An economic assessment of the feasibility of speed reduction schemes near ports

Thalis Zis[a*], Dominic Peter[a], Robin North[a], Panagiotis Angeloudis[a]

[a]*Centre for Transport Studies, Department of Civil & Environmental Engineering, Imperial College London, London, SW7 2BU, United Kingdom*

Abstract

The growing trends of world trade have led to an increase in the environmental effects of shipping. The IMO has set guidelines to reduce impacts of shipping while ship-owners have also aimed to reduce their fuel costs adapting the practice of slow steaming. International regulation has been introduced to tackle these impacts on a local level and ports have also started to consider additional mitigation measures to address energy consumption and local pollutant emissions. One of the most promising port policies that link local and global reduction policies has been the introduction of speed reduction policies in areas surrounding the port, with significant success in the recent past. This study builds on previous work which introduced a framework for the estimation of emission reductions through port policies, and assesses the financial feasibility of a speed reduction policy near ports for the major actors involved; port authority, ship-owners and shippers. Different policy specifications (speed limit, area size) for various ports are examined, and the scope for reduction in pollutant emissions (carbon dioxide, sulphur dioxide, nitrogen oxides and black carbon) is presented for two typical container terminals. Results show that the average trip distance of vessels calling and departing is crucial in terms of feasibility from the shippers' perspective, while the geographic location of the port and its type govern the feasibility from the port authority's point of view. The economic repercussions of the adaptation of such policies are discussed, and guidelines for its implementation are presented.

Keywords: slow steaming, speed reduction policies

1. Introduction

1.1 Maritime emissions

The maritime sector moves about 90% of world trade with a steady increase in cargo volume. This transportation activity has a significant toll on the environment with the international shipping sector accounting for approximately 3.0% of the global CO_2 emissions (Buhaug et al., 2009). Despite the increasing efficiency of engines used in international shipping, the low quality of bunker fuel results in significant emissions of sulphur emissions with estimations of 8% of anthropogenic SO_2 emissions (Eyring et al., 2005) attributed to shipping. Nitrogen and particulate matter emissions are an additional concern from the operation of marine engines. The contribution of the maritime sector to NO_x is estimated to be 30% (Corbett et al., 2007) whereas the share for Black Carbon reaches 2% (Lack et al., 2008). The resulting emissions of the operation of marine engines have significant global effects, but perhaps the most important concern in recent years has been the detrimental effect to local exposed population. Key factors contributing to the environmental footprint of the maritime sector include fuel quality, engine efficiency and hull design.

1.2 Drivers for Environmental Efficiency

[*] Thalis Zis. Tel: +44-207-594-2706
Email address: thalis.zis09@imperial.ac.uk

Key actors in maritime transportation include ship operators, shippers, port authorities and regulatory bodies. Decisions and policies developed by these actors influence the environmental performance of maritime shipping.

1.2.1 Regulations

The International Maritime Organization (IMO) has introduced industry-wide measures to reduce GHG emissions, resulting in a specific set of reduction measures, both technical and operational including improved hull, propeller and engine design targets (IMO, 2008). Additionally, fuel quality has been regulated with the specification of the maximum allowed sulphur content in fuel globally and the introduction of Sulphur Emission Control Areas (SECAS) in the Baltic Sea, the North Sea and the English Channel where ultra-low sulphur fuel use is enforced within these waters (IMO, 2009). The North American Emission Control Area (ECA) came into effect in 2012 which also targets Nitrogen and Particulate Matter emissions. Another ECA in the US Caribbean Sea is expected to take effect in the start of 2014. The ECAs mandate the maximum allowed sulphur emissions, and the ship operator may opt to use any other "fitting, material, appliance or apparatus or other procedures, alternative fuel oils, or compliance methods" to have at least the same effect in terms of emissions reductions (MARPOL Annex VI).

The European Union has mandated the use of low sulphur-content fuel for inland waterway vessels and ships at berth in Community ports (European Commission, 2005). Similar regulations have been developed by the California Air Resources Board which requires that vessels in the vicinity of Californian ports (24 NM distance) have to use high quality fuel with a 0.1% of sulphur. Table 1 summarizes the sulphur content regulations.

Table 1: Sulphur fuel content (%) regulations (MARPOL VI)

Activity	*Rule*	*2005-2012*	*2012-2015*	*2015-2020*	*2020-*
Travel within SECA	MARPOL VI	1.5	1	0.1	0.1
Travel outside SECA	MARPOLVI	4.5	3.5	3.5	0.5
Berth (Europe)	Directive 2005/33/EC	-	0.1	0.1	0.1

1.2.2 Slow steaming

In an evolving climate of environmental, legislative and financial pressures, slow steaming has become increasingly common practice in commercial shipping in recent years. Many shipping companies have voluntarily adopted slow steaming and new ships are designed to operate at lower speeds.

The main driver for speed reductions across journey has been the significant reduction of operational costs associated with the drastic drop in fuel consumption. Deployment of additional vessels at times of excess transport capacity to meet with transport demand has made slow steaming feasible (Benford, 1981). The associated reduced fuel consumption has important environmental benefits (Corbett, 2009), as even with the additional journeys generated to meet transport demand overall fuel consumption and emissions is reduced (Cariou, 2010). A comprehensive review on the taxonomy of speed models found in the literature so far is provided by Psaraftis and Kontovas (2013). Profit maximizing speeds (Meyer et al., 2012) have been a subject of various studies examining the effects of slow steaming. However, the local effects of speed reduction policies near ports has not been extensively researched, as slow steaming is by default considered a full journey practice.

1.2.3 Port authority policies and decisions

The aforementioned regulations affect all types of marine engine activity; however regional concerns have forced ports to additionally consider mitigation measures due to the impacts of the port operations on the surrounding areas. The impacts of port operations on the surrounding area can be attributed to three main categories; maritime operations, in-port operations and generated traffic outside the port's gates. The mechanisms through which each of the above contributes to the environmental footprint of a specific port differ in each case, as do the potential mitigation measures. The maritime operations affecting local air quality near ports can be further broken down to ship movements of approaching vessels, manoeuvring movements just before berth, and the hoteling activity of the vessel while stationary at berth. A summary is provided in Figure 1.

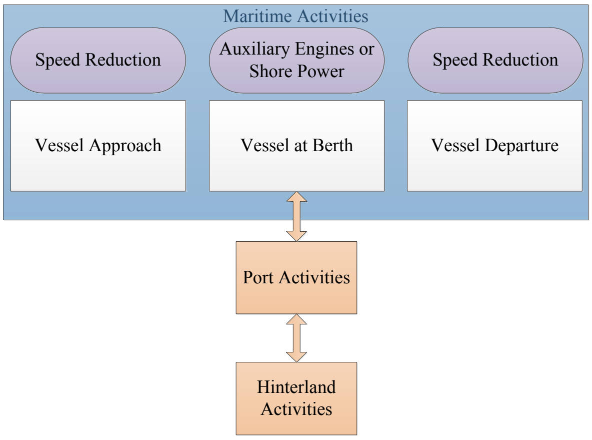

Figure 1: Contributors to a port's footprint

Port authorities are developing various initiatives to address each of the contributors. Some of the most widely advertised programs are summarized in Table 2.

Table 2: Green agendas of ports around the world

Port	*Low sulphur fuel and/or scrubbers*	*Speed reduction*	*Alternative Marine Power (or Cold ironing)*	*Ship design and operational aspects*	*Port operations, electrification, hinterland operations*
Singapore	Green Port Programme			Green Ship Programme, Green Technology Programme	
Long Beach	Main engine low-sulfur Fuel incentive Program (≤0.2%)	Green Flag Program (speed ≤ 12 kn within 40NM)	Shore Power Electricity (four berths)	Smoke Stack Reductions (maintenance, control and alternative fuel)	
Los Angeles		Green Flag Program			Clean truck programme
Antwerp			Trial	Rewards for clean vessels	
Rotterdam				Reduced fees for LNG vessels	Investing in RES

With regards to the efficiency of near-ports maritime activities, the main options available are targeting fuel quality, energy provision of ships at berth and occasionally rewarding cleaner vessels. Of particular interest are the voluntary Speed Reduction Programmes developed by the port authorities of Los Angeles (POLA) and Long Beach (POLB).

1.3 The effects of near-ports speed reduction policies

In parallel to the development of voluntary speed reduction programmes, cruise speed differentiation has been proposed (Wang and Meng, 2012) and could be applied in cases where it is known that the berth scheduled for a particular vessel will still be occupied at the expected time of arrival. In that case, port operators could issue an instruction to the vessel to reduce its speed and arrive at a time when the berth will be free, instead of idling outside the port with additional environmental burden for the local area. Extensions of the berth allocation problem have been proposed to reduce total fuel consumption and emissions by maximizing berth productivity (Golias et al., 2010).

Speed reduction policies in the vicinity of ports take advantage of the significant reduction in fuel consumption within the policy zone, however the additional travel time has interesting consequences to the ship operator's complying decision. In the following sections, a methodology that calculates the fuel consumption, the resulting emissions and the associated costs for the ship operator and the port authority is presented. We examine the feasibility of such programmes and determine the relevant variables illustrating with real-world scenarios for ports based on Felixstowe and Los Angeles. The subsequent effects on emissions of CO2, SO2, NOx and black carbon are then quantitatively assessed. Economic analysis is carried out on each of the policies, with regards to added journey time and cost savings due to reduced fuel consumption. The culmination of this research is policy recommendations in terms of parameters and potential incentive schemes for the ports under consideration and a method for applying the framework to other locations.

2. Methodology

2.1 Activity based methodologies

The Environmental Protection Agency (EPA, 2000) has developed an activity based methodology to estimate emissions for the major pollutants. A similar methodology was proposed by Dolphin and Melcer (2008). These methods essentially convert fuel consumption in to emissions by using appropriate emission factors which are based on the fuel type, engine used, and operating characteristics. Adaptations of these methodologies have been used in a variety of studies on the environmental impact of transport (Corbett et al, Cariou, Psaraftis and Kontovas). This study builds on some of the existing methodologies with a particular focus on vessel activity near ports when speed reduction programmes are in place.

A vessel journey consists of three distinct journey phases: cruise, maneuvering and in-port time (Corbett, 2002). The fuel consumption can be determined by considering the engine activity within each phase. During cruise the main engines are operating near design speeds to provide the necessary thrust for propulsion, while the auxiliary engines are operating to satisfy the vessel's electrical requirements. In the maneuvering phase, the main engines may be switched off (for sufficiently long berth durations) and the auxiliary engines are working at high loads (POLA, 2011). When the vessel is docked, the auxiliary engines are operating to provide power for the vessel's hoteling activities, and additionally the auxiliary boilers are fired to keep the fuel for the main engines warm. In the case where alternative marine power is provided to the vessel (cold ironing), the auxiliary engines are switched off resulting in significant local emissions reductions (Zis et al. 2013) and only the boilers are used to maintain the fuel temperature at the desired levels.

2.2 Cruise fuel consumption and role of speed

For a vessel travelling a distance of D (NM) with a constant speed V (knots), the required fuel (kgs) can be found by:

$$FC_{cruise} = 10^{-3} \cdot SFOC_{main} \cdot EL_{main} \cdot EP_{main} \cdot \frac{D}{V} + 10^{-3} \cdot SFOC_{aux} \cdot EL_{aux,cruise} \cdot EP_{aux} \cdot \frac{D}{V} \qquad (1)$$

Where SFOC (g/kWh) is the specific fuel oil consumption of the engine used, EL (%) the engine load and EP (kW) the nominal engine power installed. Typically the maximum continuous rate during cruise ranges between 70 and 90% assuming that the engine operates near its design speed (Cariou, 2010).

Vessel types, engine age and engine characteristics vary the behavior of SFOC during engine load changes. The rule of thumb that engine power is proportional to speed cubed is adapted. A speed reduction would result in a severe drop in the EL, with a small increase in SFOC. Travel time (and thus activity time) will increase, but overall the fuel consumption will decrease. Figure 2 shows the fuel consumption per NM travelled at various speeds, for a typical large containership with a 2-stroke slow speed main engine installed as well as its SFOC curve (MAN, n.d.). The error bars plotted along the y-axis illustrate the variability of fuel consumption with engine load.

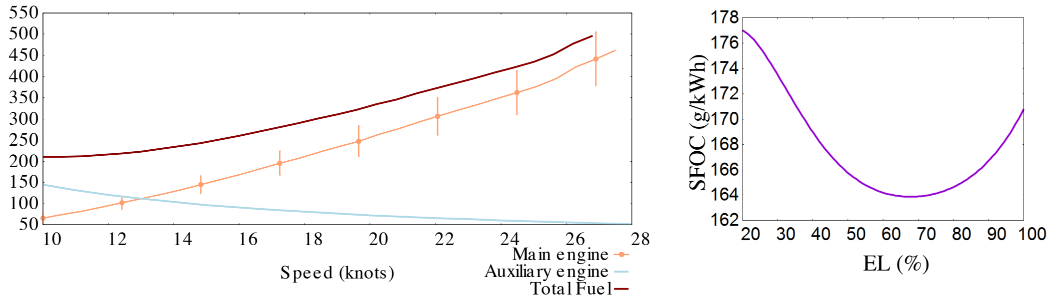

Figure 2: Fuel Consumption per NM travelled

2.3 Emission factors

The resulting emissions P_i can be obtained by multiplying fuel consumption with the respective emission factors EF_i.

$$P_i = EF_i \cdot FC_{ME_{zone}} \tag{2}$$

A factor of 3.17 is used to estimate carbon dioxide emissions. The 2009 update of the IMO GHG study suggests adjusting these factors depending on the fuel used. For sulphur dioxide emissions, the content of sulphur in the fuel is critical. Multiplying fuel consumption with 0.02 times the percentage of sulphur present in fuel gives the SO2 emissions. NOx emissions depend on engine type and range from 0.087 for slow speed engines to 0.057 for medium speed engines (Dolphin and Melcer, 2008). Black Carbon emission factors vary substantially between vessels and can increase significantly with reductions in engine load (Lack and Corbett, 2012). We adapt a basic value of EF_{BC} 0.0008 ± 0.00023 g/g-fuel for container ships (Lack et al, 2009) taken to represent emission at the vessel's design speed, with EF_{BC} for reduced loads derived from the curves of Lack and Corbett (2012). Emission factors for all species are summarised in Table 3.

Table 3: Emission factors for major pollutants (g/g)

Pollutant P_i	*Basic Emission Factor EF_i*	*Fuel*		
		LNG	HFO	MDO
CO_2	3.17	2.6-2.8	3.021	3.082
		Fuel Sulphur Content ($S_\%$)		
SO_2	$0.02 \cdot S_\%$	2012-15: 3.5%, SECA 1.0%, EU berth 0.1%		
		Engine Speed		
		Slow	Medium	
NO_x	0.057, 0.087	0.087	0.057	
		Engine Load		
Black Carbon	0.0008 ± 0.00023	*variation is a function of EL*		

2.4 Port emissions inventory

To estimate emissions within an area a bottom up approach may be used. Necessary information includes the activity taking place within the area, the vessel specifications and movement patterns. Port authorities usually publish their short term expected incoming traffic as well as the most recent activity. From a theoretical perspective, ship arrivals can be modelled through Poisson processes and berth durations conform to Erlang distributions (El-Naggar, 2010). Queuing theory is also applied for the berth scheduling problem, as well as for the modelling of traffic within canals as found in the literature for the Bosporus Straits (Mavrakis and Kontinakis, 2008). Saxe and Larsen (2004) estimate air pollution from ships in three Danish ports based on port activity and model the dispersion of major pollutants. Similar methodologies are used by port authorities published in their annual emissions inventory. Anticipated growth of traffic can also be modelled to allow estimations of resulting emissions. In this work, online published data of the incoming vessel traffic into two ports was used to develop the inventory.

3. Speed reduction programs

The Port of Los Angeles and Port of Long Beach were the first to implement voluntary speed reduction programs in 2008, as part of the Green Flag Programme. Initially, a policy zone of 20NM was established where ocean going vessels commiting to reduce their speed down to 12 knots for at least 90% of their annual calls, would be compensated with a reduction of 15% of their first day dockage fee for each call. This policy zone was then extended to 40NM with a 30% discount, and both schemes are now running in parallel. Compliance so far has been very high surpassing 90% for the 20NM program and 70% for the 40NM in 2011 for POLA. This has led to significant reductions of pollutants in the area due to the decreased fuel consumption within.

3.1 Local benefits

The associated cost reductions from reduced fuel consumption are a more minor consideration as these represent only a small fragment of the total trip. In addition, there are indirect benefits that could arise associated with speed reduction around the port. The application of such a scheme would mean that in a buffer area around the port, vessels would be arriving at either a universal speed, or at the very least at reduced speeds. This could improve potential queuing phenomena and help relieve bottlenecks at the berths. The extent of the environmental benefits depends on the speed limit, the policy zone length and the baseline travelling speed. The scope for reduction in pollutants can now be estimated for a variety of ports where the vessel fleet, arrival and departure times are known: For n ships k each travelling at a constant speed V_0 in the vicinity of a port within a zone of length z, the total emissions of pollutant i can be found using equation 4.

$$p_{i,port} = EF_i \cdot 2\left(\sum_{k=1}^{n} SFOC_{main,k} \cdot EL_{main,k} \cdot EP_{main,k} \cdot \frac{V_0}{z-0.5} + \sum_{k=1}^{n} SFOC_{aux,k} \cdot EL_{aux} \cdot EP_{aux} \cdot \frac{V_0}{z-0.5}\right) \quad (3)$$

The emission savings from compliance can be found by using equation 4 and changing the values of speed, SFOC and EL according to the policy specified. The 0.5NM is illustrating the assumption that at the last/first half mile of the journey when the maneuvering takes place the fuel consumption is not changing with the travelling speed within the zone. The savings can then be compared to total footprint of the maritime activity of the port (including the zone of interest, maneuvering movements and berth energy requirements). The effects of a speed reduction policy of 12 knots for a 12NM zone in the ports of Felixstowe and Los Angeles is illustrated in Figure 3.

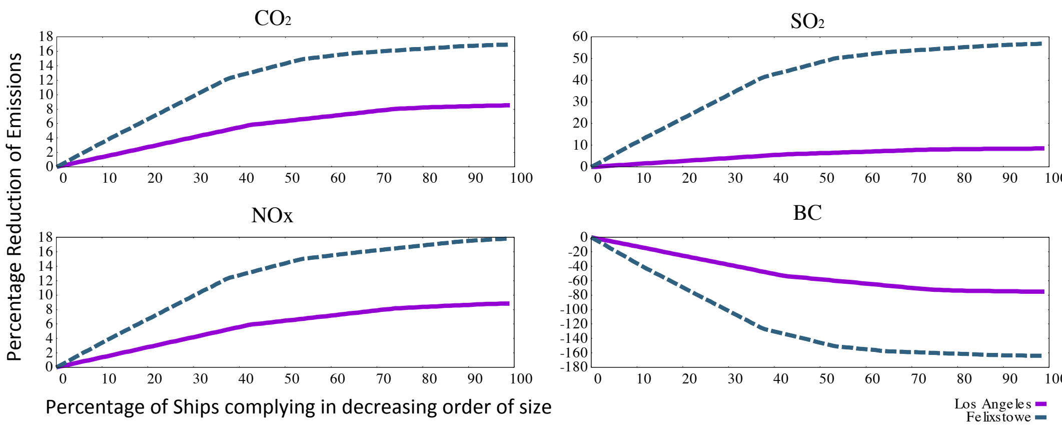

Figure 3: Potential emission savings through near-port speed reduction

The horizontal axis represents the percentage compliance of vessels arranged in a decreasing order of size, while the vertical axis shows the percentage change in the total emissions of maritime activity in the port. Average berth durations were used. It appears that this policy could result in significant reductions of each port's footprint, with the notable exception of Black Carbon emissions where a relative increase is observed.

3.2 Compliance criteria

In similar voluntary schemes theoretically all vessel types could comply. The high level of compliance especially amongst container ships in the Californian ports provides evidence that generally ship operators are better off conforming to the speed reduction. However, since there are not many similar schemes currently operational it is interesting to examine whether the policies in California are deployed in the most effective way. In this section, we aim to identify the drivers and main parameters governing a complying decision from the ship operator's perspective.
A complying decision to a speed limit V_l would significantly reduce fuel consumption within the policy zone, and coupled with the reward offered by the port authority the ship operator would see their operating costs reduced. However, reducing the speed for even the shortest distance increases the total travel time for each journey (incoming and outgoing) as shown in equation 5

$$t_{lost} = \frac{z}{V_l} - \frac{z}{V_0} \tag{4}$$

Ship operators can be somewhat flexible with regards to their arrival time at berth, but large delays are not acceptable as additional costs can be carried due to contract violations (for cargo ships). The exact costs of a time delay are difficult to quantify as these depend on the cargo loaded and the actual delay. The ship operator also has the option of slightly increasing their cruise speed outside the policy zone to compensate for time lost from compliance. In this case, the overall fuel consumption will increase and compliance would occur only if the reward from the port authority is greater. This additional cost is a function of the ship type as well as the overall trip distance. For shorter trips the required increase in speed is larger, moving the engine operation point further away from the optimal. Environmentally, if the vessel complies with the program but at the same time increases travelling speed outside the zone the overall emissions are increased (globally) despite the reduction near the port as depicted in Figure 4 for a trip distance of 500 NM and a policy zone of 12NM for various speed limits imposed on large container ship.

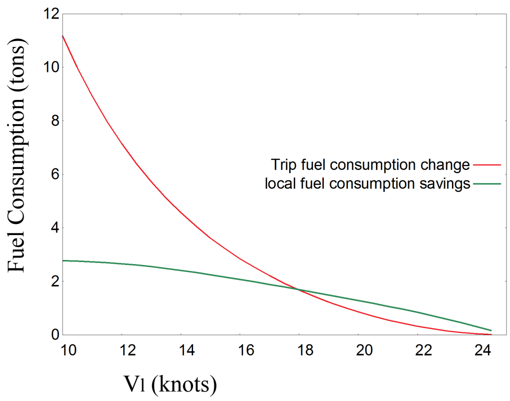

Figure 4: Fuel consumption for increasing speeds outside of policy zone

4. Selected Case Studies

4.1 Data Collection

The subsequent analysis considers the arrival and departure of vessels in March 2013 at the port of Felixstowe and the port of Los Angeles as seen in Figure 5. Container vessels with lengths greater than 100m are considered to represent ocean going vessels. Schedule information was collected for each vessel; arrival and departure times into each port to retrieve time spent at berth, previous port call and distance, next port call and distance.

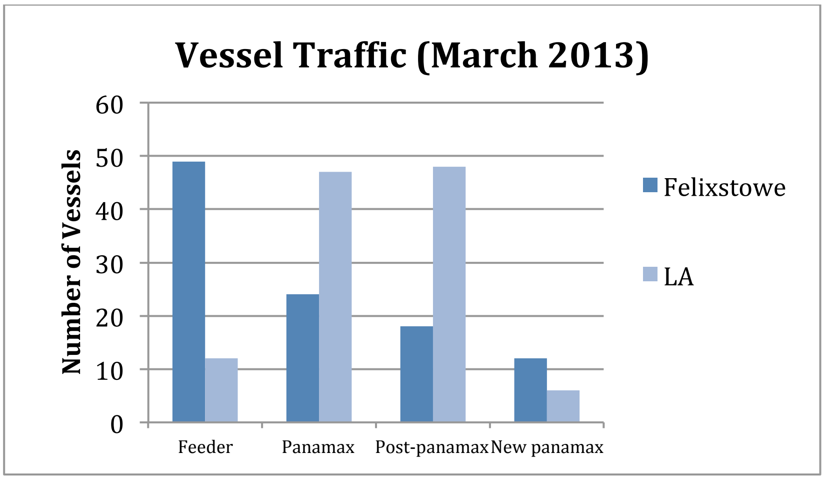

Figure 5: Vessel traffic in LA and Felixstowe

Where necessary data (design speed, installed power, SFOC) of a vessel for the estimation of pollutant emissions was missing a classification into typical container ships was used, with the typical vessels and their specifications presented in Table 4.

Table 4: Containership classes used for missing data

Containership Class	*TEU Capacity*	*EP_{main} (kW)*	*Engine Speed*	*Speed (knots)*	*$SFOC_{main}$ (g/kWh)*	*EP_{aux} (kW)*
Feeder	1000 - 3000	8400	Medium	19.9	178	1848
Panamax	3001 - 5000	35678	Slow	23.9	175	7849
Post-Panamax	5001 - 10000	65000	Slow	24.2	175	15000
New panamax	10001 - 14000	75000	Slow	24.6	172	16500
ULCC	14001 -	81000	Slow	25	165	22000

It has to be noted that in the following analysis, we consider that the design speed is used when a vessel is not complying. Furthermore design speed is used as there is little verified data on actual operating speeds. This assumption ensures that the calculated savings from a complying decision are not overestimated.

4.2 Baseline case

To facilitate comparisons we assume that all vessels would be travelling at their design speeds in the policy zone, the maneuvering phase takes place at the last/first 0.5NM and the berth duration is the one published in the port authorities website.

Table 5: Baseline emissions inventory

Pollutant (tons)	**Port**					
	Los Angeles			*Felixstowe*		
	Zone (per NM)	*Maneuvering*	*Berth*	*Zone (per NM)*	*Maneuvering*	*Berth*
CO2	3952.9	401.88	12424	2109.8	264.85	3374
SO2	2.5	0.25	7.83	13.3	0.17	2.1
NOx	101.7	7.23	223.4	51.6	4.76	60.7
BC	1.3	0.10	8.1	0.7	0.06	2.2

Comparing the two ports it is obvious that the at-berth emissions are far greater in LA, almost triple than in Felixstowe whereas the cruise and maneuvering emissions are also higher due to the increased traffic. The even higher difference at berth emissions is due to the lengthier duration observed in LA. However, the cruise-sulphur emissions are lower in Felixstowe, because of the tighter regulation regarding sulphur content from CARB. Sulphur emissions at berth are very low for both ports as a similar ultra-low sulphur content policy applies to both ports (CARB and EU port respectively). A different speed zone would not affect the berth and maneuvering emissions, however the zone emissions would change as seen in Table 5.

Table 6: Baseline emissions inventory for different zones

Pollutant (tons)	**Port**							
	Los Angeles				*Felixstowe*			
Zone length (NM)	*12*	*20*	*40*	*60*	*12*	*20*	*40*	*60*
CO_2	3952.9	6702.8	13577.4	20452.1	2109.8	3557.5	7246.8	10916
SO_2	2.5	42.3	85.6	129.0	13.3	22.6	45.7	68.9
NO_x	101.7	172.5	349.4	526.4	51.6	87.4	177.1	266.8
BC	1.3	2.2	4.4	6.7	0.7	1.2	2.4	3.6

4.3 Potential of speed policies

In this section we examine the total emissions saved through a speed reduction policy for different speed limits and zone lengths. We consider three zones, 12,20 and 40NM to reflect a realistic zone length for Felixstowe (as many trips are very short) and allow comparisons with the existing scheme at LA. We consider three different speed limits of 12, 15 and 18 knots, and compare with regards to feasibility from the ship operator’s perspective. Table 6 summarises the potential for emissions reduction if all vessels complied with each policy.

Table 7: Potential for emissions savings

Speed limit: 12 knots

Pollutant savings (tons)	**Port**					
	Los Angeles			Felixstowe		
Zone length (NM)	12	20	40	12	20	40
CO_2	1013.1	1717.9	3479.8	855.2	1450.2	2937.5
SO_2	0.63	1.1	2.2	5.4	9.2	18.5
NO_x	28.7	48.6	98.4	23.1	39.2	79.4
BC	-0.96	-1.6	-3.3	-0.95	-1.6	-3.3

Speed limit: 15 knots

Pollutant savings (tons)	**Port**					
	Los Angeles			Felixstowe		
Zone length (NM)	12	20	40	12	20	40
CO_2	577.6	979.4	1983.9	536.7	910.1	1843.6
SO_2	0.36	0.62	1.25	3.4	5.7	11.6
NO_x	16.2	27.5	55.8	14.7	24.9	50.4
BC	-0.39	-0.67	-1.4	-0.38	-0.65	-1.3

Speed limit: 18 knots

Pollutant savings (tons)	**Port**					
	Los Angeles			Felixstowe		
Zone length (NM)	12	20	40	12	20	40
CO_2	192.8	326.9	662.1	219.3	371.9	753.3
SO_2	0.12	0.21	0.42	1.38	2.35	4.75
NO_x	5.4	9.1	18.5	6.17	10.5	21.2
BC	-0.05	-0.10	-0.20	-0.10	-0.17	-0.35

We observe that in all cases an almost linear relation stands for savings and zone length while a lower speed limit shows greater savings but also greater increase in BC emissions. Regarding BC emissions, an 18 knot limit has an almost neutral effect which can be attributed to the fact that the engines are operating closer to design levels where the BC emission factors do not increase as much. For both ports the sulphur emissions are not reduced significantly as there are very strict limits in sulphur content and as a result the baseline emissions are not that high in the first place. This fact can also be explained in POLA and POLB's policy programs which are 'marketed' as nitrogen emissions reduction programs (POLA, POLB websites).

4.4 Effects in trip duration

A port authority has to consider whether it is worth investing in such a scheme. The key decisions have to do with the zone length, the speed limit, different tier programs and most importantly the incentive offered to a ship operator. With regards to zone length, each vessel would have a different float depending on its trip schedule (previous-next port of call) and operating speed. Having only a one-tier vessel speed reduction program would fail to capture some ship operators who would not have the time to comply, or risk having lower environmental returns by increasing compliance with a small zone. Similar arguments stand for the speed limit imposed, as it also depends on each vessel's specifications. However, a different speed limit tier implementation would be more difficult to monitor and could also contribute to queuing phenomena in the proximity of the port.
Table 8 presents the average extra time incurred (arrival and departure) assuming all vessels examined in March 2013 would comply (excluding the ones travelling with lower speeds than the imposed limit).

Table 8: Average time lost with compliance

Zone length (NM)	**12**	**20**	**40**
Speed limit (knots)		**Los Angeles**	
12	0.56	0.94	1.90
15	0.32	0.52	1.06
18	0.12	0.18	0.36
		Felixstowe	
12	0.66	1.10	2.17
15	0.3	0.50	1.01
18	0.18	0.28	0.58

We observe that on average the delay at the longest zone and lower speed limit (as in the POLA and POLB programs) is close to 2 hours. This time interval is significant (depending on the previous and next trip length), however it can be expected that it is within the expected time window of arrival for a vessel. Additionally, if a vessel agrees to comply to the program it is in the port authority's interest to account for the delay and provide a convincing incentive to the ship operator. It should be noted that if the ship operator was investing this extra time in slow steaming across the trip rather than the final leg within the zone, operating costs would be lower and a well-informed ship operator could opt for this decision with reduced local environmental benefits enjoyed near port (but actual global benefits achieved).
However, the very high compliance rate reported by POLA and POLB, raises the question as to why do ship operators sacrifice this additional time near port instead of across the trip. This can be attributed to the additional existing regulation from CARB that vessels within 24NM of the shore have to use very low-sulhpur content fuel. This fuel is significantly more expensive, up to 50% pricier in 2013. Therefore, the ship operator by reducing their speeds for the vessel speed reduction program, manages to severely cut his fuel consumption within the regulation area of CARB. In effect, the ship operator manages to reduce its fuel cost, comply to the regulation and additionally take advantage of the incentive. This fact may also explain the lower compliance rate at the 40NM zone.

4.5 Economic repercussions

Identifying an optimal pricing policy for the incentive provided to each ship is a difficult task. In the case of the Californian ports, the incentive is provided as a percentage of the first day dockage fees payable by the ship. The dockage fees are depending on the vessel length. The economic costs for a ship complying with the decision are not a function of the vessel's length, but rather a function of its fuel consumption savings (or extra costs) and thus the installed engine power, and also the cost of a potential contract violation due to any delay on the containers shipped. The latter, is especially difficult to estimate and in this analysis we consider that for a delay of up to 4 hours no penalty is borne, and for higher delays the vessel would increase speed outside the zone. Table 9 summarizes the main cost elements for full implementation of the vessels calling in March 2013 assuming the same pricing system used by POLA, average fuel prices of the same month and additional cost if all vessels would increase their speed of the zone.

Table 9: Cost elements (March 2013 traffic and prices)

	Port					
	Los Angeles – 167 vessels			Felixstowe – 169 vessels		
Zone (NM)	**12**	**20**	**40**	**12**	**20**	**40**
PA Cost ($)	44316	73860	147720	29322	48870	97740
Fuel saved Local (tons)	320	542	1097	270	450	912
Total Fuel ($) no delay	62064	102316	150664	18720	107293	822946
Pollutant	**Cost per ton of local pollutant reduction ($/ton)**					
CO_2	43.74	43	42.45	34.52	33.93	34.03
SO_2	6933	6845	6728	5471	5378	5393
NO_x	1547	1520.4	1501	1278	1256	1258.9

We observe that the expected port authority cost is higher for Los Angeles due to larger vessels arriving as well as the absolute emissions reduction achieved. A larger zone would be marginally more cost effective in each port, while comparing the two ports Felixstowe would achieve more for fewer resources. Table 9 also shows that if all vessels complied and at the same time would increase their speed off the zone, the additional fuel consumption would be higher and the total fuel costs higher even though pricier fuel is saved within the zone. We can also see that the total fuel costs outweigh the port incentive, which could be translated as no compliance for many ship operators with the current scheme. This is particularly evident for the case of Felixstowe (in all cases). In contrast, for LA the difference is not that high indicating that the overall distances are long enough to allow a reasonable speed without increasing total fuel costs above the incentive. Thus, for the Felixstowe a higher incentive (or a lower speed limit) should be provided in order to have realistic expectations with regards to local emissions savings. The costs per ton of pollutants can be used as a guide to compare with other emission reduction policies and technologies as well as prices in emissions trading schemes.

5. Conclusions

This paper examined the feasibility and effectiveness of speed reduction policies near ports. We extended a framework for the estimation of pollutant emissions in the near port area from maritime activity. The potential for percentage reduction of emissions within a terminal was calculated for different policy specifications and the cost per ton of pollutant was assessed. The trade-offs experienced by ship operators were discussed with respect to time constraints and alternative options of using the additional time. The local benefits enjoyed through a complying decision are contrasted with the additional fuel consumption and resulted emissions should a ship operator increase travelling speed off the zone. The cost of similar policies constitutes vessel speed reduction schemes affordable and effective with regards to local benefits. However, in order to improve the effectiveness of such policies the characteristics of the port and the visiting fleet need to be carefully examined to ensure that the implemented policy will be cost effective and capture as many ship operators as possible. Suggestions for future work include comparisons of similar schemes with other technologies, and the specification of the most cost-effective policy specification for each port (zone length, speed limit, incentive for each ship, different tiers).

Acknowledgments

This work was co-funded by the project “Scholarships Greek State Scholarship Foundation” from the resources of OP “Education and Lifelong learning” of the European Social Fund (ESF) and the NSRF 2007-2013.

References

1.Benford (1981). "A simple approach to fleet deployment". *Maritime Policy & Management: The flagship journal of international shipping and port research*, **8:4**, 223-228

2.Buhaug, Ø *et al*. (2009). "Second IMO Greenhouse Gas Study 2009". International Maritime Organization

3.California Air Resources Board (2012). "Ocean-Going Vessels – Fuel Rule". Available at: http://www.arb.ca.gov/ports/marinevess/ogv.htm [Accessed July 2013]

4.Cariou, P. (2011), "Is slow steaming a sustainable means of reducing CO2 emissions from container shipping?". *Transportation Research Part D: Transport and Environment,* **16**, 260–264.

5.Corbett, James J. (2002). "Emissions from ships in the northwestern United States." *Environmental science & technology* **36(6)**. 1299-1306.

6.Corbett, J.J., Wang, H., Winebrake, J.J., (2009). "The effectiveness and costs of speed reductions on emissions from international shipping." *Transportation Research Part D: Transport and Environment* **14**, 593–598.

7.European Commission (2005). "Directive 2005/33/EC amending Directive 1999/32/EC as regards the sulphur content of marine fuels". Available at: http://www.ops.wpci.nl/_images/_downloads/_original/1264149906_2005eudirectivesulphurcontentofmarinefuels2005_33.pdf [Accessed at May 2013]

8.Dolphin, M.J. and Melcer, M. (2008). "Estimation of Ship Dry Air Emissions". *Naval Engineers Journal*, **120(3)**, pp.27–36.

9.Environmental Protection Agency (EPA 2000), "Analysis of Commercial Marine Vessels Emissions and Fuel Consumption Data." Available at: http://www.epa.gov/oms/models/nonrdmdl/c-marine/r00002.pdf [Accessed March 2012]

10.European Commission (2005). "Service Contract on Ship Emissions: Assignment, Abatement and Market-Based Instruments." Available at: http://ec.europa.eu/environment/air/pdf/task1_asign_report.pdf [Accessed August 2012]

11.European Commission (2009). "Directive 2009/29/EC amending Directive 2003/87/EC so as to improve and extend the greenhouse gas emission allowance trading scheme of the Community."

12.International Maritime Organization (2008). "Prevention of Air pollution from ships". Available at: http://www.imo.org/blast/blastDataHelper.asp?data_id=26402&filename=INF-6.pdf [Accessed March 2012]

13.Lack D.A., Corbett J.J., (2012). "Black carbon from ships: a review of the effects of ship speed, fuel quality and exhaust gas scrubbing". *Atmospheric Chemistry and Physics*, **12**, pp. 3985-4000.

14.MAN Diesel A/S (n.d.). "Low Container Ship Speed Facilitated by Versatile ME/ME-C Engines." Available at: http://www.mandieselturbo.com/files/news/filesof8410/5510-0038-04.pdf [Accessed May 2013]

15.Psaraftis, H.N. and Kontovas, C.A., (2010). "Balancing the economic and environmental performance of maritime transportation." *Transportation Research Part D: Transport and Environment*, 15(8), pp.458–462.

16.Psaraftis H.N., Kontovas C.A., (2013). Speed models for energy-efficient maritime transportation: "A taxonomy and survey." *Transportation Research Part C* (26), pp. 331-351

17.Port of Los Angeles (2009). "Vessel Speed Reduction Incentive Program Guidelines." Available at: www.portoflosangeles.org/pdf/POLA VSRIP_111209_ca_cp.pdf [Accessed June 2013]

18.Port of Los Angeles (2011). "Inventory of Air Emissions – 2011". Available at: http://www.portoflosangeles.org/pdf/2011_Air_Emissions_Inventory.pdf [Accessed March 2013]

19.Saxe, H., Larsen, T., (2004). "Air pollution from ships in three Danish ports". *Atmospheric Environment* **38**, 4057–4067.

20.Zis, T., North, R.J., Angeloudis, P., Bell M.G.H., (2013). "A systematic evaluation of alternative options for the reduction of vessel emissions in ports." *Transportation Research Board 92nd Annual Meeting* (No. 13-5346).