Understanding ship operating profiles with an aim to improve energy efficient ship operations

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Abstract

On 1st January 2013 the IMO introduced Maritime Energy Efficiency Regulations in order to benchmark the energy efficiency of new ship designs and to create a framework for the management of energy efficient ship operations for all new and existing ships. It is necessary that energy efficiency improvements for design and operational performance reflect an understanding of the ship's operational profile, rather than its design condition alone. A ship design is typically carried out by optimising the hull form for a limited range of operating conditions, acknowledging that in recent years there have been significant advancements in the application of ship design optimisation processes, particularly with increasing computing capabilities. However, a vessel only operates in its design conditions a small proportion of the time.

This paper presents an analysis of operating profiles for different ship types and identifies key trends of the operating profiles over recent years. This analysis considers; the proportion of time spent in ballast or laden, in port, manoeuvring or sailing; operational speed ranges, mean draft ranges. The analysis has been undertaken using reports commonly known as 'noon' and 'port' reports that are predominantly completed by seafarers using a variety of observation methods.

Keywords: Operating Profiles; Energy Efficiency, Operations

1. Introduction

Energy efficiency has always been an important factor to minimise ship operational costs, yet it has not always been a focus during design and operation. However, over the past decades there has been increased pressure to reduce greenhouse gas emissions, specifically carbon emissions, with an aim to mitigate Climate Change. This pressure has been driven at an International level through the United Nations Framework Committee on Climate Change treaty, UNFCCC, subsequent protocols and accords detailing commitments, and the International Maritime Organisation, IMO, implementing changes for the shipping industry. These developments have coincided with the global financial crisis starting around 2007 that has impacted on the shipping industry and incentivized innovation, developments and implementation of energy efficient measures, both design and operational.

Within the shipping industry significant changes towards energy efficiency have only recently been seen with the addition of maritime energy efficiency regulations entering into force on the 1st January 2013: noting that some predominantly larger companies have started implementing energy efficiency measures in anticipation (Moller, 2012), (Armstrong, 2013),(Jackson & Mccann, 2013),(Berglund, 2013). The maritime energy efficiency regulations are amended to Annex VI of MARPOL with the addition of a chapter 4, Regulations on energy efficiency for ships. They include the Energy Efficiency Design Index, EEDI, and the Ship Energy Efficiency Management Plan, SEEMP. The EEDI benchmarks the design of a new ship against a reference line giving an allowable EEDI value limit for a given deadweight. Compliance with the EEDI is mandated for all new ship designs above 400 gross tonnage and it is intended that the reference lines become more stringent over time. The calculation of the EEDI includes parameters that can be used to represent a predicted operational profile of a ship,

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such as capacity, speed, main engine and auxiliary power requirements. There are also correction factors for weather conditions and ship types where specific considerations are needed (IMO, 2012a). The SEEMP is a management plan that should be constructed specifically for a ship detailing the suitable operational measures that can be implemented and the personnel responsible for the implementation. Example measures include improved voyage planning, weather routing, just in time, speed optimization, optimized ship handling (IMO, 2012b). It is mandatory that a SEEMP is developed for all new and existing ships above 400 gross tonnage and above.

To strive towards more energy efficient ship designs, it is first important to consider existing operational practices and how they have changed, and are expected to change, over the years. Furthermore current operational practices can be reviewed as part of a strategy to identify the best measures to improve operational energy efficiency. Therefore the aim of this paper is to share average operational profile trends for a few case ship types, and discus how the identified trends impact on design and operation considerations for energy efficiency. The data used to perform this analysis and details about the case ships are discussed before the operating profiles are presented considering the following: voyage type distributions, speed distributions, draft distributions, fuel consumption distributions.

2. Analysis of case data

The data used to perform the analysis of the operational profiles is taken from reports recorded onboard typically by seafarers using a variety of different observation methods. These reports are mostly 'noon reports', i.e. recorded each day at noon whilst full away sailing at sea. There are also 'port reports' and other reports that are recorded on approach to port, on arrival, daily in port, on departure. Depending on the company, the combination and labelling of the fields within the reports vary. However, despite the differences in labelling, it was possible to draw comparisons between the values for the different case ships presented in this study. The type of fields included within the ship reports are listed in Table 1:

Table 1. List of typical fields within the ship reports used to perform the analysis presented in this paper

Report date/time	Estimated time of arrival	Wind force	Total heavy fuel oil consumption
Duration	Location	Wind direction	Total low sulphur fuel oil consumption
Sailing hours	Port of departure	Sea force	Total marine diesel oil consumption
Report type (sailing, arrival, departure)	Port of arrival	Sea direction	Total marine gas oil consumption
Passage type (ballast, loaded)	Latitude (degrees)	Swell force	Main engine heavy fuel oil consumption
Mean draft	Latitude (minutes)	Swell direction	Main engine low sulphur fuel oil consumption
Forward draft	Latitude (compass)	Current direction	Main engine marine diesel oil consumption
Aft draft	Longitude (degrees)	Current speed	Main engine marine gas oil consumption
Trim	Longitude (minutes)		Main engine power
Comments	Longitude (compass)		Main engine RPM
Observed speed	Vessel Heading		Slip
Observed distance			Auxiliary heavy fuel oil consumption
			Auxiliary low sulphur fuel oil consumption
			Auxiliary marine diesel oil consumption
			Auxiliary marine gas oil consumption

In some records the amount of low sulphur fuel oil was specified, however it was not contained in the majority of records, thus the total fuel oil consumption value was selected without separation. Additionally, mean draft values were only contained in a few reports. In some cases it was possible to obtain and correlate the draft data from another collected data sources, but this was not possible for all of the case ships.

The record sets for each ship were obtained from four different companies. Even within the sets from one company there were differences, for example; start dates of the records, different recording systems, different fields available for different ships dependent on observation methods available. Further to this, it was found that many records were not complete and had fields missing. Some fields demonstrated zero values that could be considered as missing values (i.e. where zero would have been an unreasonable value). Further fields were identified to contain unreasonable values, which are be expected to have occurred due to imprecise human observation, process and/or transcription error. The records containing missing or unreasonable fields were removed from the analysis being performed.

For the remaining data it is also acknowledged that many parts contain elements of uncertainty, predominantly due to:

- **Observation methods:** e.g. viewing and deciding on the Beaufort value from the bridge. Tank soundings.
- **Field Units:** a Beaufort value is more unambiguous than wind and sea speed/height, direction, …)
- **Observation period:** averaged or instantaneous
- **Lack of specified procedures:** when should an averaged or instantaneous value presented
- **Human error:** recording, calculations, transcription

However, for the analysis presented within this paper only the following fields were utilised:

- **Report date time** –used to determine the time difference between consecutive reports
- **Report type** – used to determine ballast and laden voyages (cross-checked with the draft)
- **Voyage type** –used to determine the voyage type (cross checked with speed and draft)
- **Speed** – considered as the average speed for the report duration
- **Main engine heavy fuel oil consumption**
- **Auxiliary engine heavy fuel oil consumption**
- **Main engine marine diesel oil consumption**
- **Auxiliary engine marine diesel oil consumption**

  Used to determine the fuel consumptions for each voyage
- **Mean draft –** used where available

For many of the operating profiles the results have been presented for each year. Where a voyage (defined as the arrival at a port to the arrival at the next port) started and finished in different years, the whole voyage was included in the year that the voyage ended in. It was not possible to separate the port time into time spent loading and unloading.

Record sets for the following ships were collected and the average results for each ship type and size are presented in this paper:

- 4 Bulk Carriers
- 1 Handysize tanker
- 4 Aframax tankers
- 5 Suezmax tankers
- 2 Post Panamax Container ships
- 4 Post Panamax plus Container ships

3. Operating Profiles

3.1 Voyage type distribution

Figures 1, 2 and 3 demonstrate the percentage of time spent in port and sailing in either ballast or laden each year. For all graphs there does not appear to be a strong increasing or decreasing trend over the years, although variations can be seen.

Figure 1 demonstrates that in the case of bulk carriers they spend the least amount of time in port (similar to that of the case of containers). They also have a comparatively high loaded utilization compared to the case of tanker ships: around 40% of the year spent sailing in laden.

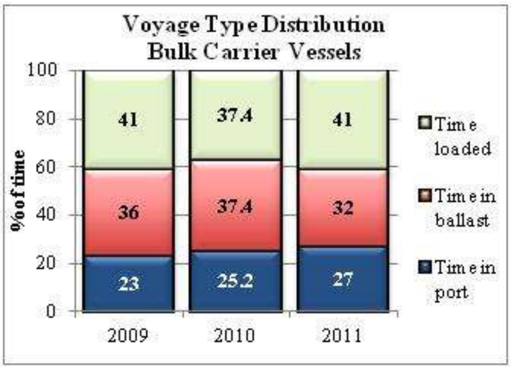
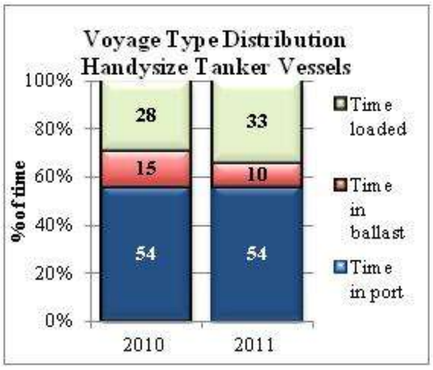
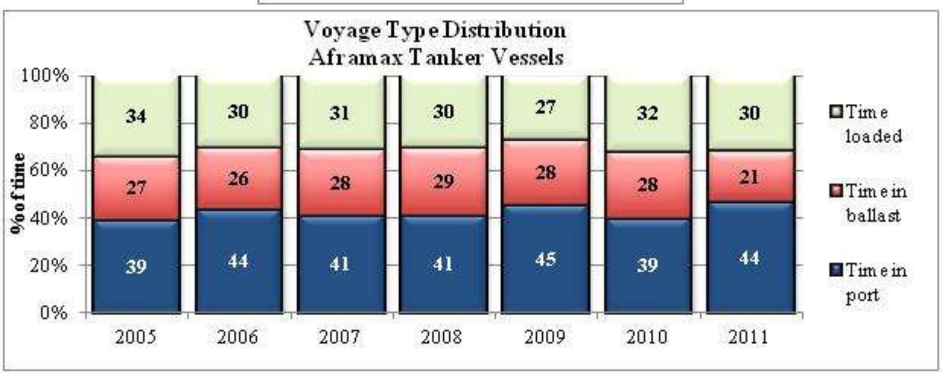


Figure 1. Voyage type distribution for the case bulk carrier vessels

Figure 2 demonstrates that the larger tankers spend less time in port: the average is 54% for Handysize, 42% for Aframax and 32% for Suezmax over the years. The proportion of time spent loaded also increases for the Suezmax case vessels with an average of 33.8% over the years, compared to 30.5% for Handysize and 30.6%, for Aframax tankers. The Handysize tankers demonstrate reduced time in ballast (average of 12.5%) compared to Aframax (average 26.7%) and Suezmax (average of 33%) case tankers. These trends are expected with the type of operation for each ship. For example, Handysize tankers tend offer a service transporting refined products generally on shorter and more costal routes. This can be supported by comparing Figures 4 and 5; where the Handysize tanker makes more voyages in one year resulting in more port stops and the voyage days are shorter in comparison to the Suezmax tanker. Dependent on the geographical location of the ports and the availability of products to transport, this may be the reason for the Handysize tankers being able to reduce the amount of time they operate in ballast condition. On the contrary, the Aframax and even more so the Suezmax tankers tend to make longer voyages. Whilst this means that they spend a lesser proportion of time in port, the ballast leg appears to increase: this will particularly be the case when operating between locations with high oil production and no oil production.





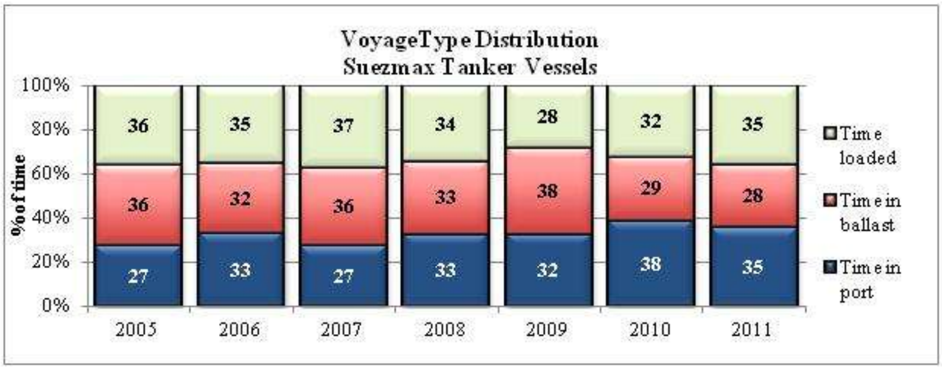


Figure 2. Voyage type distribution for the case tanker vessels

The first difference between the containers vessels (Figure 3) and the tankers and the bulk carriers, is that they do not operate with a ballast leg. However, the Post Panamax container vessels show a very small proportion of the year sailing in ballast. A review of the data was conducted and it can be concluded that these ballast percentages relate to two voyages, one for a ship in 2004 and the other for a different ship in 2012. This is therefore not considered usual practice. Figure 3 shows that in the case Post Panamax plus vessels spend less time in port and a larger percentage of time sailing: a likely influence of operational route.

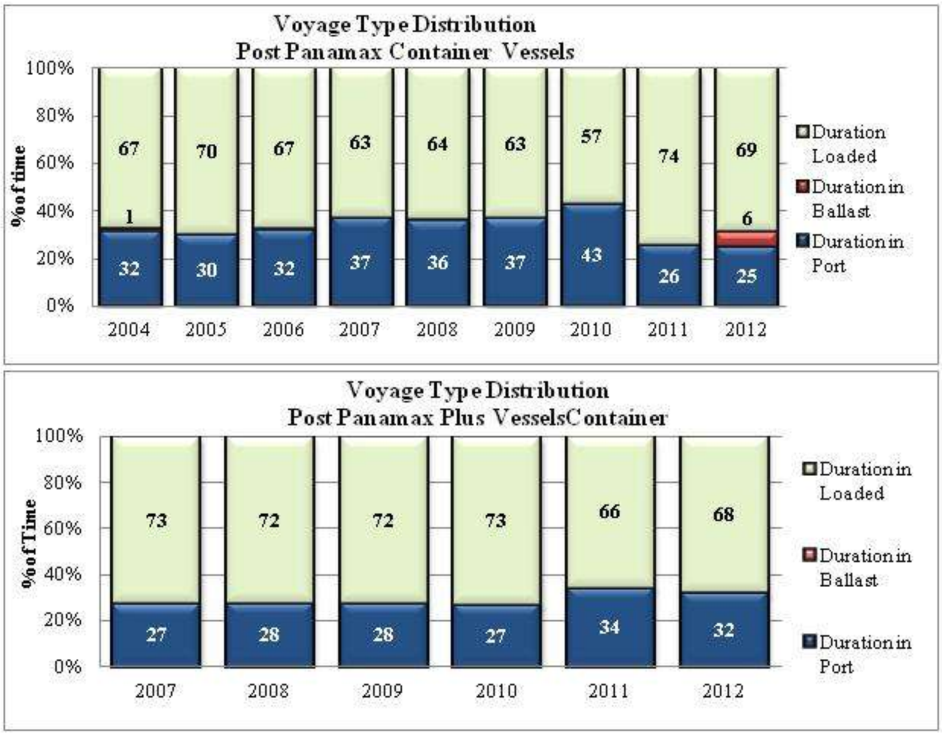


Figure 3. Voyage type distribution for the case container vessels

Figures 4 and 5 show the number of days that a case vessel spent in port and sailing for each voyage within an example year. The amount of port time varies and this will greatly depend on many logistical issues, such as; ship arrival, berthing availability, unloading/loading resources and personnel, cargo readiness, commercial voyage agreements, ship inspections and certificates, etc. Despite certain delays being inevitable due to the long and complicated logistic chains, there are certainly elements that can be improved to increase the utilization (days sailing laden, cargo loaded) of ships. This includes the installation of efficient port resources as well as early and good communication and resource management between all stakeholders involved. For example, where an inevitable inefficiency is observed (such as a port delay) then good communication and management can allow for alternative operational energy efficient measures to be implemented, such as just in time arrival (Intertanko & OCIMF, 2010).

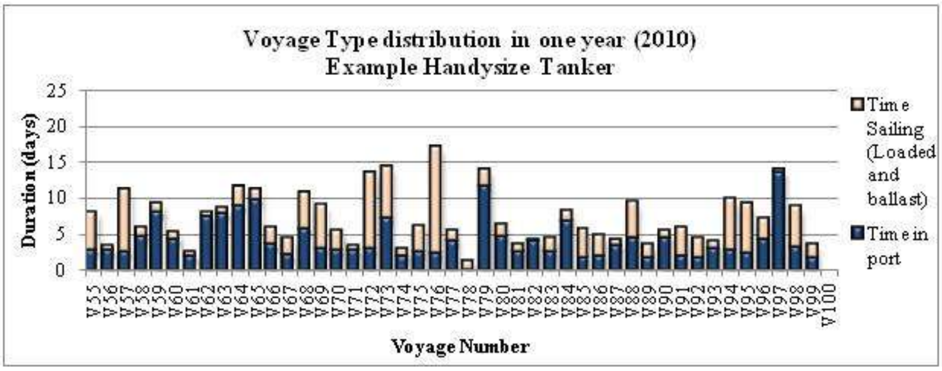


Figure 4. Voyage type distribution for an example Handysize tanker vessel

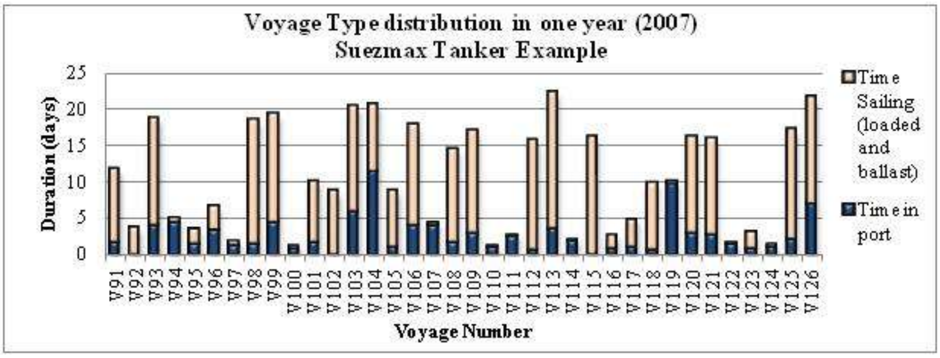


Figure 5. Voyage type distribution for an example Suezmax tanker vessel

3.2 Speed distribution

Figures 6 to 8 show the percentage of time in a year that the case ship types spend at different speeds (using 0.5 knot speed intervals). The ballast and laden distributions are presented next to each other and they have been given as a proportion of the total time sailing during that year. It should also be noted that the effects of weather (which will directly influence speed) have not been isolated in this data set.

Figure 6 demonstrates that the case bulk carriers operate at faster speeds when sailing in ballast than when sailing in laden. Between 2009 and 2010 the there is a slight decrease time spent at higher speeds, and a greater distribution of speeds used, for both ballast and laden.

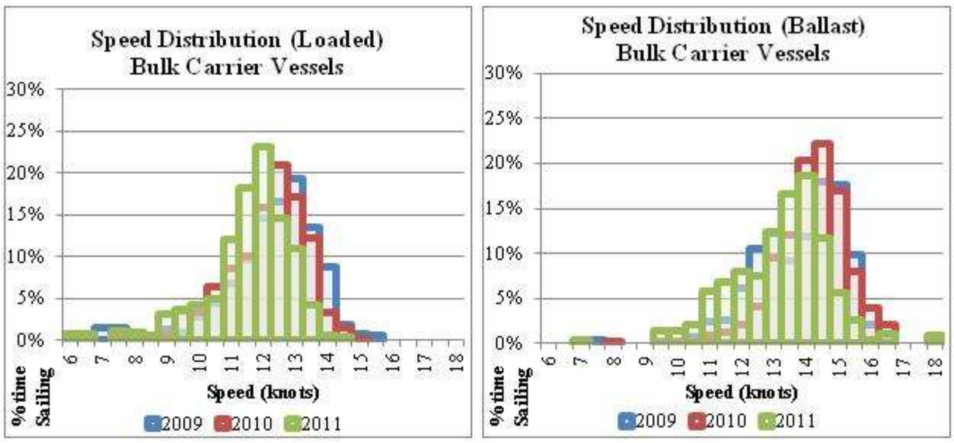


Figure 6. Speed distribution of bulk carrier vessels in ballast and laden

Figure 7 shows that the Suezmax (larger) tankers operate at higher speeds than the Aframax and then the Handysize size of tankers. In all ballast cases, the operational speeds have become increasingly more distributed towards lower speeds over the years. This is also the case for the Aframax vessels whilst laden; showing the largest/most predominant shift towards low speeds. This decreasing speed trend is expected as the shipping industry has faced a rise in fuel costs over the years.

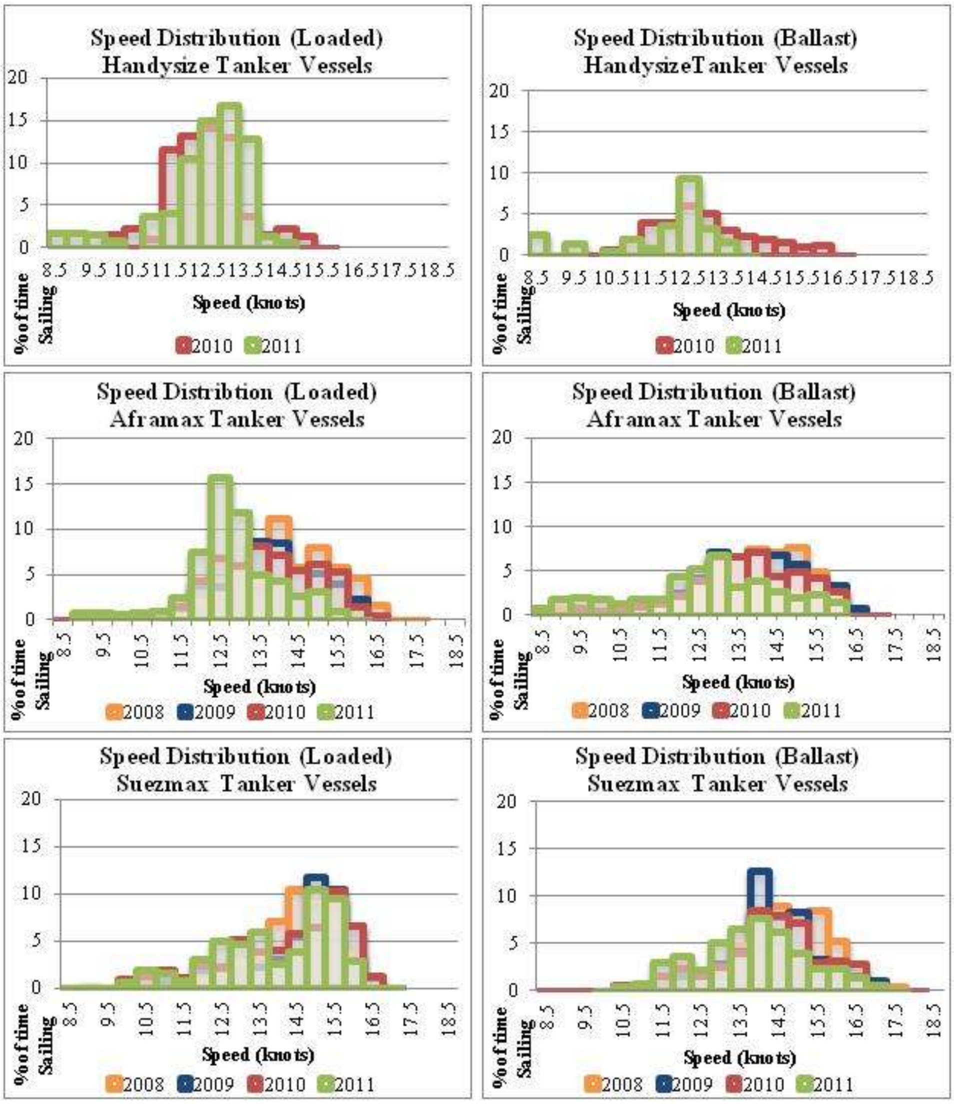


Figure 7. Speed distribution of tanker vessels in ballast and laden

The speed distributions shown for the container vessels have been presented on two graphs one for years 2006 to 2008, and one from 2009 to 2012. It can clearly be observed from Figure 8 that in 2009 the proportion of time spent at 20 and 24 knots starts to decrease considerably and the speeds observed become increasingly more distributed towards the lower speeds. [It is not possible to make a comparison with the bulk carriers and tankers as the data was not available before 2009 and 2008].

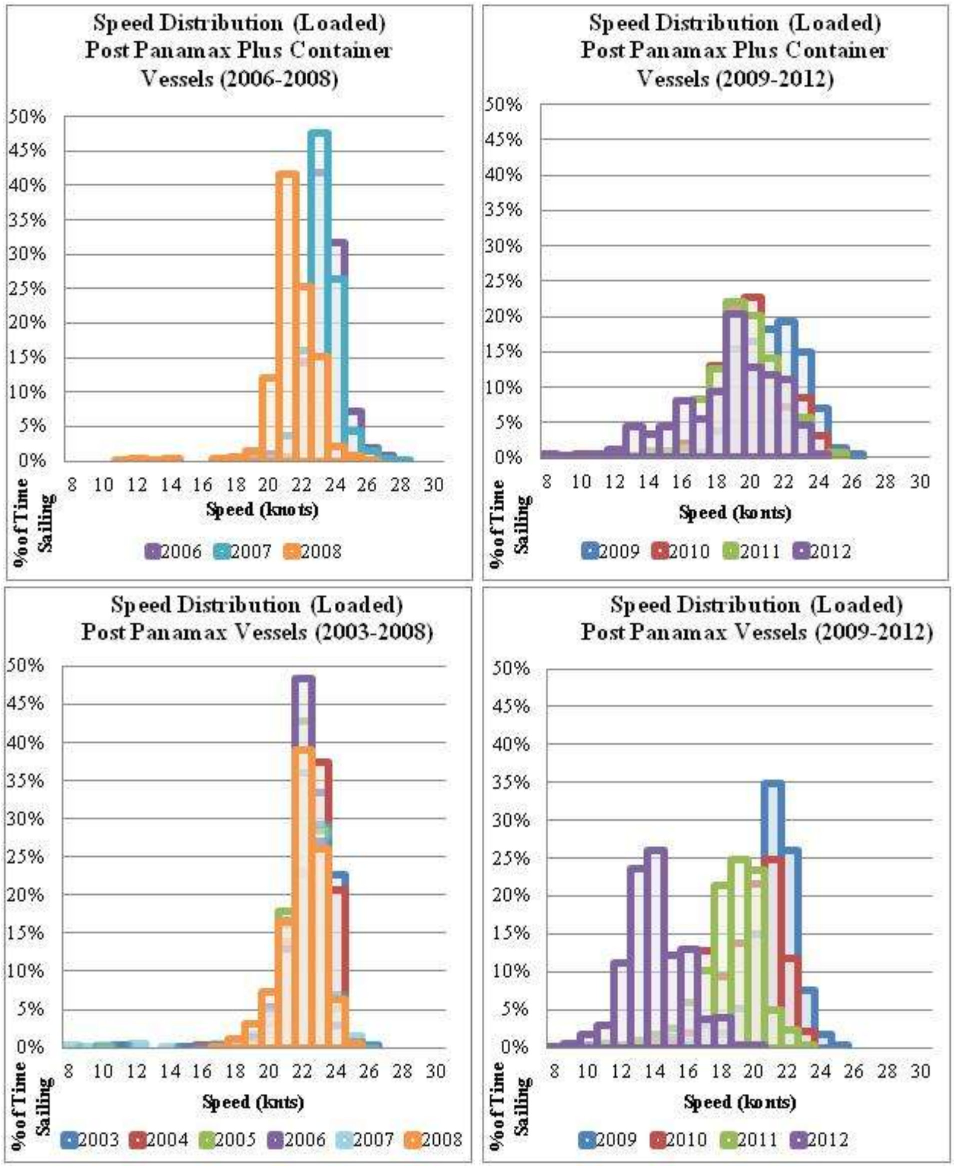


Figure 8. Speed distribution of container vessels

Such speed changes are important for both design and operational considerations. The ship's design speed appears in the denominator of the EEDI calculation. However, the power term being in the numerator of the calculation and therefore due to the approximately cubic relationship between speed and power, a balance towards reduced power requirements (i.e. lower design speeds) is incentivised. Dependent on market trends and how much influence energy efficiency regulations will have over speed when the market picks up there is a scope to consider changes to the design speeds and hence main engine selection. Armstrong (2013) discusses how 'vessels built after the year 2000 have excess reserve power on their main engines. These vessels were probably built to meet market requirements supported by low fuel prices indirectly contributing to increased fuel consumption due to engine size.'

Regarding operations, investment management should also be aware of the technologies that are available as retrofits to improve efficiency at low load operation; such as slide fuel valves (MAN Diesel, 2009), common rail (Wärtsilä, 2004), slow steaming kits (Wiesmann, 2010), turbocharger cut out (MAN Diesel, 2010). Vessel superintendents, technical managers and seafarers should be reminded and aware of the effects that low engine load and low speed operations have on the maintenance of the main engine. They should also be aware of good operational practices that can be implemented to reduce the effects of reduced speed operation. Seafarers should also know how to operate any installed technologies to their maximum energy efficiency saving potential.

3.3 Cargo Load (mean draft) Distribution

Figure 9 gives the distribution of the time spent loaded with an amount of cargo (presented as a percentage of the fully loaded condition) for the case Aframax and Suezmax tankers. It is apparent that whilst the vessels operate predominantly at one draft in ballast, there is a much greater range of drafts utilised during the laden condition. The minimum percentage loaded will be representative of the limiting draft to avoid propeller emergence. The loaded drafts are distributed from fully loaded to around 70% and 77% of the cargo load for the Aframax and Suezmax tankers respectively. Whilst the Figure 9 also demonstrates loaded conditions at lower drafts, similar to that of ballast, these only account for a small percentage of the time and are not considered as standard practice: on further investigation, comments made within the data indicate that these light loads tend to represent time at anchor and drifting but further analysis is needed for finite conclusions to be drawn.

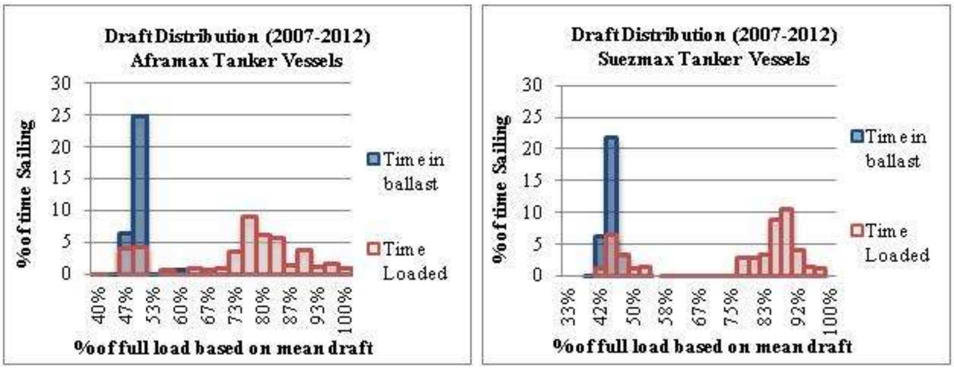


Figure 9. Mean draft distribution of tanker vessels

Figure 10 presents the cargo loaded distribution for the Post Panamax Plus container vessels. No ballast drafts are shown referring back to Figure 3. Whilst there is a relatively large distribution of loads the vessels predominately operate between 60% and 75% load. The cargo loading will very much depend on the contracted route of the vessel and the availability of cargo at each port.

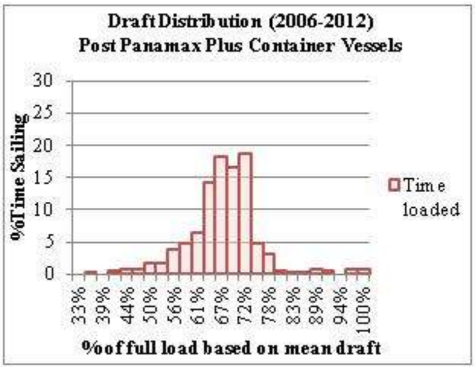


Figure 10. Mean draft distribution of container vessels

3.4 Usefulness of understanding of operational profiles

Figures 1 to 10 have presented operating profiles that show average trends for specific case ship types and sizes. It should be noted that the type of charter and routes will influence these operating profiles. However, the general trends presented can be used to improve insight into current operations. This is particularly useful for modelling trends within the world fleet and estimating fuel consumption over a period of time, and hence carbon emissions.

Understanding the current trends of operation, in conjunction with predicted future market trends, allows for improved design options to be considered; such as the right determination of vessel parameters and characteristics (e.g. design speed, design draft, ...) to reflect the expected future operation (including routes) for the ship. Hull optimisation could be further improved by taking account of more than one design points, relating to the expected range of operational profiles; (Howett, Day, & Incecik, 2012). Furthermore, the design and selection of hull coatings should be carried out considering the operational profile of the ship: particularly related to duration in port and operational speed.

Considering ship operation, the profiles discussed provide a great insight about utilisation. This presents the opportunity to exercise various alternatives measures to reduce fuel consumption, and hence carbon emissions, in a most cost efficient way. Such exercises may include: evaluating the feasibility to reduce port time by improving the efficiency of loading and unloading; improving the design of port facilities and technologies to maximise the energy efficiency of the operations; voyage optimization (including route planning) to reduce fuel consumption. Furthermore, analysis of current operating profiles for individual ships will allow for identification of how operations can be improved in the relative short term to increase energy efficiency and reduce carbon emissions in a cost effective way: i.e they can form a foundation for developing a management strategy such as the SEEMP.

4. Conclusions

From the discussion presented in this paper, it can be concluded that different ship types have different operating profiles. Much of these profiles are characterised by the intended operation of the ship (i.e. voyage length, service speed) however, logistic and economical influences impact on the profiles.

The amount of time spent in port, sailing laden and sailing in ballast varies for each ship type: predominantly representative of logistic influences (e.g. influenced by economies of scale). There appears to be no significant trend regarding the amount of time spent in port, sailing laden and sailing in ballast over time.

It was found that in recent years an increasingly smaller proportion of the time is spent at higher speeds. Over the past three years specifically, a wider range of operational speeds have been observed and the distribution has shifted towards lower speeds. This trend is more noticeable with the higher speed container vessels than the slower speed bulk carriers and tanker vessels. The trend towards lower speeds is as expected with the rise in fuel prices over the past years.

Whilst there is little distribution of drafts used whilst sailing in ballast (for bulk carrier and tanker vessels), there is a range of operational drafts utilised when laden; ranging from fully loaded to 70%, 77% and 60% for the case Aframax tankers, Suezmax tankers and Post Panamax Plus container vessels respectively.

The operational profiles represented in this paper provide useful information to cross check expected operational profiles when modelling ship fuel consumption and hence carbon emissions. Individual ship analysis presents the opportunity to improve the energy efficiency of both the design and operation of ships by considering current operational practice and the actual range of operational parameters for design.

A significant amount of work that can follow this analysis by further utilizing the data collected. On the same level of analysis it will be possible to look at fuel consumptions, encountered weather and therefore the proportion of time spent operating in different weather conditions rather than Beauforts 0, 1 and 2. Specific analysis for individual ships can be carried out how performance changes when operating in different weather conditions and over time due to hull and propeller fouling and degradation. Furthermore, individual voyages can be analyzed to identify speed profiles and the potential for voyage optimization.

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