VESSEL OPTIMISATION FOR LOW CARBON SHIPPING
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ABSTRACT
Squeezed between pressures of the economic downturn, the abundance of ships in certain sectors, and an avalanche of regional and international regulations aimed at reducing shipping’s impact on climate change, some ship owners and managers have looked to innovate and seek opportunities to grow their influence in shipping markets. Under economic pressure, a number of ship owners turned to hot or cold lay-ups, scrapping unproductive tonnage, or simply getting out of the business. Others looked at the ever increasing cost of bunkers and decided to position themselves as more efficient operators with high quality services to offer. In this respect, some concerted optimisation efforts at Teekay directed in the areas of technical, commercial and operations have helped increase fleet utilization and profitability while ensuring safety and reliability of service. Some of the technical optimisation efforts include PBCF installation, CPP reprogramming, Fuel Slide valve upgrade, Alpha lubricator retrofit, Sonic cleaning of economizer, and Cylinder oil consumption optimisation. Operational optimisation initiatives include Cargo heating management, Weather routing, Hull & propeller performance monitoring, and Engine performance monitoring. Commercial optimisation includes development of tools that provide a better understanding of technical and operational limitations from a commercial standpoint. Initiatives like developing procedures for slow steaming operations and the creation of Speed vs. Fuel consumption matrix provide value-added input and technical insight. These tools support channelling efforts on allocation of the best positioned asset to a fixture and being able to select the speed and fuel consumption for both ballast and laden voyages in order to positively affect net voyage revenue. One salutary outcome of the economic downturn has been a sharp reduction in contribution of GHG emissions by shipping. With a revival in fortune of the shipping industry one can expect a corresponding increase in GHG contributions. But does that really need to be the case? Some of the lessons learned since 2009 have contributed significantly to low carbon shipping - like slow steaming. With a strategic alignment of stakeholders’ interest to lessen shipping’s impact on GHG emissions, these practices can continue to be used.

Keywords: Low Carbon Shipping, Vessel Optimisation

NOMENCLATURE
BHP / Ps  Metric Brake Horse Power
CASPER® Computerised Analysis of Ship Performance
CO₂ Carbon Dioxide
CPP Controllable Pitch Propeller
g/kWh Grams per Kilowatt hour
GDP Gross Domestic Product
GHG Green House Gases
kW Kilowatts
MCR Maximum Continuous Rating
MT Metric Tonnes
NOₓ Nitric Oxide and Nitrogen Dioxide
PBCF Propeller Boss Cap Fin
RPM Revolutions per minute
SCOC Specific Cylinder Oil Consumption
SEEMP Shipboard Energy Efficiency Management Plan
SFOC Specific Fuel oil Consumption
SOₓ Sulphur Oxides
SPC Self Polishing Copolymer paint
Teekay Teekay Shipping Ltd.
TLP Technical Leadership Program

1. INTRODUCTION
The unprecedented economic downturn and recession of 2008-09 forced many shipping industry operators to find innovative ways to optimise; cover their costs and remain in business while awaiting an economic recovery. Taking ships out of service, either by laying them up or scrapping, as well as slowing down the operating ships has been practiced.

This paper discusses vessel optimisation initiatives that make a difference in minimizing fuel consumption and contributing to low carbon shipping. Also, the paper attempts to take a step back and analyse, in a holistic manner, the roles of various stakeholders in the marine industry. This includes emphasizing the need for collective involvement in creating a sustainable shipping environment for the future.

Before reading further please note as a caveat that observations are from the perspective of the oil tanker industry, specifically from experience gained by Teekay operating a large fleet of aframax tankers.

2. IMPACT OF WORLD ECONOMY
Until 2008 the Marine Industry focus was primarily limited to emissions reduction enforced by regulatory requirements. Soon after the recession, focus shifted to fuel efficiency and energy...
conservation, being driven by business requirements.

The impact of a recession on tanker trade is shown below, the graph depicting Global GDP growth (Figure 1), and the aframax crude oil tanker trade specific to Teekay (Figure 2).

![Graph of Global GDP Growth](image)

Figure 1: Global GDP Growth (Percent; quarter-over-quarter, annualized), Source: IMF Staff estimates

![Graph of Distance Travelled & Corresponding Fuel Consumption](image)

Figure 2: Source - Teekay database

As seen in Figure 2, the total distance travelled by a fixed sample of Teekay aframax vessels peaked in 2008, followed by a steep drop. To counter the sudden changes to business requirements, optimisation initiatives were developed and implemented to ensure voyage costs were minimized and returns maximized.

### 3. LOW CARBON SHIPPING AND OPTIMISATION

The average aframax tanker consumes approximately 18,000 MT of fuel per year, of which approximately 85% is consumed by the Main Engine. The remainder is equally split between Auxiliary Engines and Auxiliary Boiler. Based on the data in Figure 2, the fuel efficiency calculation in miles per metric tonne of fuel reveals a 12% improvement, shown in Figure 3.

![Graph of Fuel Efficiency in Miles/MT](image)

Figure 3: Source – Teekay database

This significant improvement in fuel efficiency was achieved mainly from optimisation efforts with minimal investment and effective implementation. The process of developing and implementing optimisation initiatives are discussed below. The sequence of implementation followed the Deming cycle of PLAN, DO, CHECK, ACT.

#### 3.1 CREATING OPPORTUNITIES FOR OPTIMISATION

Opportunities for optimisation can be broadly classified into three categories: Technical, Commercial and Operational. These categories can be applied to new buildings as well as older vessels.

Opportunities are created by:
- Developing an insight by researching and analyzing technical and operational data.
- Performing a gap analysis of the perceived expectations of the different stakeholders.
- Applying first principles and endorsing fundamental engineering practices.
- Developing appropriate tools to bridge the gap between technical and commercial ship operations.

As an example, Economic Load and Economic Speed are commonly used terms, associated with efficiency and sometimes used interchangeably. While Economic Load is the operational point of the Main Engine with the least specific fuel oil consumption, Economic Speed is the minimum continuous speed the vessel can perform, or the lowest Main Engine load the vessel can operate for prolonged periods of time.

Analyses of operational and performance data reveal that 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 the engine size.
Speed versus power graphs are shown in Figure 4 comparing sample aframax vessels built before and after year 2000.

Based on the operational data reported, the vessels built after year 2000 are usually operated in the load range of 65-75% (Main Engine load). Reasons for the excess margin of reserve power are:

- The design service speed is 14.7 knots but the vessel is usually chartered at 14 knots (approx. 2000 BHP of reserve power).
- The vessel is loaded to approximately 80% cargo capacity instead of 98% as per design.

Additionally, the plot in Figure 5 depicts the speed to power profile as reported by the aframax vessels. Based on the above, the engine size could lead to a window of opportunity. Some of the options for optimisation here include:

- De-rating the Main Engine by modifying turbocharger, readjusting engine timing etc.
- Installation of a more efficient propeller which could absorb more Main Engine power.
- Possible retrofits like Shaft Generator avoiding Aux. Engine usage while at sea.

With appropriate vendor support, quantification by cost benefit and payback analysis, optimisation can be envisaged.

Energy Audit processes could provide an alternative to conventional methods in identifying optimisation opportunities to ensure:

- All major energy consuming machinery onboard is operated and utilised:
  1. To its fullest efficiency.
  2. Without energy losses such as steam leaks, air leaks etc.
- Evaluation by benchmarking operational and performance parameters.
- Identifying other opportunities for energy saving.

3.2 EVALUATION OF OPPORTUNITIES FOR OPTIMISATION

A systematic approach to explore opportunities could open up potential avenues for optimisation. Developing a rationale and a structured format for evaluation will go a long way in prioritizing these opportunities.

While boundaries are pushed to enhance optimisation opportunities, the three R’s - Risk, Reliability & Revenue can be used to form a framework for the evaluation.

Risk takes into account the effect of optimisation on safety and environment. Reliability is asset management, focusing on short term benefits vs. long term losses, reputation, and vessel availability. Revenue is the impact to the bottom line.

3.3 IMPLEMENTATION OF OPTIMISATION INITIATIVES

Building on the research and analysis carried out earlier, due diligence is required to develop the opportunity into an initiative. Additional research and risk assessment is required to plan the implementation and package the initiative to ensure the following issues are addressed:

- Perception vs. Reality: New optimisation ideas generally challenge conventional thinking and traditional practices. New initiatives should be packaged to make a convincing case, providing answers to many varied questions.
- Change Management: Provide clear objectives and expectations of the initiative through effective communication, streamlined processes, and well defined roles and responsibilities of stakeholders. This will bring about effective change management.

3.3 (a) Technical leadership program

All the optimization initiatives were rolled up to create the Technical Leadership Program (TLP) that would enthuse end user involvement and develop an inherent synergy for initiatives to
leverage each other. This program was used as a platform to address specific requirements of each of the optimisation initiatives: involvement of stakeholders, roles and responsibilities, feedback mechanisms, benchmarks and measurements of success.

3.3 (b) Quantification of optimisation benefits

Quantification is a significant aspect of the development and roll-out process. It is about measuring the effectiveness of the initiative. This requires development of benchmarks either based on empirical relations, or using historical data to validate the impact of the initiative.

Optimisation being a relatively new field of interest, methodologies or mechanisms for benchmarking processes, is still evolving.

Measurement and quantification of efforts and benefits add significant value in establishing new initiatives. Occasionally, debate occurs around the use of unconventional benchmarks. These get tweaked for accuracy and become part of the learning process while working towards continuous improvement.

Other challenges that could be faced with measurement and quantification include inconsistent reporting, management of perceptions, and margins of accuracy.

3.3 (c) Feedback and review of optimisation efforts and benefits

Feedback is the single most effective measure that can sustain and increase the momentum of an initiative. The TLP was used as a platform to implement the feedback and review process on three levels:

1. Vessels: To encourage end-user involvement. Systems and processes were developed to provide regular feedback, and in some cases instant feedback. The primary focus was limited to the operational parameters against benchmarks.
2. Ship Managers: To keep updated on the status and to drive optimisation as part of day to day operations. The focus was on performance and scope for improvement.
3. Senior management: To review the progress and to improve transparency and accountability. The focus was on performance enhancement, fleet efficiency and quantification of efforts.

4. PERFORMANCE OPTIMISATION TOOLS

Teekay conceived, developed and uses a whole suite of performance optimisation tools that contribute to maintaining overall efficiency of the fleet. Optimisation can generally be classified into two types: Those that help improve efficiency and those that help maintain efficiency. These are applied to vessels to enhance operational, technical and commercial optimisation.

Performance optimisation tools that assist in maintaining efficiency and monitoring deterioration assure reliability, mitigates risk of fuel penalty; in other words, contributes to cost avoidance than cost savings which is a significant component of optimisation as well.

4.1 OPERATIONAL OPTIMISATION

4.1 (a) Hull & Propeller performance Optimisation

Increase in resistance due to hull and propeller condition is continuously monitored to measure performance, determine appropriate maintenance required and to execute in a timely fashion.

Teekay uses Computerised Analysis of Ship Performance (CASPER®) as a tool to monitor the fleets’ hull & propeller performance. CASPER® establishes a mathematical performance model for each vessel, covering all speeds and drafts, based on the sea trial data.

Observed performance is then compared to the actual performance during sea trial conditions. The increase in resistance due to hull or propeller condition is reported as “Added Resistance.” Vessels submit observation data once a week and performance deviations are flagged, shortly after they start deteriorating. This drives decisions around in-service maintenance and dry-docking.

![Graph showing drop in added resistance following maintenance activities](image)

Figure 6: Drop in Added Resistance following maintenance activities. Source – CASPER®

4.1 (b) Main engine performance optimisation

According to MAN Diesel & Turbo (2011), a one bar increase in maximum cylinder pressure will decrease the Specific Fuel Oil Consumption (SFOC) by 0.1-0.2 g/kWh.

A tool to monitor engine performance was developed in-house to provide vessels with “real time” feedback on key main engine performance parameters based on reported observations.
Additionally, Cylinder lubricating oil scrape down analysis by Flame Marine is used to diagnose and assist in troubleshooting maintenance and performance issues.

4.1 (c) Cargo heating management

Based on analyses of historical data, averaged over a 12 month period, heated cargoes constituted approximately 10% of the total cargoes carried by Teekay. Over 20,000 MT of heavy fuel oil was used for cargo heating, averaging approx. 100 MT per heated cargo voyage.

With no established benchmark or guidance for cargo heating, analysis of historic data revealed inconsistencies in practises onboard which had a significant potential for fuel savings. The cargo heating management concept was developed by Teekay and Blue Water Trade Winds Pvt Ltd. as a tool to leverage the operational expertise of the vessel staff and shore based voyage managers, by optimal estimation, planning, and monitoring of cargo heating operations onboard.

The philosophy of Cargo Heating Management concept is to carry out cargo heating operations by planning and monitoring. The cargo temperature and fuel consumption are benchmarked with planned or desired results, and are executed by ship staff in compliance with the charter.

Sound engineering practises are integrated into the detailed cargo heating plan, which is developed based on modelling the ambient conditions and calculated drop/rise in cargo temperatures, along with the quantity of heat absorbed by the cargo.

By optimisation, the fleet average daily fuel consumption (for heated cargoes) has been reduced from 8 MT/day to 5.5 MT/day in year one, and with further enhancements now averages 3.9 MT/day.
4.1 (d) Route optimisation

Route optimisation is about voyage planning, taking advantage of the weather and currents. This optimises voyage distance and time travelled based on currents and continuously monitored weather forecast while mitigating weather related risk. Route optimisation integrates voyage planning with elements of safety management, cost management and emissions management by saving fuel, avoiding weather related damage and delays. All sea voyages are monitored and evaluated by Weathernews Inc. (WNI) for bad weather conditions to maximize safety and minimize voyage cost. Measured operational savings can be up to 3% in fuel apart from time savings.

4.1 (e) Trim optimisation

The Trim Optimisation concept is about reducing resistance due to the hull form by, for example, maintaining immersion of bulbous bow and maintaining propeller immersion during partially laden voyages. Teekay was one of the initial proponents of this concept after conducting a model test study of an aframax tanker in 2005. Trim tools were developed and implemented which, when validated by trials for optimised trim, yielded mixed result for different hull forms. Presently, a more pragmatic approach is practised which is based on operational trials from varied trim conditions for different displacements. Some of the operational risks and challenges could include the oversight of bending moments and shear forces when practising trim optimisation. Additionally, the varying trim due to fuel and fresh water consumptions, ballast exchange requirements, vessel design for trim by stern (like locations of drains and scuppers) and vessel control during bad weather conditions are some of the practical challenges. Validated fuel savings in aframax tanker trials have been less than 1% on those vessels with hull forms where the concept worked. Due to the trim optimisation concept’s significant operational influence, it is better executed when decided operationally convenient by the staff onboard. Slow steaming program, which has a much more significant impact on daily fuel consumption, has limited the pursuit of trim optimization development further as the benefit is significant and measurable only at higher speeds.

4.2. TECHNICAL OPTIMISATION

4.2 (a) PBCF retrofit

The Propeller Boss Cap Fin (PBCF) enhances the propeller efficiency by eliminating the hub vortex created behind the propeller by converting it into useful thrust and reducing torque.

According to MOL Techno-Trade Ltd. (2011), inclusion of PBCF reduces the torque of the propeller by an estimated 3% and increases thrust by over 1%, boosting fuel efficiency by 3-5%.

A model test was conducted which indicated an improvement in propeller efficiency by 4% at 14 knots. A full scale test was carried out in April 2009 and the performance was validated by two independent methods, confirming the results of the model test.
4.2 (b) CPP programming

Certain vessels, built for future conversion to Shuttle tankers, consumed 10-12% more fuel compared to the conventional vessels. Investigation revealed that the CPP propellers were programmed for Shuttle Tanker operations, which were optimised for better manoeuvrability and not for conventional steaming.

A potential 5% fuel saving on existing CPP vessels has been possible by reprogramming the propeller for conventional steaming.

The graph below, though not directly connected with the CPP reprogramming initiative, has been shown to depict the optimum specific fuel consumption zone for a CPP propeller.

4.2 (c) Fuel slide valve upgrade

Fuel Slide Valves have been a standard fitment on MAN B&W NOx Tier-I compliant vessels. According to MAN Diesel & Turbo, by being retrofitted with slide valves, vessels could achieve the following:

- Improved Main Engine low load operational performance.
- Better combustion process due to high pressure injection and atomization.
- Reduced fouling of exhaust gas ways and economizer.
- Reduced fouling of piston top-land as there is no dripping fuel.
- Less visible smoke formation in exhaust from the funnel.
- Lower hydrocarbons, NOx and particulate matter emission levels.

4.2 (d) Cylinder oil consumption optimisation

According to MAN Diesel & Turbo, optimal cylinder lubrication philosophy is based on best overall economy and safe cylinder condition. Overdosing...
of alkaline cylinder lubrication has two negative effects:

- Bore-polish phenomenon – Accumulation of calcium deposits on piston top-land, causing increased wear and tear, affecting performance and reliability.
- Suppressing cold corrosion completely, limits the necessary refreshment of liner surface (open graphite structure). In other words, corrosion should be controlled rather than prevented.

These negative effects are time-based and damage can be severe, depending on the magnitude of overdosing.

Teekay has been a pursuivant of cylinder oil optimisation since 2002 and the effect of fleet wide reduction in average Specific Cylinder Oil Consumption (SCOC) is obvious from the graph shown below. The cumulative cylinder oil savings have been over 15 million litres in the past ten years.

According to Kockum Sonics, the basic principle of sonic cleaning is to create sound waves carrying an energy level that exceeds the forces that tend to make particles suspended in a gas flow adhere to each other and the surrounding surfaces. Sonic cleaning prevents build-up by breaking the particles before they can form a hard layer.

4.3. COMMERCIAL OPTIMISATION

4.3 (a) Slow Steaming

Slow steaming guidelines for low load operations (25% Main Engine load), and ultra-low load operations (down to 10% Main Engine load), were developed with the engine makers and shared with the fleet vessels for running at minimum continuous speeds. Risk assessment carried out was followed by certain modifications to the engines. Retrofitting of slide valves and alpha lubricators, sonic cleaning devices, supply of slow steaming nozzles and auxiliary blower motors were amongst these modifications. Moreover, modifications made to the engines and economizers helped minimize technical risks such as scavenge fires and fouling of economiser.

A concerted effort from the senior management, ship managers, and staff onboard enabled a very successful implementation of the slow steaming practices presently followed onboard Teekay vessels.

Risk Assessment and assurance on certain operational bottle-necks (like fresh water production onboard) were addressed as part of the procedural document for slow steaming in order to ensure safe and reliable operation. With over 18 months of slow steaming experience, there have been no reported
operational or technical incidents as a result of the slow steaming initiative.

Figure 21: Source – Teekay database

Based on Figure 21, it can be seen that the average ballast speeds have dropped 1.6 knots and average laden speeds have dropped 1.1 knots since 2008. The effect of this speed reduction has enormous impact on minimising carbon emissions as shown in Figure 22.

### 4.3 (b) Speed and fuel consumption

A dynamic matrix on speeds and fuel consumptions was created to ensure more accurate voyage estimates for the fleet vessels. Using preliminary CASPER® data as reference, fuel consumption tables were developed down to 10% MCR of Main Engine at 0.5 knot intervals. This ensures appropriate voyage planning to minimize voyage costs by maintaining a tight control over speeds and fuel consumptions, as well as aligning technical and commercial performance.

Figure 22: Speed vs. Fuel consumption curves for a typical aframax tanker. Source: CASPER®

**Figure 23: Snapshot of the Teekay Fleet Speed vs. Fuel Consumption table (SFM-2G matrix)**

5. **HULL COATING & DRYDOCKING STRATEGY**

Enhanced hull coating strategies have been developed and adopted as part of the dry-docking strategy. These strategies came about as a result of what was learned through operational requirements.

A performance comparison was carried on identical sister vessels performing similar trade shown in Figure 24, using the highest grade SPC coating with the conventional grade SPC coating. Following a full blast of the hull at the 10th year dry-dock, the data translates to a post dry-dock performance benefit of 2.5 MT/day.

This strategy has proven payback that has been validated by the hull performance monitoring program.

Figure 24: Performance comparison of 2 sister vessels; Source - CASPER®

6. **CONTINUOUS IMPROVEMENT AND NEXT STEPS TO FURTHER OPTIMISATION**

The momentum of the drive towards further optimisation continues. With some of the most significant optimisation initiatives already discussed
in this paper, there are other supplementary and complimentary initiatives in place as well:

- Supply of cylinder drain oil analysis kits onboard to support cylinder oil optimisation program in addition to Flame Marine analysis.
- Supply and installation of Diesel Performance Analysers to measure Main Engine and Auxiliary Engine performance.
- Installation of Shaft power meters to ensure accurate power measurement onboard.
- Installation of AMOT Main Engine bearing monitoring systems to ensure optimal reliability.
- Main Engine system lubricating oil filter upgrades to mitigate lubricating oil-related failures.
- Development of Shipboard Energy Efficiency Management Plan (SEEMP) to create awareness and to drive alignment of efforts onboard vessels.

Based on the review and feedback process, continuous improvement has been embraced as an integral part of the optimisation drive. Contributions from continuous improvement have been in the areas of new initiative development, tweaking of benchmarks, and further enhancements to processes and procedures of these initiatives.

7. STAKEHOLDER INVOLVEMENT

After analysing the significance and benefits of all the discussed vessel optimisation initiatives in low carbon shipping, the single initiative that stands out as yielding maximum benefit is slow steaming. On an average it was found 65% speed was achieved with 35% fuel consumption. However, the sustainability of slow steaming initiative is directly related to market conditions and is driven by fuel prices, freight rates, and demand. This means that normal steaming operations could revert to the pre-2009 levels when the world economy fully recovers.

Table 1: Involvement of major stakeholders in oil transport

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In Table 1, some of the major stakeholders in oil transport and supply are listed, along with their role in ship design and operations. While all stakeholders are committed to a greener environment and low carbon shipping, the pursuit for optimisation could vary based on the resources available, and the economic climate. This is where an alignment in mandate of all relevant stakeholders in the oil supply chain is required to ensure sustainable low carbon shipping.

According to a documented research by Corbett et al., on the Container vessels, “speed reduction, energy cost, and profits are inexorably linked because energy is an important cost factor to shippers. Also, speed reductions save energy across the fleet, even when additional ships are needed to maintain service.” “The international community is expressing determination to reduce CO₂ emissions from marine shipping. Speed reductions would seem, from short-run simulations, to be able to significantly reduce CO₂ emissions. Emissions reduction across a range of containership routes can be up to 70% when the speed is halved. On average, marginal costs are higher than reported in studies that do not consider lost profit from reduced service. When additional ships are added to maintain scheduled frequency, lower speeds still provide CO₂ reduction on most routes, albeit at less reduction given the higher costs.”

Below is a comparison of two scenarios by Corbett et al. in Figure 25, where “Scenario 1 assumes less frequent arrivals (longer intervals due to slower speeds), and Scenario 2 assumes speed reductions accompanied by additional vessels to maintain arrival frequency.”

### Figure 25: Comparison of Scenarios 1 and 2 optimal speed reduction and corresponding CO₂ reductions at different fuel prices.

8. CONCLUSION

As the global economy limps towards recovery and ship operators are being pulled between various regulatory requirements like ballast water regulations, sulphur emissions control, and NOx emission control, low carbon shipping has taken a backseat. Development of any technology that could provide a significant drop in the CO₂ Index is questionable. Moreover, with the reduction in the CO₂ Index, NOx and SOx emissions are automatically reduced as well. With the influx of new tonnage out of the shipyards and from layup, it would be a prudent practice to make slow steaming a norm for the future. Once
the global economy starts flourishing, the CO₂ Index will continue to remain low, and all stakeholders will have to re-engineer their processes to accommodate slower cargo movement, and to further invest in research and development to sustain slow steaming in the future. The hypothesis that high fuel prices could help in reducing emissions is arguable as in most cases the fuel costs are borne by the Charterer, and not the vessel operator. If slow steaming is seen as a remedy for low carbon shipping, it is suggested that sharing the benefits of slow steaming among stakeholders, and/or forming strategic partnerships among stakeholders to work towards low carbon shipping should be considered. As well, regulatory enforcement of slow steaming could be considered to sustain low carbon shipping in the foreseeable future.

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