Advanced Methods of Optimizing Ship Operations to Reduce Emissions Detrimental to Climate Change

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ABSTRACT

Maritime shipping is an important and economical mode of international cargo transportation, but it does contribute significant amounts of greenhouse gases (GHG) associated with global warming. The quantity of GHG emission from combustion of petroleum-based fuels is directly proportional to fuel consumption. A computer program called Voyage and Vessel Optimization System (VVOS) provides the ability to reduce a ship's fuel consumption and associated GHG emission without increasing transit time. This is done by optimizing the ship’s operation in response to ambient ocean conditions (wind, waves, and currents), taking into account ship performance criteria and safe operating limits. The resulting savings can be verified with computer simulations and post-voyage analyses using individual ship performance models, voyage logs, and historical weather data. At today’s record-high fuel costs, the savings offered by this technology easily justify the cost of its implementation.

OVERVIEW

This paper first provides a background for evaluating the potential impact of commercial shipping on global warming, and explains current methods used to estimate its contribution of greenhouse gas (GHG). The relative severity of various exhaust components is discussed, as well as means that are available for controlling them. For example, for each ton of distillate or bunker fuel consumed by the ship, approximately 3 tons of carbon dioxide (CO2) are emitted into the atmosphere. Although a certain amount of CO2 is absorbed by the ocean boundary layer, photosynthetic plants, and algae, any excess can remain in the atmosphere for decades. Ongoing monitoring of fuel consumption by each class of ship (bulk carrier, oil tanker, general cargo, container, etc.) will help us determine where to focus our attention for the greatest benefit.

A computer program called Voyage and Vessel Optimization System (VVOS) incorporates advanced voyage optimization algorithms that take into account the ship’s hull design, propulsion system, and sea keeping models, as well as user-defined safe operating limits. Using this program, a captain can plan and execute a voyage that takes advantage of the ambient ocean conditions through optimal speed and route management. In doing so, significant reductions in fuel consumption and GHG emission are possible without increasing voyage duration. We will present several examples of the magnitude of savings that are possible by comparing simulations of different methods of ship operation for a given voyage, including constant speed, constant RPM, “sprint-and-loiter” (commonly used to ensure on-time arrival), intelligent speed management, and optimization of the route itself. We will demonstrate how potential savings can vary with the location of the passage, the direction between ports, the overall distance, time of year, type of vessel, and flexibility of schedule. Other important variables include cargo load, ballast, trim, and fuel quality. The complexity of these variables requires further study to fully understand their interactions and to quantify them accurately.

We will also provide constructive input to the International Maritime Organization’s guidelines (MEPC/Circ.471, 29 July 2005) for establishing CO2 emission indexing as a means of monitoring and comparing efficiencies of individual ships, classes of ships, and overall methods of cargo transportation with regard to GHG emission. Initially, a ship’s index can be estimated by simulating past voyages using known performance parameters, voyage data logs, and a historical database of ocean weather. Later, this index can be adjusted by continually monitoring and recording actual ship performance and voyage data, and by conducting post-voyage analyses. In this way, any lost efficiency, for example, from increased hull or propeller roughness, malfunctioning engines, or other causes, can be promptly detected, and its effect on fuel consumption evaluated. Ship maintenance can be scheduled using real performance data rather than an arbitrary period based on past experience. Performance monitoring may also be used to fine-tune VVOS in a real-time adaptive learning process.

BACKGROUND

Many people have accepted long term climate change as a given. Others believe the climates are in a temporary warming cycle. No one, however, can deny that a global warming trend is occurring today. What we can do is strive to slow the trend, with a goal of reducing potential anthropogenic causes to levels where natural processes may be able to maintain a balance. Due to
the longevity of some GHGs in the atmosphere, certain actions will not result in any noticeable change for decades. Other actions, such as reducing emissions of particulate matter (PM), will have an almost immediate beneficial effect.

Commercial ship engines burn distillate or residual diesel fuel called “bunker fuel”. This low grade fuel, also known as No. 5 or No. 6 fuel oil, is highly viscous, needing to be preheated before it can be pumped, and is typically high in pollutants, especially sulfur. It is, in fact, the cheapest liquid fuel available. Even so, the cost of bunker fuel has risen dramatically along with other petroleum products, increasing more than 400% (from $170/ton) since 2000 and 230% (from $300/ton) since a year ago, to over $700/ton today.

Maritime shipping, which emits approximately 4% of the world’s total GHG, is one of the lowest contributors of GHG among commercial transportation methods. Nonetheless, it remains a substantial source of emissions of carbon dioxide (CO₂), nitrogen oxides (NOₓ), sulfur dioxide (SO₂), and particulate matter (PM). Until recently, ship-generated NOₓ was the greatest concern for policy-makers because it is a major source of localized air pollution around coastal and port cities. However, policies intended to address global climate change must encompass a broader range of emissions, including CO₂, SO₂, and PM. Furthermore, it is increasingly evident that the impact on global warming from emissions of carbon ash, a normal product of bunker fuel combustion, may be greatly underestimated. This is because the black soot in the atmosphere and on the ocean and ice surfaces reduces reflectivity and increases heat absorption. While SO₂ in itself is not a greenhouse gas, it is a source of polluting acid rain, thereby making it environmentally hazardous.

Calculating CO₂ Emissions

In a 2005 publication of the International Maritime Organization (IMO) to establish guidelines for voluntary ship CO₂ emission indexing, a method was presented of calculating fuel mass to CO₂ mass based on the carbon content of fuel [4]. This calculation results in the recommended default values shown in Table 1.

90% of all international transport of goods by tonnage is handled by commercial shipping, driving a vigorous rise in the number of cargo ships operating globally. In a comprehensive and informative report prepared by multiple agencies for the IMO in 2000, researchers concluded that in 1996, approximately 138 million metric tons of distillate and residual diesel fuel were consumed by the commercial shipping industry. This resulted in the generation of 437.5 million metric tons of CO₂ (3.2:1 by weight), along with 10.3 million tons of NOₓ, 5.8 million tons of SO₂, and 1 million tons of carbon monoxide (CO) [6]. Several sources estimate that the growth of the shipping industry averages approximately 5% per year, reportedly growing 45% between 1990 and 2004 in Europe alone [7].

HOW GHG DISSIPATES

There are several means by which greenhouse gases are dissipated by natural processes. For CO₂ and other products of petroleum fuel combustion, the principal processes include mixing into the ocean’s boundary layer and photosynthetic reduction by plants and algae.

As long as CO₂, NOₓ, and SO₂ remain in the atmosphere, however, they may be present for decades. Furthermore, NOₓ reacts with sunlight and volatile organic compounds (VOC) to form photochemical smog, and can cause breathing problems in young children and lung disease from prolonged exposure. SO₂ is a source of acid rain.

<table>
<thead>
<tr>
<th>Type of Fuel</th>
<th>ISO Specification</th>
<th>Fuel Carbon Content % by mass</th>
<th>CO₂:Fuel ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diesel/Gasoil</td>
<td>ISO 8217 Grades DMX through DMC</td>
<td>87.5%</td>
<td>3.206</td>
</tr>
<tr>
<td>Light Fuel Oil</td>
<td>ISO 8217 Grades RMA through RMD</td>
<td>86%</td>
<td>3.151</td>
</tr>
<tr>
<td>Heavy Fuel Oil</td>
<td>ISO 8217 Grades RME through RMK</td>
<td>85%</td>
<td>3.114</td>
</tr>
<tr>
<td>Liquid Petrol Gas</td>
<td></td>
<td>81%</td>
<td>2.968</td>
</tr>
<tr>
<td>Natural Gas</td>
<td></td>
<td>80%</td>
<td>2.931</td>
</tr>
</tbody>
</table>
WHERE TO FOCUS OUR EFFORTS

While estimates indicate that GHG emissions from ships are similar in volume to the aviation industry, a reduction of ship emissions will have a more immediate positive effect on reducing global warming because they occur close to the earth’s surface, where natural absorption by the ocean and neighboring land masses is most effective. By comparison, airplane emissions are in the upper atmosphere, where far fewer natural mechanisms exist to break down or absorb detrimental gases and PM. This is the main reason aviation GHG emissions present a more serious problem with regard to global warming than ships. Reducing ship-generated carbon ash should result in especially rapid benefit, as, unlike most gases, it only remains in the atmosphere for a matter of days or weeks.

Lloyds World Fleet Statistics, updated annually, summarizes the composition of the world’s propelled seagoing merchant ships of 100 gross tons and above. As seen in Fig. 1, in 1996, the top 4 categories of ships generated 77% of all ship-generated GHG [6]. It would therefore be prudent to focus initial efforts on these ships, while closely monitoring changes in vessel category distribution on a regular basis. For example, liquid gas tankers are one of the fastest growing sectors of the shipping industry.

EFFECTIVE METHODS OF REDUCING EMISSIONS

All other things being equal, emissions are directly proportional to fuel consumption. It is clear that an effective means to reduce emissions is to reduce fuel consumption. As an added benefit, reduced fuel consumption will reduce cost, an increasingly critical factor in the economic equation for commercial shipping. What is the most effective means of reducing fuel consumption?

A variety of methods to reduce fuel consumption and associated GHG emissions were studied in the 2000 IMO report [6], including technical measures (new ship designs, maintenance of the hull and propellers, and fuel improvements) and operational measures (fleet planning, weather routing, speed management, optimization of trim, ballast, rudder pitch, and reducing time in port). However, their overall conclusion was that the most immediate effective course of action was simply to reduce speed. The report proposes that an overall speed reduction of 10% would result in a 23% reduction of CO2 emissions. Slowing even more to 20% should reduce CO2 by close to 50%. This is because bunker fuel consumption by a ship’s main engines can be empirically shown to be proportional to the third power of the velocity, which in actual practice has proven to be a good approximation.

WHAT IS VOYAGE OPTIMIZATION

A simple mandate to reduce speed would be a very “hard sell” to the commercial shipping industry, whose economics depend in part on fast transit times. Furthermore, because of the tight logistics of modern ports and connecting ground transportation, a ship arriving late can result in significant additional costs, effectively negating any savings made in fuel consumption. Therefore, a common strategy of operation is “sprint and loiter,” i.e., run at high speed, conditions permitting, for the majority of the passage, and then slow down for the final leg to ensure arrival at the allocated time. This is likely to result in a worst-case scenario from the point of view of fuel consumption.

Fig. 1: CO2 emission (million metric tons) by vessel type in 1996
Advanced computerized optimization of ship operations offers intelligent speed and route management that can significantly reduce fuel consumption and associated emissions while maintaining the same overall transit time. In a program developed by a team of engineers led by Dr. Henry Chen, a ship’s speed and route can be optimized based on the wind, waves, and currents, taking into account the ship’s performance criteria such as hull shape, horsepower, load, trim, ballast, pitch and roll limits, and other factors. This program has evolved over 20-years of research and development to become Voyage and Vessel Optimization System (VVOS), offered by Jeppesen Marine.

The VVOS program incorporates advanced voyage optimization algorithms that include the ship’s hull design, propulsion systems, and sea keeping models, as well as user-defined safe operating limits. A proprietary 10-day weather forecast, including wind, waves, currents, and special weather warnings, is available for download from Jeppesen Marine’s Commercial Operation Center. This download is updated twice daily, and can be accessed by telephone modem or internet 24/7.

The program can be used in several different modes, including route planning, weather routing, speed management, sea-keeping, avoidance of parametric roll and other unsafe motion, and post voyage analysis. The user may specify a single route or a boundary of acceptable routes from the port of origin to the destination, as well as the desired departure and arrival times. The program then calculates the time of passage and fuel consumption, optimizing the ship’s route and velocity to suit the ambient ocean conditions while observing the specified schedule and the ship’s performance and safe operating limits. If an envelope of routes is specified, the program can find the optimum one, and exclude any that exceed specified limits. If no viable solution is possible, VVOS will report the cause of the problem, such as excessive sea states or insufficient transit time.

The program’s capabilities can be augmented with the addition of hardware sensors such as 6-DOF motion monitors, RPM and shaft torque gauges, and GPS, which allow real-time performance monitoring. Recording actual voyage data allows post voyage analysis that can be used to verify and fine-tune the VVOS algorithms, and also to monitor the ship performance and fuel quality for evidence of degradation. Automatic notifications may be given when preset thresholds are approached or exceeded.

Jeppesen Marine offers real-time consultation services, available upon request around the clock. In this service, shoreside experts in commercial maritime operations monitor the ship’s progress throughout its route, and, using Jeppesen’s shore-based VVOS server, send recommendations to the ship captain as needed. Training is available, either on-site or at Jeppesen’s facility in Alameda, CA.

The VVOS image in Fig. 2 illustrates a typical container ship transiting from Seattle, Washington to Nojima Saki, Japan along a standard Great Circle route. The passage is scheduled to take 7.5 days (181 hours), arriving June 10, 2008. Using VVOS, the ship’s passage along the selected route has been simulated using the latest 10-day forecast for wind, waves, and currents. The red triangle shows speed-optimized solutions with arrival times that range from 7 hours early to 29 hours late, taking into account the ambient conditions and the performance limits of the ship. The blue bar indicates the optimized solution for on-time arrival, in this example, consuming 1168 tons of fuel. If the captain increases speed to arrive 7 hours earlier (4%), an additional 119 tons of fuel (10%) is consumed. It should be emphasized that because each of these solutions has been optimized for the day-to-day weather conditions and the ship’s performance limits, both solutions are best case with regard to fuel consumption. Yet at current fuel prices, the unnecessary cost of an early arrival can be tens of thousands of dollars in a single voyage.

The same voyage and forecast were simulated using a constant speed throughout the voyage for an on-time arrival, in this case 23 knots (although the ship is forced to slow down in some segments due to ambient sea and/or weather conditions). In this example, fuel consumption was 1070 tons, an increase of 2 tons over the optimized speed solution. The same voyage and forecast were simulated using a constant speed throughout the voyage for an on-time arrival, in this case 79 RPM. In this case, fuel consumption was 1080 tons, an increase of 12 tons over the optimized speed solution. We also examined a “sprint and loiter” scenario, where the ship was operated at a speed of 25 knots for the first 6 days, and then slowed to 18 knots for the last 40 hours, again for an on-time arrival. In this situation, the ship consumed 1225 tons of fuel, 57 tons (5%) more than the optimized speed solution.

However, we can do even better by optimizing both the route and the speed with regard to the sea and weather conditions, as shown in Fig. 3. Here we set north and south boundaries for the voyage, creating a grid of possible routes. In this analysis, each possible route segment is examined for optimum speed resulting in an on-time arrival and minimum fuel consumption while observing ship performance and safe operating limits. The routes in blue are those that offer possible though not optimal solutions. The pink route is the solution that offers the best combination of fuel consumption, on-time arrival, and safe operating conditions. The green route segments do not have possible solutions. Again, the red triangle shows possible solutions for early or late arrival times with a range of 36 hours. The blue bar shows the solution for on-time arrival, with fuel consumption of 1156 tons. As shown in Fig. 4, even though the optimized route is only slightly different from the standard route examined earlier, it offers fuel savings of 12 tons ($8400 at $700/ton) even over the optimized speed solution.

The results of these simulations are summarized and compared in Fig. 5.
Fig. 2: VVOS screen showing solutions for speed optimization on a standard fixed trans-Pacific route

Fig. 3: VVOS screen showing route optimization for the same trans-Pacific passage
Our next study demonstrates the effects of vessel type, passage direction, location, and time of year on fuel consumption and potential savings achievable with VVOS. Four typical vessel types were selected for the simulation:

- A Panamax container ship sailing a trans-Pacific trade route
- A Post Panamax container ship sailing a trans-Atlantic trade route
- A bulk carrier on an Australia-Japan route
- A tanker on the US west coast trans-Alaskan pipeline trade route
On each route, the following sailing strategies were simulated and compared with the VVOS optimized voyage plan for the same arrival time:

- Sprint and loiter over a standard minimum distance route
- Constant speed over a standard minimum distance route
- Constant RPM over a standard minimum distance route
- Optimized speed over a standard minimum distance route

The exercise was conducted for each ship on four typical roundtrip passages for the same time period during the months of January and July 2005. Environmental conditions for the simulations were drawn from our 30-year hindcast ocean weather and wave database. Tables 2-5 show the potential fuel percentage and cost savings using $700 per ton of marine bunker fuel.

These are only single point studies, but we can observe that the overall fuel savings using voyage optimization is highest in the winter trans-Pacific passages, where ships encounter more severe weather than in the summer and in other geographic locations. Notwithstanding, savings are still possible even in the summer months since optimizing speed, i.e. slow down in head seas and speed up in following seas, and utilization of ocean currents can be implemented. Sprint-and-loiter is consistently the worst practice and can waste a substantial amount of fuel in a single voyage.

In the longitudinal routes from Australia to Japan and Long Beach to Alaska, the potential savings are smaller because these routes have less room to maneuver due to navigation restrictions and company policies. Most tankers and bulk carriers do not have fixed schedules. They sail at an “economic speed” instructed by the charters. Their voyages are typically longer and because of the slower speed, the savings are less compared to the high powered container ships. Nevertheless, significant savings still can be regularly obtained practicing intelligent speed management, utilizing currents, and avoiding sprint-and-loiter.

Another simulation experiment was conducted to demonstrate potential fuel savings that may be realized in one year of operation. For this simulation, we selected a Panamax container ship making trans-Pacific passages between Tokyo and Long Beach. In this comparison, eastbound and westbound passages were simulated for the same ship and load conditions for each week throughout one year (2006), generating the histograms shown in Fig. 6-7.

The green bars represent the differences in fuel consumption between a standard Great Circle route (minimum distance) using constant speed and a VVOS-optimized voyage. As one would expect, fuel consumption is generally higher for the winter passages than in summer months when the weather is not as severe. Occasionally, there were spikes due to tropical cyclones during the typhoon season. The difference between the standard and optimized routes diminishes in good weather, but increases when storms develop along the path of the standard route. Optimized routes were able to avoid the storms and still arrive on-time with reduced fuel consumption.

The charts in Fig 8-9 show the number of occurrences of the fuel saving magnitudes in 10-ton increments for the 200+ passages studied. (The first column includes any savings between 0 and 10 tons.) These results indicate that VVOS can yield significant reductions in fuel consumption and associated GHG emission while maintaining on-time arrivals.

From this study, it is evident that regular use of VVOS for route planning and execution would result in an overall reduction of the standard deviation throughout the period of operation, as well as an increase in the mean saving. In other words, fewer gross operating errors would be made that result in large quantities of wasted fuel and unnecessary GHG emissions, and average annual savings would increase.

It should be noted that these simulations indicate the potential savings that a relatively unskilled captain may obtain when using VVOS. An experienced captain may intuitively use voyage planning techniques similar to certain VVOS algorithms, and may match or exceed its capabilities in many cases. However, in situations where operational choices are subtle, and only a few percent savings may be on the table, VVOS should routinely provide more consistently positive results. Certainly, even 1% saved on a transoceanic voyage that consumes several thousand tons of fuel can represent substantial cost savings and GHG reductions. Moreover, captains with less experience can improve their seamanship performance immediately when they start to use VVOS.

The simulations generated by VVOS can be readily verified for a given ship by importing its actual recorded voyage data into the program. As a minimum, parameters should include planned schedule, actual schedule and route (from GPS), speed, horsepower, and fuel consumption. Adding ship motion allows evaluation of VVOS’ sea-keeping model. The same voyage can be simulated using hindcast weather data, and the actual and simulated fuel consumption compared to validate and/or refine the model. The same voyage can then be optimized by VVOS to determine what magnitude of improvement may have been possible.
Table 2: Potential fuel savings per passage of a Trans-Pacific Panamax Container ship

<table>
<thead>
<tr>
<th>Extra % fuel over Optimum Base Tons</th>
<th>Eastbound January</th>
<th>Westbound January</th>
<th>Eastbound July</th>
<th>Westbound July</th>
<th>Average Savings in 1 Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Route/Spd Optimized</td>
<td>985 Tons</td>
<td>1298 Tons</td>
<td>811 Tons</td>
<td>865 Tons</td>
<td>990 Tons</td>
</tr>
<tr>
<td>Speed Optimized</td>
<td>13%</td>
<td>0%</td>
<td>0%</td>
<td>7%</td>
<td>5%=$35K</td>
</tr>
<tr>
<td>Constant Speed</td>
<td>14%</td>
<td>4%</td>
<td>1%</td>
<td>8%</td>
<td>7%=$49K</td>
</tr>
<tr>
<td>Constant RPM</td>
<td>15%</td>
<td>3%</td>
<td>1%</td>
<td>10%</td>
<td>7%=$49K</td>
</tr>
<tr>
<td>Sprint &amp; Loiter</td>
<td>17%</td>
<td>7%</td>
<td>2%</td>
<td>11%</td>
<td>9%=$62K</td>
</tr>
</tbody>
</table>

Table 3: Potential fuel savings of a Trans-Atlantic Post Panamax Container

<table>
<thead>
<tr>
<th>Extra % fuel over Optimum Base Tons</th>
<th>Eastbound January</th>
<th>Westbound January</th>
<th>Eastbound July</th>
<th>Westbound July</th>
<th>Average Savings in 1 Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Route/Spd Optimized</td>
<td>745 Tons</td>
<td>874 Tons</td>
<td>664 Tons</td>
<td>730 Tons</td>
<td>753 Tons</td>
</tr>
<tr>
<td>Speed Optimized</td>
<td>2%</td>
<td>4%</td>
<td>0%</td>
<td>0%</td>
<td>2%=$11K</td>
</tr>
<tr>
<td>Constant Speed</td>
<td>2%</td>
<td>5%</td>
<td>2%</td>
<td>0%</td>
<td>2%=$11K</td>
</tr>
<tr>
<td>Constant RPM</td>
<td>3%</td>
<td>4%</td>
<td>3%</td>
<td>0%</td>
<td>3%=$16K</td>
</tr>
<tr>
<td>Sprint &amp; Loiter</td>
<td>6%</td>
<td>9%</td>
<td>6%</td>
<td>5%</td>
<td>7%=$37K</td>
</tr>
</tbody>
</table>

Table 4: Potential fuel savings per passage of a trans-Alaskan pipeline trade Tanker

<table>
<thead>
<tr>
<th>Extra % fuel over Optimum Base Ton</th>
<th>Northbound January</th>
<th>Southbound January</th>
<th>Northbound July</th>
<th>Southbound July</th>
<th>Average Savings in 1 Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Route/Spd Optimized</td>
<td>750 Tons</td>
<td>596 Tons</td>
<td>584 Tons</td>
<td>570 Tons</td>
<td>625 Tons</td>
</tr>
<tr>
<td>Speed Optimized</td>
<td>6%</td>
<td>4%</td>
<td>1%</td>
<td>0%</td>
<td>3%=$13K</td>
</tr>
<tr>
<td>Constant Speed</td>
<td>7%</td>
<td>5%</td>
<td>2%</td>
<td>1%</td>
<td>4%=$18K</td>
</tr>
<tr>
<td>Constant RPM</td>
<td>7%</td>
<td>4%</td>
<td>1%</td>
<td>2%</td>
<td>4%=$18K</td>
</tr>
<tr>
<td>Sprint &amp; Loiter</td>
<td>8%</td>
<td>7%</td>
<td>3%</td>
<td>5%</td>
<td>6%=$26K</td>
</tr>
</tbody>
</table>

Table 5: Potential fuel savings per passage of Australia to Japan Bulk Carrier

<table>
<thead>
<tr>
<th>Extra % fuel over Optimum Base Ton</th>
<th>Northbound January</th>
<th>Southbound January</th>
<th>Northbound July</th>
<th>Southbound July</th>
<th>Average Savings in 1 Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Route/Spd Optimized</td>
<td>1118 Tons</td>
<td>936 Tons</td>
<td>938 Tons</td>
<td>928 Tons</td>
<td>980 Tons</td>
</tr>
<tr>
<td>Speed Optimized</td>
<td>2%</td>
<td>1%</td>
<td>0%</td>
<td>0%</td>
<td>1%=$7K</td>
</tr>
<tr>
<td>Constant Speed</td>
<td>2%</td>
<td>1%</td>
<td>1%</td>
<td>2%</td>
<td>2%=$14K</td>
</tr>
<tr>
<td>Constant RPM</td>
<td>3%</td>
<td>1%</td>
<td>2%</td>
<td>1%</td>
<td>2%=$14K</td>
</tr>
<tr>
<td>Sprint &amp; Loiter</td>
<td>4%</td>
<td>2%</td>
<td>5%</td>
<td>3%</td>
<td>4%=$27K</td>
</tr>
</tbody>
</table>
Variations of potential fuel savings between Optimized and Standard Routes
PanaMax Container Ship from Tokyo to Long Beach during 2006-2007
Mean per Passage = 30 Tons, Standard Deviation = 41 Tons, Sample Size = 103

Variations of potential fuel savings between Optimized and Standard Routes
PanaMax Container Ship from Long Beach to Tokyo during 2006-2007
Mean per Passage = 52 Tons, Standard Deviation = 61 Tons, Sample Size = 104

Fig. 6-7: Histogram comparing standard and optimized passages over the same trans-Pacific route for one year
Number of Potential Fuel Saving Passages using VVOS versus Standard Routes
PanaMax Container Ship from Long Beach to Tokyo (Weekly 2006-2007)
Mean per Passage = 52 Tons (6.3%), Standard Deviation = 61 Tons, Sample Size =104

Number of Potential Fuel Saving Passages using VVOS versus Standard Routes
PanaMax Container Ship from Tokyo to Long Beach (Weekly 2006-2007)
Mean per Passage = 30 Tons (3.7%), Standard Deviation = 41 Tons, Sample Size =103

Fig. 8-9: Frequency of the magnitude of potential savings during a year of trans-Pacific passages

IMPORTANCE OF WEATHER FORECAST

Voyage optimization cannot be successful without high quality wind, wave, and current forecasts. If the forecast varies greatly from one update to the next, an optimized route solution can quickly become obsolete and in some cases difficult to revise effectively. One of the keys to VVOS’ ability to perform consistently is the high quality of its weather data.

VVOS weather data may be downloaded via Internet or telephone modem from Jeppesen’s Commercial Marine Operations facility. 10-day wind and wave forecasts are derived from several direct pipelines of weather forecast products from the U.S. National Weather Services (NOAA) as well as the European Center for Medium Range Forecast (ECMWF) and the U.S. Navy.
Wind and directional wave spectra are generated at 6-hour intervals for up to 10 days using state-of-the-art numerical forecast models. The forecast is updated twice daily. Tropical storm tracks and intensities issued by the U.S. Navy’s Typhoon Center and the Miami National Hurricane Center are converted into wind fields and then run through a wave model so that sea and swells generated by the tropical storms are properly represented in the wave forecast. Tropical storm forecasts are updated four times a day.

Each forecast is manually evaluated and adjusted by experienced marine meteorologists at Oceanweather Inc., located in Cos Cob, CT, to ensure quality control and correct input for tropical storms. Since the national centers do not allow manual intervention when running the wind and wave models, sea and swells generated by tropical storms are sometimes incorrectly depicted. If a captain, not realizing the sea and swell travels faster than the storm itself, tries to cut across the path of a tropical cyclone, he could put the ship in danger, such as occurred in 1980 when MV Derbyshire was lost due to Typhoon Orchid.

Oceanweather also maintains a 30-year hindcast wave and weather database for the world’s oceans. In combination with VVOS, this historical database can be used to conduct comprehensive simulations under various conditions, for example, to test ship performance models, or to determine the most favorable time of year for towing large structures from one port to another.

CO2 INDEXING

In 2005, the IMO published preliminary guidelines for establishing a CO2 index as a means of monitoring and comparing the amount of GHG emitted by a given ship or ship type [4]. The proposed index is a straightforward calculation based on fuel consumption per ton-miles.

\[
\text{Index} = \frac{\sum FC_i \times C_{\text{Carbon}}}{\sum m_{\text{cargo},i} \times D_i} \quad \text{(gram CO2/tonne identical mile)}
\]

IMO proposes that the initial index could be derived after recording data from six months (for newly built ships) to one year of operation (for existing ships). We would argue that an initial index could be generated with VVOS, in combination with its 30-year hindcast weather database. Using the best available modeling data for a given vessel, VVOS can simulate its theoretical fuel consumption for anticipated routes and loads over many years of operation using actual historical weather data. Once in operation, voyage data recording can be used to verify the initial index, and monitor ship performance for evidence of excess fuel consumption due to operational and/or maintenance issues.

We question the usability of the CO2 index as it is now defined, arguing that it may be oversimplified. As it stands, there is no incentive to use a route that maximizes fuel savings. As we have seen, VVOS demonstrates that the shortest path between two points is not necessarily the most fuel-efficient one. Furthermore, fuel consumption varies greatly with the geographical location and direction of passage, as well as the time of year. Also, given two ships with equal cargo capacity, a faster ship may have higher fuel consumption, but this may be offset by its ability to transport more cargo per year. These factors should be taken into account in the index calculation.

While proposing specific solutions to these questions is beyond the scope of this paper, certain conceptual approaches are suggested:

- The index should be calculated using the minimum distance between each port of call. This would allow direct comparison of fuel consumption of different ships sailing the same passage.
- A time factor should be added to cargo weight-distance based on the duration of each passage (i.e. total number of passages per year) in order to normalize the index for vessels of different speeds.
- Just as a different index is needed for each ship or ship type, separate indices may be needed for different routes and geographical locations.

CONCLUSION

Optimization of ship operation in relation to weather and wave forecasts, currents, ship performance, and safe operating limits can result in substantial and repeatable reductions in fuel consumption, GHG emissions, and cost of operation. The 2000 IMO study suggests traditional weather routing (i.e. that does not include or only loosely addresses specific ship performance and limits in its calculations) can reduce ship-generated GHG emissions by up to 2-4%, but we would argue that VVOS, with its accurate modeling, advanced algorithms, and high quality forecasts, will consistently give better results. The potential gains offered by VVOS increase as the weather becomes more severe, while reliability of on-time arrival is improved and safe operating limits are observed. These gains can be verified by post-voyage analysis.

The capabilities of VVOS are enhanced by monitoring actual ship performance data in real-time with existing instrumentation and specialized sensors. VVOS can use these data to improve its modeling and calculation accuracy, and can give advance warning of unsafe conditions such as impending parametric roll. Changes in performance over time can be monitored and trig-
ger alarms at predetermined thresholds, such as accumulation of marine growth on the ship hull, propeller degradation, and/or out-of-tune or malfunctioning engines. It also allows the ship owner to remotely monitor the condition and operational history of his fleet.

One of the key justifications of a sprint-and-loiter strategy is the high cost of late arrival, which, at least in prior years, could outweigh fuel cost savings, and is often cause for poor performance reviews of a ship captain. Using VVOS has been demonstrated to greatly improve reliability of on-time arrival without resorting to this wasteful strategy. It also can give greater advance notice of late arrival to port facilities and connecting services, and more accurate prediction of the revised arrival time. With sufficient advance notice, the cost of occasional late arrivals can be minimized. This gives the ship captain more flexibility to make a committed effort to reduce fuel consumption and associated emissions.

VVOS is an application of advanced technology with potentially substantial benefits and little or no downside. It increases the ship captain’s total situational awareness, improving his decision-making toward achieving greater safety and repeatability in the operation of the ship. The potential savings in operating costs will quickly pay for the technology, and our earth and its inhabitants will benefit from the reduction of commercial shipping’s contribution to global warming.

REFERENCES


