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Effect of Carbon Emissions on Commercial Operation of Tankers

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Abstract: At present, the commercial operation of tankers on spot freight market is focused on the maximization of the daily earnings by careful selection of factors such as speed and utilization, while it is subject to market freight rates and bunker prices. With the expected introduction of carbon tax, the daily earnings will be affected. This will have an effect on the way a ship is employed and operated. While the exact form of carbon tax is not yet known, it can be shown that the optimum speed will be reduced, and the level of reduction of optimum speed will depend on factors related to the freight and bunker markets as well as on the technical characteristics of the ship. The effect of reducing the emission index such as CII (carbon intensity indicator) below a desirable level is also examined. It is shown that all related factors will play a role, the extent of which depends on their fundamental relation to total emissions and ton miles. The article also examines the speed reduction needed to bring the CII to desirable level after it has exceeded it due to previous Charterer's trading pattern.

Key words: Shipping, emissions, optimization.

1. Introduction

For many years, the engines on tankers have grown bigger and bigger. In the decade of 2000, the demand was to achieve very high speeds. However, in the last 10 years we see a steady drop in the average speed of VLCC (very large crude oil carrier) tankers. Especially for ballast passages, the drop is very dramatic, having been decreased from 15 knots in 2005 to 11.05 knots in 2021 (data of a private fleet of 30 VLCCs). The speed reduction was however driven by the market supply and demand for tanker tonnage and not for environmental reasons. At the same time, the price of bunker fuel HFO (heavy fuel oil) 380 at Singapore has changed from $160\,\mathrm{usd/mt}$ to current level of $440\,\mathrm{usd/mt}$ (Jun 2023 prices), while VLSHFO price is close to 530 $\mathrm{usd/mt}$.

In the meantime, there has been a clear determination and commitment by international organizations and governments to reduce the CO_2 emissions of ships. It is thus certain that carbon tax will be applied to any cargo ship, forcing the owners to invest in environmentally friendly ship engines or to reduce emissions by operational methods such a reduction of speed. We take the approach that the tax will be a monetary amount on every ton of CO_2 emitted.

We will explain the mechanism of daily earnings or TCE (time charter equivalent) calculation with and without carbon tax as well as the mechanism of the CII (carbon intensity indicator) calculation. We will then examine how the optimum speed will be affected by the carbon tax and how the performing speed shall be reduced to keep the environmental index below a limiting value.

1.1 Modelling the TCE

TCE is defined as the net income per voyage day, net income being the freight less the voyage expenses such as bunker cost, port expenses and commission. Outlining the basic constituents, we have:

- The freight is calculated as a rate of US dollars per ton m of cargo carried, with the rate being a

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percentage (called WorldScale rate), WS_r, times a pre-calculated WorldScale flar rate, WS_f. It can be expressed as:

$$Fr = m \cdot WS_r \cdot WS_f \quad (1)$$

where m is the weight of cargo in metric tons.

- The expenses break down to:

Bunker expenses: These are the sum of bunker expenses in ballast, in laden and at port, each one being the consumption TFC_B, TFC_L, TFC_P times the bunker price BP, or

$$B_{exp} = (TFC_B + TFC_L + TFC_P) \cdot BP = \left(\left(a_B \cdot sp_B^{b_B} + FC_{AE}\right) \cdot \frac{D_B}{sp_B} \cdot \frac{1}{24} + \left(a_L \cdot sp_L^{b_L} + FC_{AE}\right) \cdot \frac{D_L}{sp_L} \cdot \frac{1}{24} + FC_P \right) \cdot BP \quad (2)$$

Commission expenses: They are simply a percentage f of the freight, or $Comm = f \cdot Fr$.

Port Expenses: P_{exp}, which are well defined for any voyage in consideration.

Other Expenses: denoted by O.

The TCE can then be expressed as:

$$TCE = \frac{Fr - B_{exp} - Comm - P_{exp} - O}{days} = \frac{m \cdot WS_r \cdot WS_f - B_{exp} - f \cdot Fr - P_{exp} - O}{\frac{D_B}{sp_B} \cdot \frac{1}{24} + \frac{D_L}{sp_L} \cdot \frac{1}{24} + D_P} \quad (3)$$

1.2 Modelling the CII

The Carbon Intensity Index, CII, corresponds to the emissions of CO_2 per cargo-carrying capacity ton mile [1, 2], or transport work, and can be formulated as:

$$CII = \frac{\sum_j FC_j \times C_{Fj}}{dwt \times D} \quad (4)$$

where:

- j is the type of fuel
- FC_j is the mass consumed of fuel j
- C_{Fj} is the fuel mass to CO_2 mass conversion factor for fuel j
- dwt is the deadweight of the ship
- D is the distance in nautical miles.

with units in $gCO_2/t.m$ or grams of CO_2 per ton mile.

For simplicity, we would assume for now on that only one grade of fuel is used. The consumption per day is of the general form $FC \propto speed^3$ (the "textbook" case). In reality, seldom does the consumption follow this simple rule. By plotting the consumption against speed in either laden or ballast condition, we end up with a form $FC = a_{L,B} \cdot speed^{b_{L,B}} + FC_{AE}$, the first term been taken from main engine and the second from auxiliary engine. CII can then be expanded in the form:

$$CII = \frac{\left(a_B \cdot speed_B^{b_B} + FC_{AE}\right) \cdot \frac{D_B}{24\, speed_B} + \left(a_L \cdot speed_L^{b_L} + FC_{AE}\right) \cdot \frac{D_L}{24\, speed_L} + FC_P}{dwt \cdot D} \cdot C_F \quad (5)$$

All indices follow smoothly, with FC_P being the fuel oil consumption at port. C_F represents the conversion factor from mass of fuel oil consumed to mass of CO_2.

1.3 TCE Optimization without Carbon Tax

TCE is optimized by maximizing the expressing function. One can solve for the optimum value of the undefined parameter(s) which make the TCE maximum, by equating the first derivative of TCE with respect to the parameter under investigation to zero. We may define optimum speed as the speed which maximizes the daily earnings or TCE. Evans and Marlow [3] have presented most of the aspects of this problem in a concise manner, although earlier publications [4] had examined the basic issues satisfactorily. More recent studies [5] have included parameters such as port waiting time, while other take a more holistic approach [6]. While most of the studies are based on the cubic law between the speed and the consumption, some consider a modified cubic law [7] based on empirical evidence. The present work considers both cubic as well as non-cubic law taking data from actual sailing conditions over an extended time period and geographical sailing range.

We will attempt to derive a formula by which the optimum speed is expressed as a function of all parameters involved using a semi-quantitative approach. A numerical approach will follow with exact results for any selection of numerical values of the parameters involved.

1.3.1 Semi-quantitative Approach

TCE can be broadly expressed as:

$$TCE = \frac{\text{NetIncome}}{\text{Days}} = \frac{\text{Income} - \text{BunkerExp} - \text{Other}}{\text{Days}} = \frac{I - B - O}{D} \tag{6}$$

At any reduced speed, there will be bunker savings S while the voyage time will be extended by T, so the new TCE will be:

$$TCE' = \frac{I - B + S - O}{D + T} \tag{7}$$

The percentage change in TCE will be:

$$\frac{\Delta TCE}{TCE} = \frac{TCE - TCE'}{TCE} = 1 - \frac{TCE'}{TCE} = 1 - \frac{1}{TCE}\frac{I - B - O + S}{D + T} = 1 - \frac{1}{TCE}\frac{TCE + \frac{S}{D}}{1 + \frac{T}{D}}. \tag{8}$$

From the last it is seen that after speed reduction, TCE is increased when the market is such that $TCE < \frac{S}{T}$.

The last expression can be used to derive an expression for the optimum speed of either ballast or laden leg to a very good approximation. Close to optimum speed, where the TCE will become maximum, the quantity $\triangle TCE/TCE$ will be close to zero, or $\triangle TCE/TCE \approx 0$, or $S/T \approx TCE$. The savings in any leg of distance D for sailing at sp_1 at daily fuel oil consumption FOC_1 compared to sp_2 at consumption FOC_2 with $sp_1 < sp_2$ is:

$$S = \frac{D}{24sp_2}FOC_2 \cdot BP - \frac{D}{24sp_1}FOC_1 \cdot BP \tag{9}$$

while the additional time T is:

$$T = \frac{D}{24sp_1} - \frac{D}{24sp_2}. \tag{10}$$

We will then have close to the optimum speed:

$$\frac{S}{T} = BP\frac{\frac{D}{24sp_2}FOC_2 - \frac{D}{24sp_1}FOC_1}{\frac{D}{24sp_1} - \frac{D}{24sp_2}} = BP\frac{\frac{FOC_2}{sp_2} - \frac{FOC_1}{sp_1}}{\frac{1}{sp_1} - \frac{1}{sp_2}} \approx TCE. \tag{11}$$

For the "textbook" case where the daily fuel oil consumption varies with the cube of the speed, $FOC \propto sp^3$, the last expression can be easily simplified to:

$$nBP(sp_2 + sp_1)sp_1 sp_2 \approx TCE \tag{12}$$

with n the proportionality constant of $FOC = n \cdot sp^3$. For sp_1 very close to sp_2 or $sp_1 \approx sp_2 \approx sp_{\text{opt}}$, we get:

$$sp_{\text{opt}} \approx \left(\frac{TCE}{2nBP}\right)^{\frac{1}{3}} \tag{13}$$

The above relation applies to either ballast or laden optimum speed: assuming that the laden speed is kept constant, the relation derives the optimum ballast speed and vice versa. It also clearly resembles the formulae derived by other means. For example, by expressing the TCE in terms of the same speed for both ballast or laden legs, a direct differentiation produces the same result. The present method gives further insight into how TCE and S/T behave close to the optimum speed.

The "textbook" case is however not observed in reality. The relation between daily fuel oil consumption, FOC and speed is, as we have seen, of the form $FOC = a \cdot sp^b$, with $b < 3$. The optimum speed can still be approximated with some more elaborated algebra. We get:

$$TCE = a \cdot BP \cdot sp_1 \cdot sp_2 \frac{sp_1^{b-1} - sp_2^{b-1}}{sp_2 - sp_1}. \quad (14)$$

The quantity $\frac{sp_1^{\gamma} - sp_2^{\gamma}}{sp_2 - sp_1}$, with $\gamma = b - 1$ can be approximated by $\gamma sp_1 \left(\frac{sp_2}{sp_1} - 1\right)$. We then get:

$$TCE = aBPsp_2 sp_1^{b-1}(b-1). \quad (15)$$

For sp_1 very close to sp_2 and to the optimum speed, or $sp_1 \approx sp_2 \approx sp_{\text{opt}}$, we get:

$$sp_{opt} = \left(\frac{TCE}{aBP(b-1)}\right)^{1/b}. \quad (16)$$

The relation above yields the same equation derived for the "textbook" case of $b = 3$.

The formulae derived are very illustrative. The optimum speed is proportional to TCE to the power of $1/b$ so in a good market the ship should sail at increased speed in either the laden or ballast leg. The optimum speed is also inversely proportional to the bunker price to the same power, but it is more accurate to say that the optimum speed depends on the ratio TCE/BP, or the interplay between the freight market and the bunker price. The parameters a and b involved in the daily fuel consumption through the relation $FOC = a \cdot sp^b$ also affect the optimum speed, so the lower the parameters are the higher the optimum speed will be.

1.3.2 Quantitative Approach

The way to maximize TCE is the common way of maximizing any function, that of demanding the first derivative to become zero.

One may also maximize the TCE for two variables. For example we can find the pair of $\{sp_B, sp_L\}$ which maximize the TCE. Although this is in practice of low importance, because the laden speed sp_L is determined by charterers, it is nevertheless valuable information which can be taken into consideration by the operator. We will demonstrate this with a few examples.

1.3.2.1 Optimum Ballast Speed

To find the optimum ballast speed, we start from the general expression of TCE which we differentiate with respect the sp_B and the derivative is made zero. The equation is solved numerically in Mathematica. The parameters used in this example are shown in Table 1. The change of TCE with ballast speed for the set of parameters of Table 1 is shown in Fig. 1.

Solving numerically for the optimum speed, equating the first derivative of TCE with respect to the ballast speed to zero, we produce Fig. 2 where the TCE is plotted against bunker price for various WS rates.

The parameters $a_{B,L}$ and $b_{B,L}$ are taken from actual records of speed and consumption of a large number of voyages and routes of a 2010-built VLCC. At periods after dry docking the parameters are improved. For example, the set $\{a_B, b_B, a_L, b_L\}$ improves from $\{0.1442, 2.2774, 0.3167, 2.1062\}$ before dry dock to $\{0.1103, 2.3934, 0.2711, 2.1735\}$ after dry dock. Besides, the same set of an ECO, 2017-built, VLCC is $\{0.0689, 2.4787, 0.4956, 1.8406\}$.

Table 1 Values of parameters involved in optimum speed derivation for the numerical study in 1.3.2.

Ballast distance (miles)	6,000
Laden distance (miles)	6,000
Laden speed (kt)	13
Cargo quantity (mt)	270,000
WS flat rate (usd/mt)	18.23
WS rate (%)	50
Commission (%)	1.25
Port expenses (usd)	250,000
Bunker price (usd/mt)	450
Port consumption (mt)	250
Port days	4
a_B	0.1442
b_B	2.2774
a_L	0.3167
b_L	2.1062

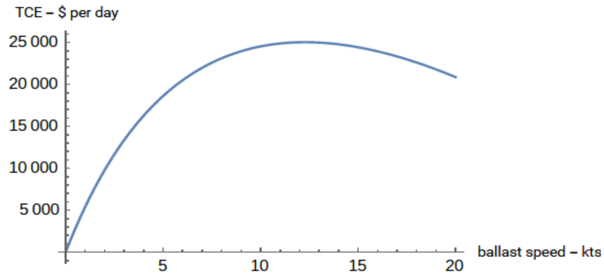

Fig. 1 TCE as a function of ballast speed.

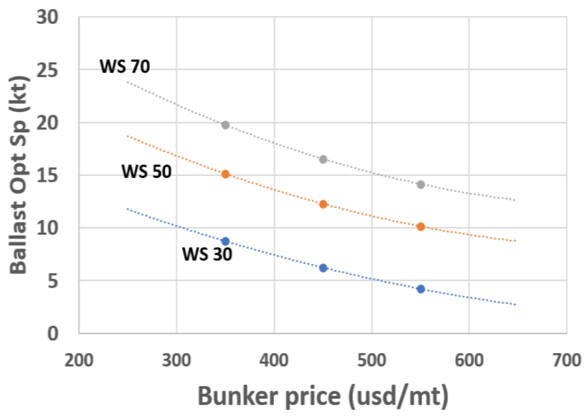

Fig. 2 Optimum speed variation with bunker price at various WS rates.

1.3.2.2 Optimum Laden Speed

The same procedure can be followed to find the optimum laden speed by keeping all other parameters, including the ballast speed, the same. The laden speed has a stronger effect on TCE because of the stronger contribution to the expenses through the consumption of the laden leg. Even more interesting is that one can find the best combination of values $\{sp_B, sp_L\}$ which make the TCE maximum. For our set of parameters of Table 1, this pair becomes $\{12.3, 11.2\}$ knots.

As discussed earlier, the formulae derived from the semi-quantitative approach are remarkably accurate. Their accuracy can be further increased by performing a two-step iteration. The methodology is as follows: firstly, we evaluate the TCE for a trial speed, from this we calculate the optimum speed using the formulae, then we take the arithmetic average and we calculate a new TCE and a new optimum speed, we again take the arithmetic mean of speed and we derive the optimum speed (2nd iteration) in excellent agreement with the numerical value.

1.4 Optimum Speed with Carbon Tax

It is not clear the exact form the carbon tax is going to take. The simplest form of carbon tax is a levy on every ton of emission [8]. The carbon tax will be:

$$Ct = FOC \cdot C_F \cdot \lambda \tag{17}$$

where λ is the tax in usd ($) on every ton of emission. The new TCE will become:

$$TCE_t = \frac{I - B - O - Ct}{D} \tag{18}$$

where TCE_t is now the TCE with carbon tax applied.

This new expression of TCE can now be treated the same way as the TCE without tax.

1.4.1 Semi-quantitative Approach

Working similarly as before, and writing Ct as $Ct = \frac{B}{BP} C_F \lambda$, we get for a change in the performing speed:

$$\frac{\Delta TCE}{TCE} = 1 - \frac{1}{TCE} \frac{I - B - O + S - \frac{B-S}{BP} C_F \lambda}{D + T} = 1 - \frac{1}{TCE} \frac{TCE + \frac{S}{D}\left(\frac{C_F}{BP} + 1\right)}{1 + \frac{T}{D}}. \tag{19}$$

In the simplest case of a standard levy on every ton of bunker fuel (contrary to every ton of emission), the optimum speed will be $sp_{opt,t} = \left(\frac{TCE_t}{aBP_t(b-1)}\right)^{1/b}$. Observing that at the optimum speed $S/T = \frac{TCE}{1+\frac{CC_F\lambda}{BP}}$, we deduct that:

$$sp_{opt,t} = \left(\frac{TCE_t}{aBP(b-1)}\right)^{1/b} \cdot \left(\frac{1}{1 + \frac{\lambda C_F}{BP}}\right)^{1/b}. \tag{20}$$

The same relation may be derived by simply replacing BP with the new bunker price $BP + \lambda C_F$. The first part on the right hand side of the expression is the relation derived earlier for the optimum speed without carbon tax, except that the TCE now is the one with carbon tax included, while the second part consists an additional correction to the optimum speed. The effect the carbon tax has on the optimum speed can be readily observed in the above formula. The optimum speed is reduced as 1. The factor C_F, or the type of fuel with high CO_2 emissions, is increased, 2. The Carbon tax stipulated by λ is increased, 3. Bunker price is increased. It is interesting to note however that for typical values of the parameters, the value of second part on the right hand side of the relation is a significant contribution to the reduction of the optimum speed. The same relation can also be broken down as:

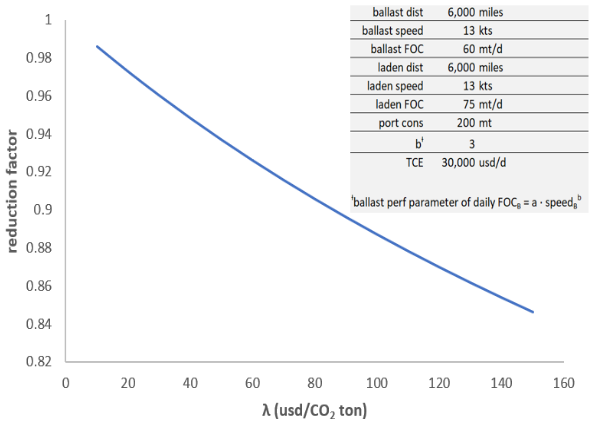

Fig. 3 Dependence of the reduction factor on carbon tax per ton of CO_2 emitted.

$$sp_{opt,t} = \left(\frac{TCE}{aBP(b-1)}\right)^{1/b} \cdot \left(\frac{1}{1+\frac{\lambda C_F}{BP}}\right)^{1/b} \cdot \left(1-\frac{C_t}{D \cdot TCE}\right)^{1/b} \tag{21}$$

where the first term is the optimum speed without carbon tax. The product of the last two terms consists a reduction factor which, when applied on the optimum speed without carbon tax, gives the new optimum speed after carbon tax. The dependence of the reduction factor on the optimum speed is given in Fig. 3 for a selected set of parameters.

The optimum speed with carbon tax applied is given by the same relation without tax but the TCE is the one after tax is applied, with:

$$TCE_t = \frac{I-B-O-Ct}{D} = TCE - \frac{Ct}{D} = TCE - \frac{\lambda C_F FOC}{D} \tag{22}$$

The application of carbon tax on every ton of emission has the same effect on TCE as that of increased bunker price.

2. Consequences of Keeping the Carbon Index below a Critical Value

There are several other outcomes which come into effect with the introduction of the new regulations. For example, the operator will need to keep the index below a certain category. We will compare the time lost and the reduced TCE due to sailing at speed below the optimum for the purpose of keeping the carbon intensity index below a critical value. Considering that the laden leg is kept at charter party speed, the operator will have to reduce the ballast speed to force the carbon index falls below a limit value. Solving for $CII \le CII_c$ we get:

$$sp_c^* = \left(24\frac{\frac{CII_c \cdot dwt \cdot D}{C_F} - FOC_L - FOC_P}{aD_B}\right)^{\frac{1}{b-1}} \tag{23}$$

This speed should be compared to the optimum ballast speed. If it is less, there will be time lost, and subsequently an income loss will incur which will be equivalent to the time lost multiplied by TCE at the market level. All the important factors which will affect the ballast speed are here. As the threshold becomes stricter, the required ballast speed will be reduced, so will if the fuel used has high C_F factor or the technical parameters a and b are increased. Another not so trivial result, though well expected, is that an increase in the ballast distance will lead to an increase in the maximum allowed speed before the CII_c is reached. Fig. 4 shows this effect schematically, for a selected set of parameters.

More simple forms for the required speed may be derived for some special cases. For example, assuming we are seeking a common ballast and laden speed, for the case of equal ballast and laden legs and for the textbook case of cubic log dependence of fuel oil consumption on speed and negligible port consumption at port, the relation becomes:

$$sp^* = \left(\frac{48CII_c \cdot dwt}{C_F(a_B + a_L)}\right)^{\frac{1}{2}} \tag{24}$$

For unequal ballast and laden legs, the above relation becomes:

$$sp^* = \left(\frac{24(D_B + D_L) \cdot CII_c \cdot dwt}{C_F(D_B a_B + D_L a_L)}\right)^{\frac{1}{2}} \tag{25}$$

while for $a_{B,L}$ other then three, a numerical solution should be sought. Some straightforward conclusions can be drawn from the above relation:

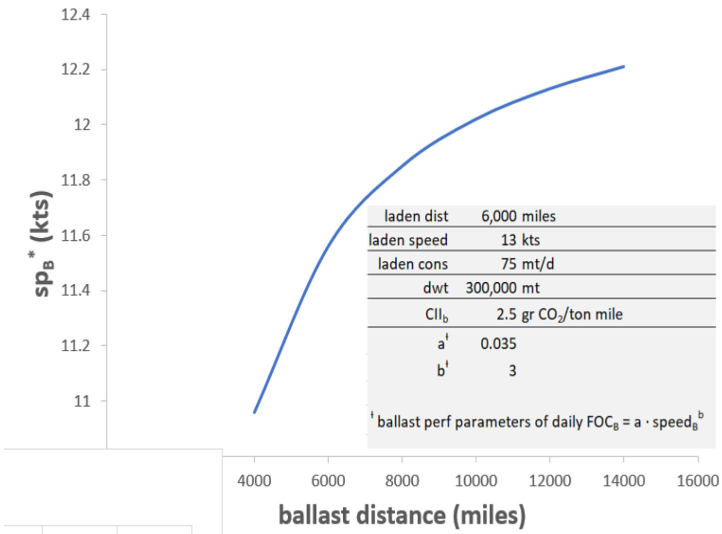

Fig. 4 Speed reduction in ballast as a function of ballast leg distance to keep the CII below a required threshold.

(1) The lower/stricter the limiting index CII_c is, the lower the performing speed should be. The relation is not linear as sp^* is proportional to the square root of CII_c.

(2) The lower the C_F factor is, the higher the performing speed can be. Therefore, switching fuel grade from HFO to LNG will allow the ship to trade at higher speed. Again, the relation is not linear.

(3) Ships with high consumptions, represented by elevated parameters $a_{B,L}$, must be operated at reduced speed.

(4) A simple re-arrangement of terms can show that if the laden distance is higher than the ballast, the required speed is reduced, leading to the counter-insight result that long ballast legs improve the carbon index while it is known that they reduce the TCE.

3. Correcting the C_{II}

One of the anticipated conditions which a ship will face in the years to come is that after a period of long or short term time charter, the vessel may be delivered back to owners with undesirable C_{II}. It will then be necessary to reduce the C_{II} by taking necessary steps, most important of which is selecting long ballast legs or reducing the speed. We will limit the discussion here to the effect of reducing the speed by calculating the maximum speed which will be needed to meet the desirable C_{II} level. This will then help the owners to calculate the time lost and the therefore the lost income due to previous charterers operational profile, as this is described in the BIMCO C_{II} clause, paragraph (j) [9], which states that: *"The Owners shall be entitled to claim from the Charterers any losses, damages, liabilities, claims, fines, costs, expenses, actions, proceedings, suits or demands suffered by the Vessel and/or the Owners which have been caused by any breach by the Charterers of their obligations under this Clause."*

We assume that for past time T the ship's C_{II} was $C_{II,T}$ and in the subsequent time t the C_{II} must be reduced to $C_{II,t}$ so that the combined $C_{II,t'}$ for the period $t' = T + t$ is below the required value $C_{II,r}$. We calculate the maximum speed needed to achieve this. By writing $C_{II,i} = FOC_i \cdot C_f / DWT \cdot D$, where $i = T, t, t'$ and $FOC_{t'} = FOC_T + FOC_t$ with the total fuel oil consumption $FOC_t = asp_t^{\beta-1} D_t / 24$, we derive that:

$$sp_t \leq \left[\frac{24 \cdot dwt}{10^6 a C_f}\right]^{\frac{1}{\beta-1}} \cdot \left[C_{II,r} - \frac{D_T}{D_t}\left(C_{II,T} - C_{II,r}\right)\right]^{\frac{1}{\beta-1}} \tag{26}$$

Some conclusions are readily made:

(1) The higher the deadweight of the ship the higher

the speed will be allowed to be.

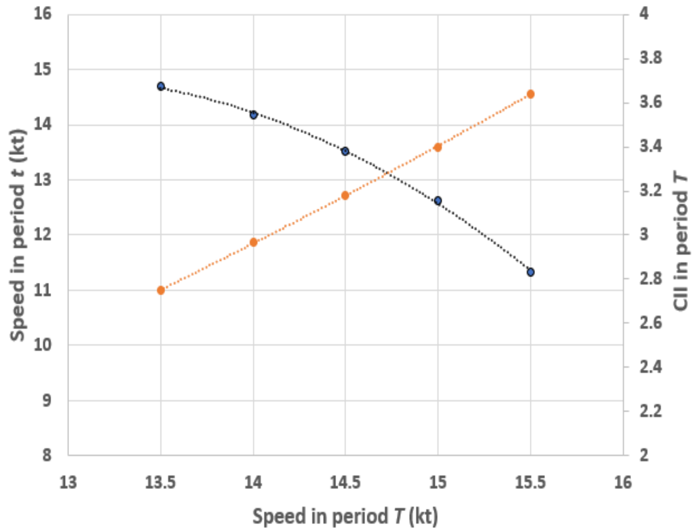

Fig. 5 Speed required (black line) in period *t* to bring CII below a required value when the speed in period *T* is known. The second vertical axis shows the attained CII (orange line) in period *T* (The values of the parameters are given in the text).

(2) The lower the conversion factor C_f, the higher the speed will be so alternative fuels with reduced emissions are more beneficial for the C_{II} and speed purposes.

(3) Ships with less consumptions, as these are reflected in the parameters a and β allow higher speeds.

(4) The speed required will obviously be higher if the target $C_{II,r}$ is higher.

(5) The speed required will be lower if the previously achieved $C_{II,T}$ is lower.

(6) The speed required will be higher the lower the ratio $\frac{D_T}{D_t}$ is and the lower the difference $C_{II,T} - C_{II,r}$ is.

Although this formula is very elegant and easy to solve, one must, in practice, solve numerically an algebraic inequality equation in which the distance D_t is expressed in terms of the time parameters t, and speed sp_t. The inequality then takes the form:

$$10^{-6} atC_f sp_t^{\beta} - 24tC_{II,r} \cdot dwt \cdot sp_t \leq D_T \cdot dwt \cdot (C_{II,r} - C_{II,T}) \quad (27)$$

In the calculation above we have used a unified speed for both ballast and laden legs for simplicity reasons. More extended versions will require to differentiate between laden and ballast consumption as well as to include port time in addition to the sailing time. Fig. 5 shows the required speed in period t given the speed in period T, for $a = 0.175$, $\beta = 3$, $T = 200$ days, $t = 165$ days, $dwt = 150{,}000$ mt and $C_{II,r} = 3$ $\mathrm{gCO_2/t.m}$.

It must be stated that there is time lost due to decreased speed on the condition that the required speed sp_t is less than the optimum speed for the period under discussion. In other words, there will not be any effect to the owners of reducing the speed if this reduced speed is below the one at which the ship would be normally operated at the prevailing market.

4. Discussion

Perfectly optimizing the TCE in practice is not always feasible. Nevertheless, understanding the parameters which affect the TCE and the sensitivity of TCE upon them is important to take the right decision. With the use of software programs which calculate the TCE, it is straightforward these days to get a very good idea of the optimum speed with minimum effort, yet a theoretical knowledge gives a deeper insight on exploiting the full capacity and the returns of any ship in any market.

The above remarks become even more important in an environment in which additional tax is applied depending on the emissions, which, in turn, depend on the performed speed. The vagueness of the tax to be applied increases the uncertainty of the effect it will have on the optimum speed, but it is evident that speed adjustments will be needed.

The enforced regulations of reporting an environmental index such as $CII,$ and acting appropriately in case the index falls outside a critical range, imposes further restrictions on the performing speed. The facts that the environmental index will be calculated on period and not voyage basis gives some flexibility to the operator, however each voyage should ideally be optimized. The effect of increased C_{II} of a certain period has been discussed with emphasis on the reduced speed which will be needed to bring the C_{II} back to desirable level.

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