Green Maritime Logistics

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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 NOx 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, NOx

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


BELUGA PROJECTS
SkySails

Green maritime logistics problems

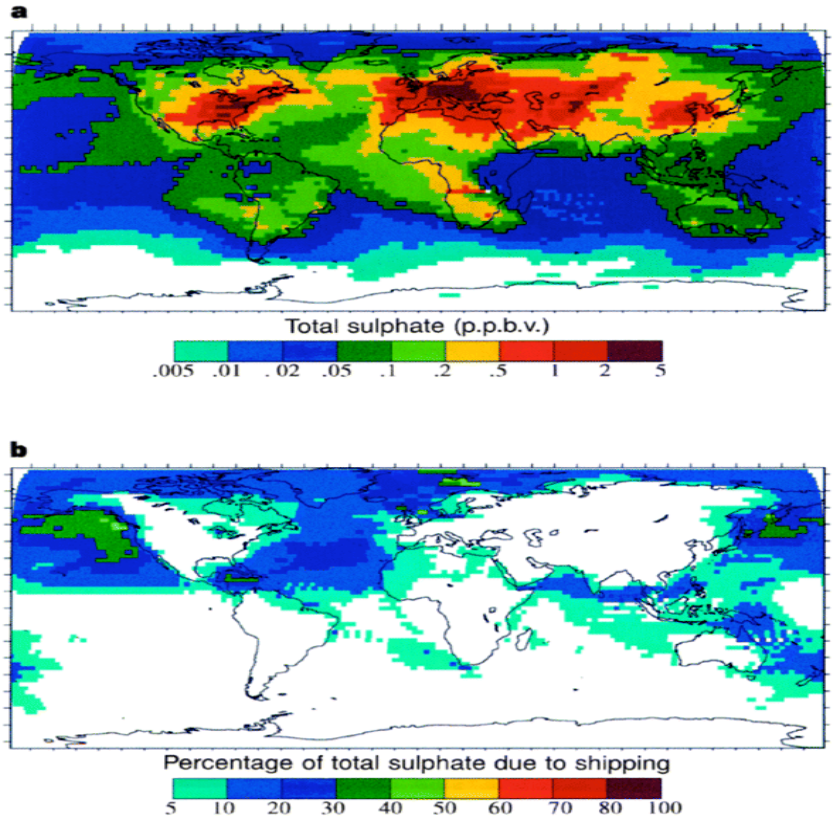
- Optimal ship speed
- Optimal ship size
- Routing and scheduling
- Fleet deployment
- Fleet size and mix
- Weather routing
- Intermodal network design
- Modal split
- Transshipment
- Queueing at ports
- Terminal management
- Berth allocation
- Supply chain management

- 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

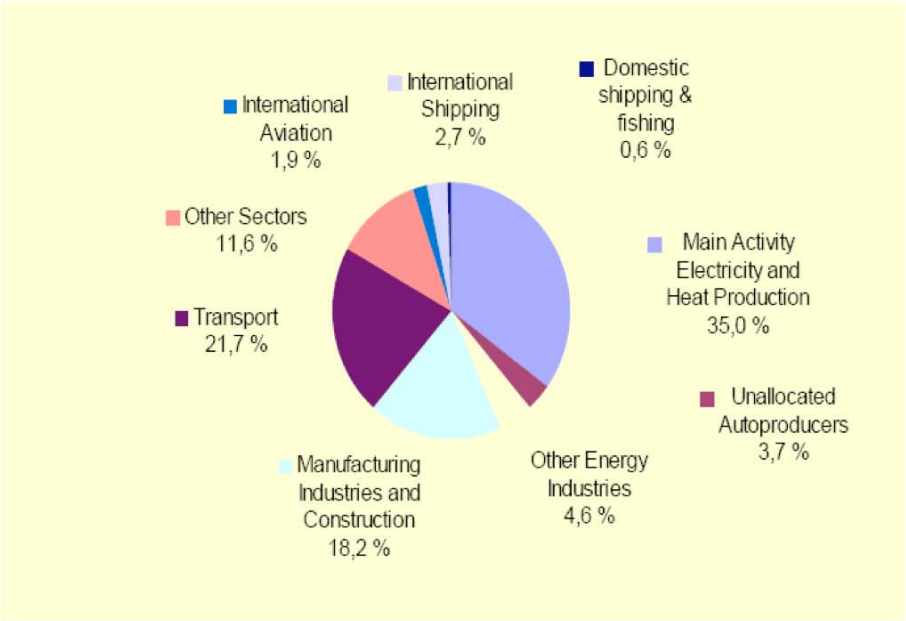
- IMO latest update of GHG study

Table 1: Consensus estimate 2007 CO_2 emissions (million tonnes CO_2). Source: Buhaug et al (2008)

	Low bound	Consensus estimate	High bound	Consensus estimate % Global CO_2 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.

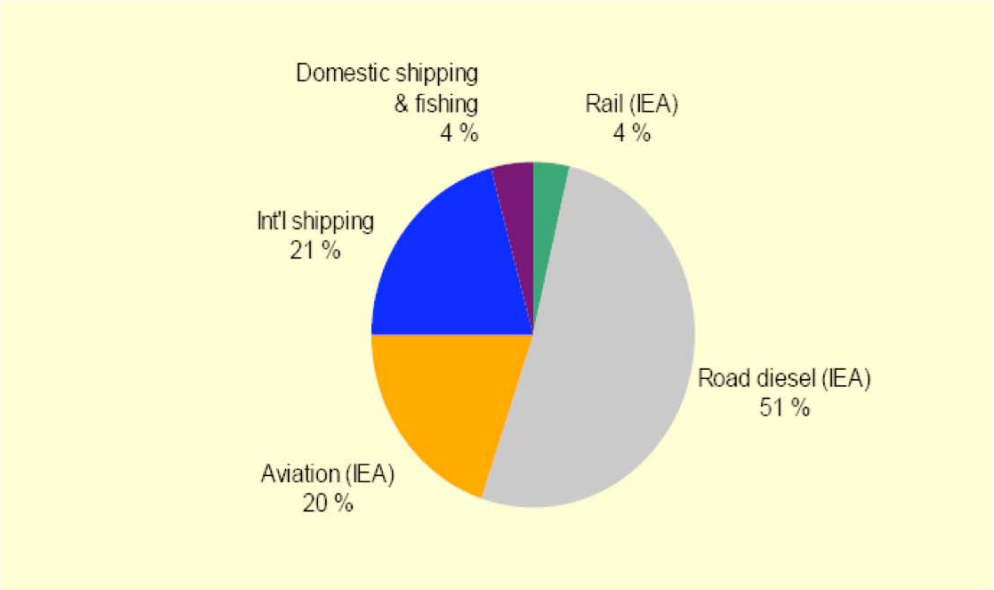
Share of global emissions



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

MARINTEK SINTEF

Comparison with other modes (2005)



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

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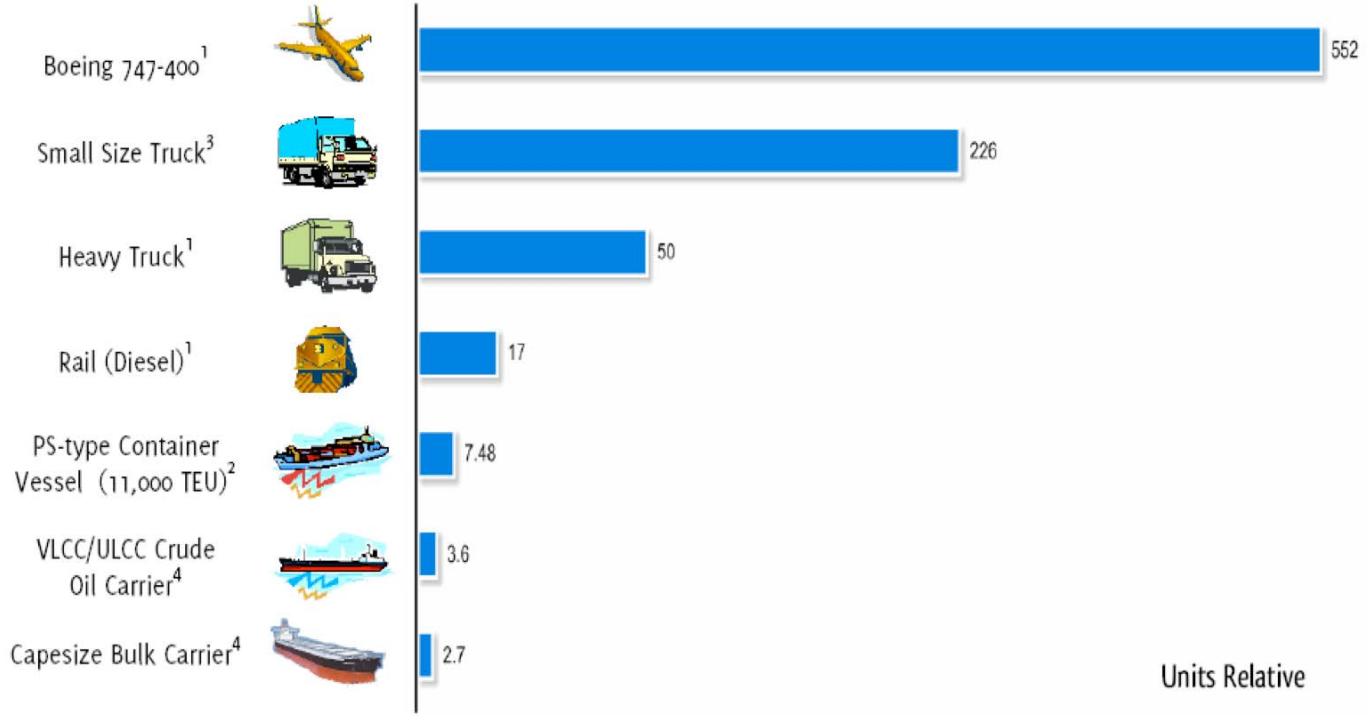
COMPARISON OF CO_2 EMISSIONS AMONG TRANSPORT MODES

(grams per tonne-kilometer)



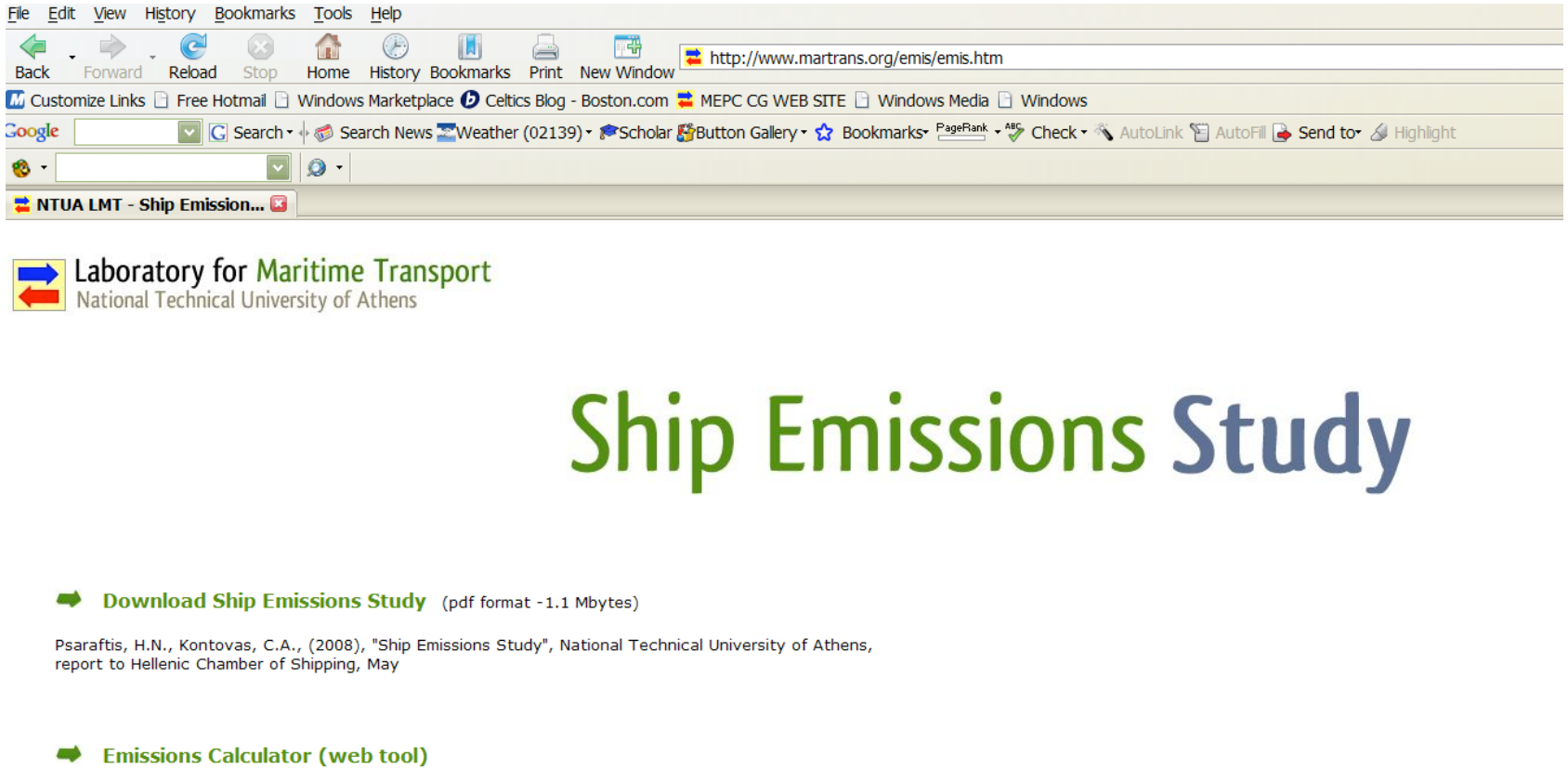
Sources:

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



Laboratory for Maritime Transport | SHIP EMISSIONS - LABORATORY F...

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LABORATORY FOR MARITIME TRANSPORT

Ship Emissions Calculator

VESSEL DETAILS

SELECT SHIP TYPE: Dry Bulk Carrier
SELECT SHIP SIZE: Handysize BC
Slow Speed En

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 %	FUEL OIL Consumption (tonnes/day)	DIESEL OIL S %	DIESEL OIL 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

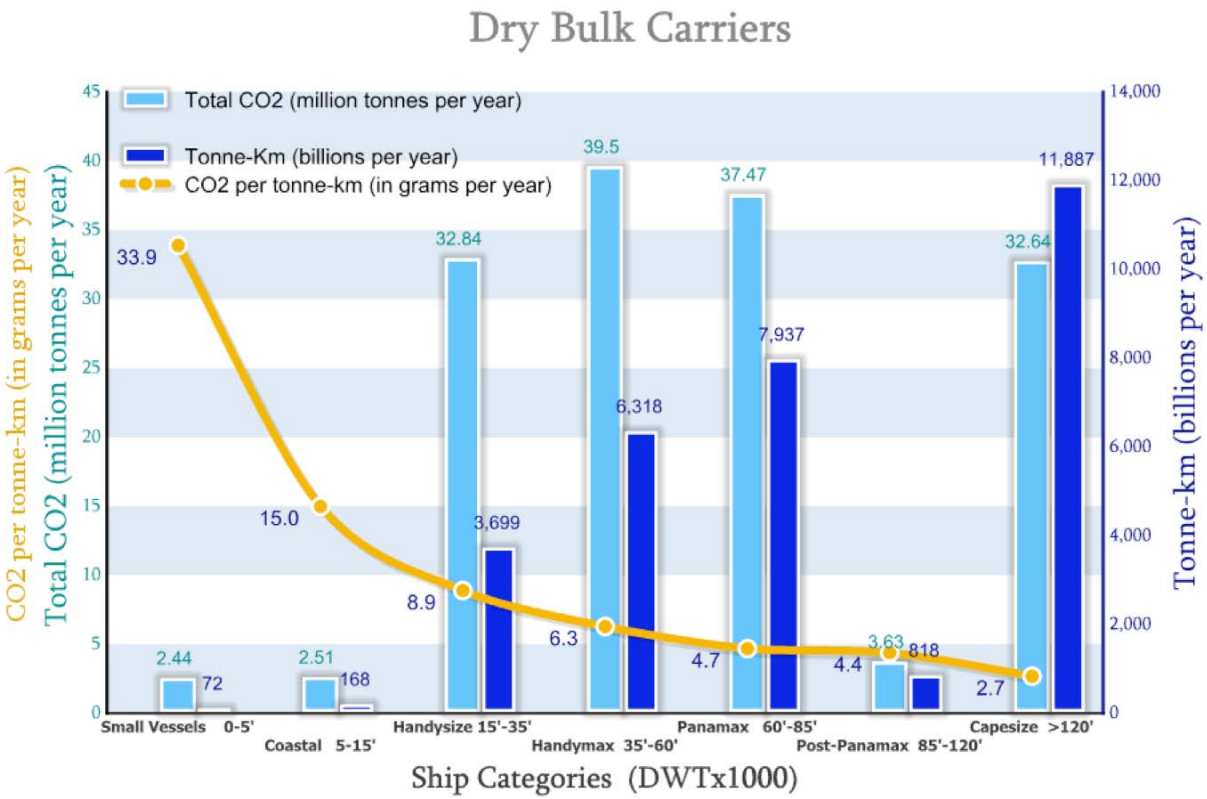
EMISSIONS

	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

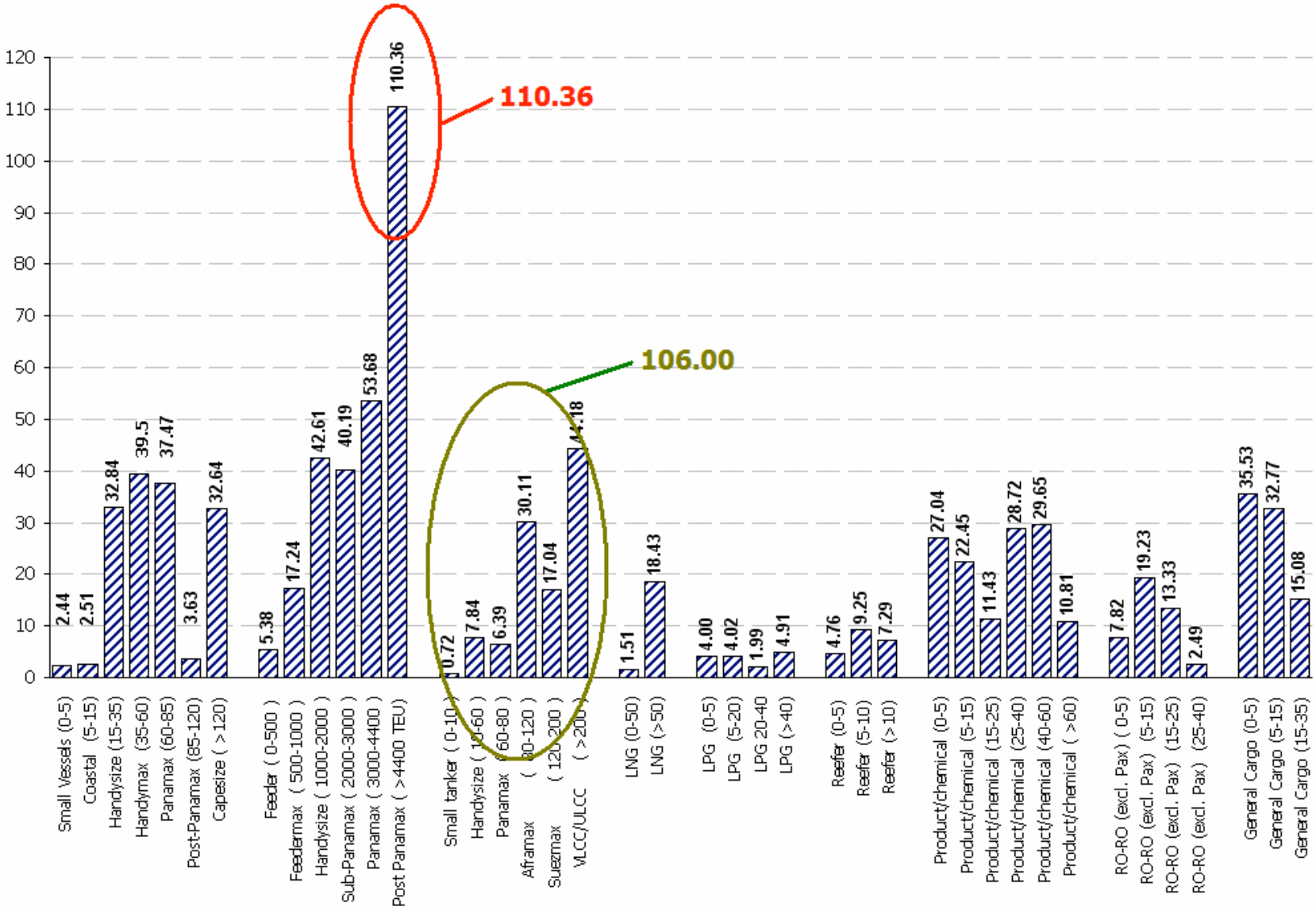
SHOW/HIDE DETAILED RESULTS | CALCULATE | HELP | ABOUT

DETAILED RESULTS

				EMISSIONS		
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			
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
Total CO2 (million tonnes per year)
Tonne-Km (billions per year)
CO2 per tonne-km (in grams per year)
CO2 per tonne-km (in grams per year)
Total CO2 (million tonnes per year)
Tonne-km (billions per year)
33.9
15.0
8.9
6.3
4.7
4.4
2.7
2.44
72
2.51
168
32.84
3,699
39.5
6,318
37.47
7,937
3.63
818
32.64
11,887
Small Vessels 0-5'
Coastal 5-15'
Handysize 15'-35'
Handymax 35'-60'
Panamax 60'-85'
Post-Panamax 85'-120'
Capesize >120'
Ship Categories (DWTx1000)

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 CO_2 (indep. of fuel type, engine type)
- 0.02*S tonnes of SO_2, where S is the % of sulphur content in fuel ($0.5 \leq S \leq 4.5$)
- 0.057-0.087 tonnes of NOx (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

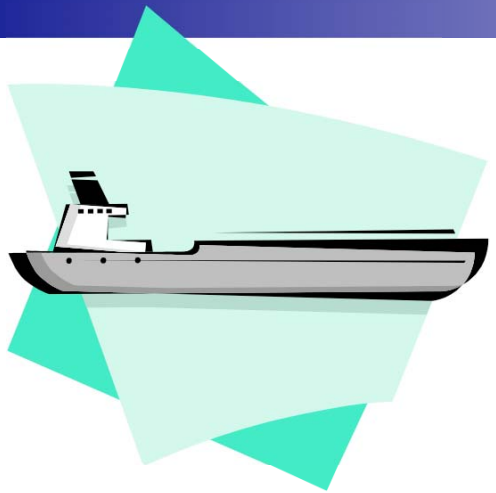
- In port: f (tonnes per day)
- At sea: F (tonnes per day)
- Effect of speed change on fuel consumption: assumed cubic for same ship, ie

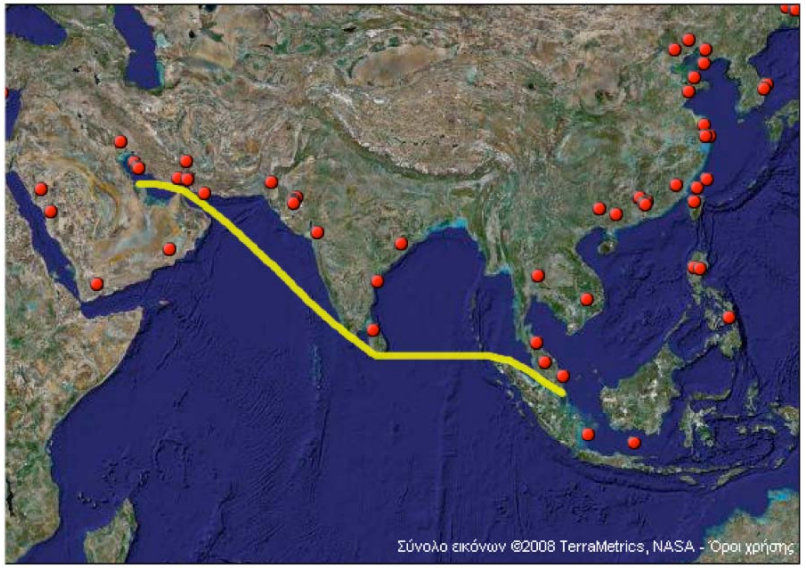
- $F_{new} / F = (V_{new} / V)^3$

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

<u>Laden Leg</u>
Speed : 14.5 Kn
Consumption : 49 tn/day

<u>Ballast Leg</u>
Speed : 14.5 Kn
Consumption : 40 tn/day

<u>At port</u>
Consumption : 116 tn/day

ROUTE DETAILS

Ras Tanura – Singapore

Distance : 3,702 nm

<u>Voyage Time:</u>
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/tonne
- Fuel bill = $69,000/day/ship

- Reduced speed v= 20 knots
- FC at 20 knots = 99.34 tonnes/day (cube law vs. 21 knots)
- Fuel bill = $60,500/day/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*50,000 = 2,190,000.
- Times 100 ships = 219,000,000.
- Total fuel burned/year/ship: 115 tonnes/day*365 = 41,975 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*50,000 = 2,085,714.
- Times 105 ships = 219,000,000 tonnes.
- Total fuel burned/year/ship: 100 tonnes/day*365 = 36,259 tonnes
- Times 105 ships = 3,807,256 tonnes
- Total fuel cost (x$600) = $2,284,353,741, **REDUCED**.

A or B better?

- B reduces CO_2 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/tonne (price of cargo)
- P=$600/tonne (price of fuel)
- OC= $20,000/day (charter rate for Panamax ship)

- Then Δ(inventory costs)= $200,000,000/yr
- Δ(charter costs)=$45,625,000/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 CO_2 averted

Formula for CATC

$$CATC = \frac{I_C WD + \frac{2O_C}{D}}{F_{CO_2} V(V - \Delta V)(2V - \Delta V)(k_1 + k_2)} - \frac{p}{F_{CO_2}}$$

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 < 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:
  - $M=N(VW/vU)$

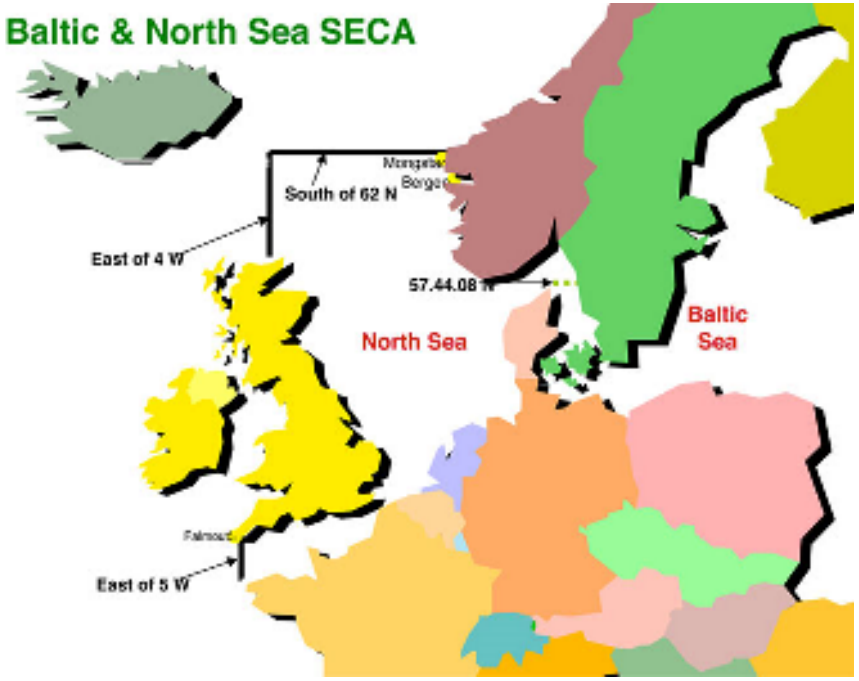
Basic result (M=N)

- **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 <u>total transit time is the same</u>.

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 <u>more total emissions</u> (of all gases, including SO2) and more total fuel spent if speed is increased outside SECA <u>to make up for lost time</u>.
- 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

Handymax Bulk Carrier W=45,000 tn

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

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

- 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

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

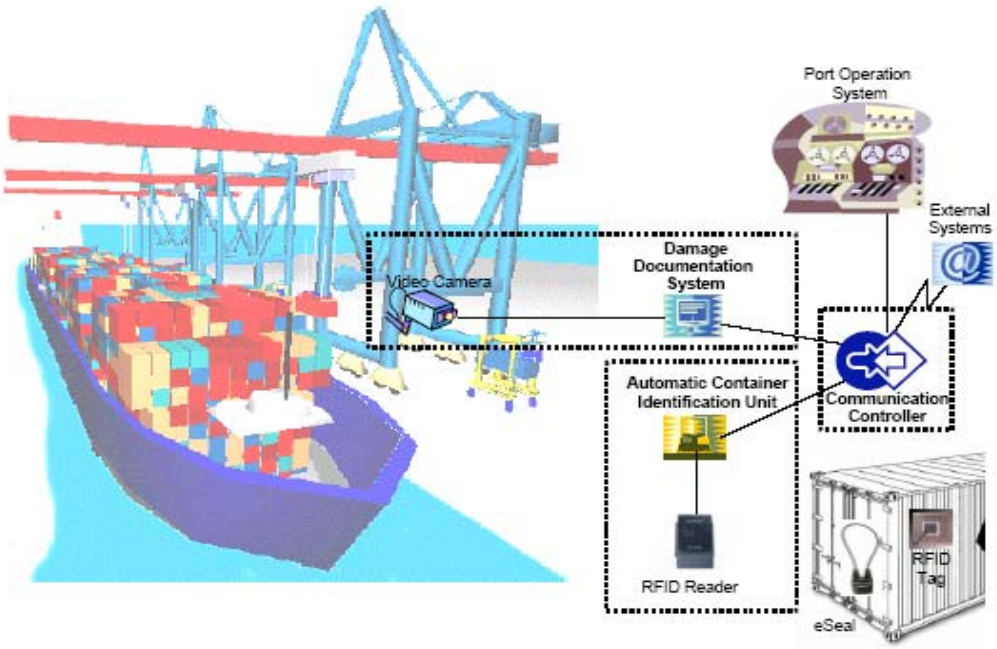
ABS - NTUA
CHINOS
DNV - NTUA
MOSES
NUS - NTUA (NOL)
PLOI-GOS

Completed Projects

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