (200 / 2000) (18 / 20)^2$

- $= 0.9226 + 0.081 = 1.0036$



This means that

- Speed reduction in SECAs will result in more total emissions (of all gases, including SO₂) and more total fuel spent if speed is increased outside SECA to make up for lost time.
- The reduced emissions within the SECA will be more than offset by higher emissions outside (for all gases).
- The fuel bill will also be higher.



Use cleaner fuels in SECAs

- If a ship is forced to use low sulphur fuel at a SECA, to reduce SO₂ emissions.
- This fuel is more expensive than high sulphur fuel. Hence freight rates go up.
- This may induce shippers to use land transport alternatives (trucking), which will increase CO₂ emissions thru the logistics chain!

Use cleaner fuels in SECAs

Ship (A->B)

V=14 Kn, 30 tn/day HFO
Fuel. Cons: 33.13 tonnes
CO2 : 105.01 tn of CO2
3,39 grams per tonKm

Truck

(w=40 tonnes v=60 km/h)
Fuel cons=43 lt per 100 Km

We need
1,125 truck trips
that produce
6 times more CO2
230 times more than
SO2 saved



371 nm =689 Km



Handymax Bulk Carrier W=45,000 tn



Cargo that will shift to road depends on :

- the unit fuel costs of each of the two options (both for low-sulphur and for high-sulphur fuel)
- how the road option is exercised (e.g., it could be 1,125 trucks doing one trip each, a fleet of 563 trucks doing two trips each, or any other combination)
- the transit times of each of the two options
- the inventory costs of the cargo

How to find out?

- Develop a model that examines these tradeoffs.
- Use the concept of **generalized cost** (taking into account value of time) and **multinomial logit** model to determine modal split.



Further research

- Get more real data to make realistic examples for these models (in progress)
- Examine other scenarios (in progress)
- Examine life-cycle aspects (in progress)
- Develop modal split model (in progress).
- Refine the models.
- Run various scenarios



Green maritime logistics problems

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 - Optimal ship size
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 - Fleet deployment
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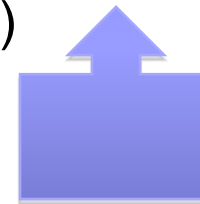
Conclusions

- Green maritime logistics is an area whose importance will increase
- Limiting emissions in one part of the intermodal chain may increase emissions in another
- Holistic approaches are necessary
- ‘Win-win’ solutions are sought

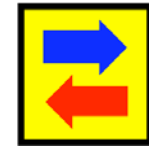


References

- Psaraftis, H.N., C.A. Kontovas, “CO2 Emissions Statistics for the World Commercial Fleet”, [WMU Journal of Maritime Affairs](#), Vol. 8, No. 1, April 2009, pp. 1-24.
- Psaraftis, H.N., C.A. Kontovas, “Ship Emissions: Logistics and Other Tradeoffs”, [International Marine Design Conference \(IMDC 09\)](#), Trondheim, Norway, May 2009 (based on DNV project)
- <http://www.martrans.org/lemis.htm>



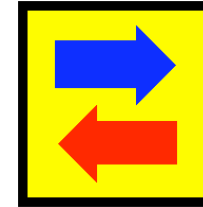
Emissions-content projects by NTUA-LMT



sponsors:

- Hellenic Chamber of Shipping
- Det Norske Veritas
- American Bureau of Shipping

Laboratory for Maritime Transport



- NTUA: Greece's oldest technological university (1836)
- School of Naval Architecture and Marine Engineering
- Division of Ship Design and Maritime Transport



LMT contexts and disciplines

- Maritime Transport
- Shipping Economics
- Shipping Management
- Intermodal Transport
- Logistics
- Shipping Finance
- Port Management, Planning and Development
- Routing, Sheduling and Fleet Management
- Advanced Ship and Marine Systems Technologies
- Operations Research Applications
- Telematics Applications
- Ship and Port Safety
- Risk and Safety Analysis
- Maritime Security
- Maritime Policy and Regulations
- Marine Accident Analysis
- Database Design and Management
- Human Factors Analysis
- Oil Pollution
- Marine Environment Protection
- Optimization of Transport Systems



Courses offered

UNDERGRADUATE:

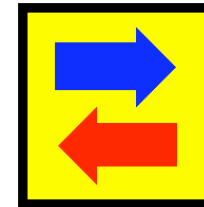
- ECONOMICS OF MARITIME TRANSPORT I
- ECONOMICS OF MARITIME TRANSPORT II
- ECONOMICS OF MARITIME TRANSPORT III (Safety and Environment Analysis)
- ELEMENTS OF SHIPPING FINANCE
- LOGISTICS IN MARITIME TRANSPORT
- PORTS AND INTERMODAL TRANSPORT
- ELEMENTS OF RISK IDENTIFICATION THEORY, SAFETY AND HUMAN ELEMENT ANALYSIS

POSTGRADUATE:

- WATERBORNE TRANSPORT SYSTEMS



Research at NTUA-LMT



Projects

NON FUNDED RESEARCH

· [Undergraduate theses / Phd Theses](#)

FUNDED RESEARCH

Ongoing Projects

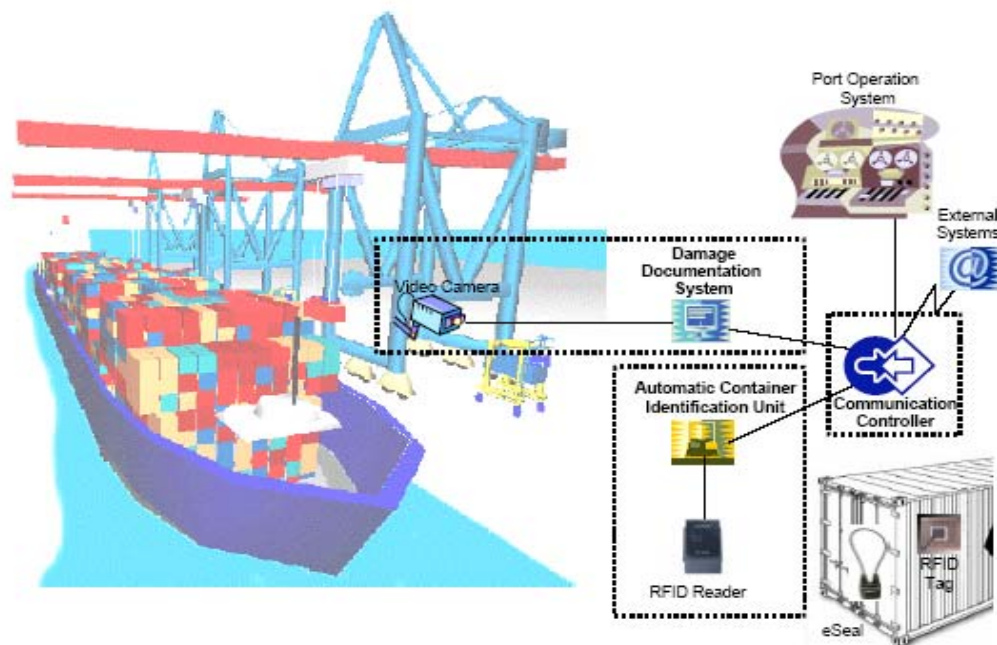
[ABS - NTUA](#)
[CHINOS](#)
[DNV - NTUA](#)
[MOSES](#)
[NUS - NTUA \(NOL\)](#)
[PLOI-GOS](#)

Completed Projects

AEGEAN	INTEGRATION
ADVANCES	MARQUAL
ATOMOS	MTCP
ATOMOS II	Oilspill Control Program
ATOMOS IV	OSH
DISC	POP&C
DISC II -ATOMOS III	PROSIT
Emissions Study (HCS)	SAFECO
EQUAL	SAFECO II
EU-MOP	SSS-CA
EVIMAR	THAMES
FLAGSHIP	THEMES
Greek Coastal Shipping	TRAPIST

CHINOS

“Container Handling in Intermodal Nodes- Optimal and Secure!”



- Development of equipment, methods and systems for optimal accommodation, fast loading and unloading of intermodal transport units and definition of optimal use of storage space both in vehicles/vessels and terminals and efficient distribution of goods.
- ISL Bremen: Leader

NUS-NTUA joint project (NOL Fellowship programme)

NTUA-NUS



ANALYSIS OF OPTIMAL CONTAINERSHIP SIZE AND ITS IMPACT ON LINER SHIPPING OPERATIONS

This is a two-year research project, jointly undertaken by the National University of Singapore (NUS) and NTUA, funding being provided by the NOL Fellowship Programme (NOL for Neptune Orient Lines). The project's duration is 1 June 2008- 31 May 2010.

Objectives

The ocean container carriers industry experiences explosive growth of sector as well as increased competition within the sector. Mergers, collaborations and considerable new investments have led to more elaborate fleets and to complex service networks with mega hubs and mega carriers. Among the many issues arising, the issue of optimal containership size has been a topic of keen industry interest because of its wide ranging impacts that affect all stack players. It is a strategic planning problem with long-term implications. This proposed project considers the optimal containership size problem applicable to the Transpacific and the Asia-Europe trade routes.

The problem of optimal containership size will be addressed in the following aspects: (a) Containership operational and cost considerations; (b) Fleet size and mix optimization; (c) Fleet deployment and routing optimisation; (d) Evaluation of impacts of containership size on hub-and-spoke operations, container-port operations and port infrastructure needs; and (e) A "holistic" approach to develop a decision support system consisting of an integrated framework of models and algorithms of distinct sub-problems.



Thank you very much!

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