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An Investigation for the Fuel Price Escalations on Optimum Speed in Maritime Transportation

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Abstract

Most of the cargoes are shipped by maritime transportation in the World since it enables moving of more commodities at the same time. Transportation costs and environmental effects as air pollution, noise are also less compared to other modes of transportation such as highway, railway and airway. Cost is a significant determinant for the decision-making of consigners during mode choice. In this study, an economic analysis approach for a unimodal transportation cost calculation has been presented and applied to a case study for maritime cargo transportation. Unit transportation costs for 10000 DWT cargo vessel have been calculated considering technical and economic parameters of the vehicle. Effect of service speed, fullness ratio and escalation rate for future fuel cost on unit transportation cost have also been investigated and shown with graphs. It is found out that unit transportation cost increases with the increase in service speed and escalation rate for future fuel cost and the decrease in the fullness ratio of the vessel. The model has also been run to illustrate how the optimum speed can vary with respect to escalation rate for future fuel costs and clearly seen that optimal speed becomes lower at high fuel escalation rates.

Keywords: Costs, Transportation, Maritime, Speed Optimization, Fuel Consumption

1 Introduction

Maritime transportation is the main transportation mode for global cargo distribution due to the shipping capacity, ability to carry cargo over long distances at low transportation costs compared to other modes of transport. Cost is a prominent factor during mode choice of a cargo and various parameters such as

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route length, vessel speed, fullness ratio, escalation rate for future fuel costs, etc. effect the value of unit transportation costs.

In this study, unit transportation cost of a 10000 DWT cargo vessel have been calculated and the alterations with respect to parameters as service speed, fullness ratio and escalation rate for future fuel prices have been shown with graphs by using Levelised Cost Method. Levelised costs are the ‘‘ratio of total lifetime expenses versus total expected outputs, expressed in terms of the present value equivalent’’ according to Nuclear Energy Agency and International Energy Agency (2005).

There are some studies utilizing from levelised cost method during the calculation of transportation cost both for cargo and passenger in the literature. For passenger transportation, Sahin and Kesgin (1991) and Alkan et. al. (1997) studied an economic analysis by using this method. Moreover, Ust and Turan (2011) applied the method to six different passenger vessels operating between Besiktas & Uskudar to estimate unit transportation costs.

For cargo transportation, Sahin et. al. (2005, 2009) have compared the unit transportation costs for highway, railway, maritime and combined transportation modes in Turkey with the application of levelised cost method. Turan et. al. (2012) made a cost analysis for the determination of the most cost-effective transportation mode between İstanbul and Denizli and as a result, they have figured out that intermodal seaway-highway transportation has the minimum transportation cost for this route. Additionally, Sahin et al. (2014) developed an approach for intermodal transportation in their study and pointed out that in the short distance transportation, single transportation modes always tend to be advantageous while the transportation distance is longer, intermodal transportation begins to be more cost-effective.

In addition to above studies, Pilot and Pilot (1999), Prakash et. al. (2008), Al-Khayyal and Hwang (2007) focused on the minimization of total transportation cost problem.

Clark et. al (2004) studied on the determinants of shipping costs and the effects of these parameters on maritime transportation. They indicated that seaport efficiency is an important determinant of maritime transportation costs besides route length and other variables. Speed optimization has also been investigated and illustrated with the derived economic model in this study. According to the literature, Psaraftis and Kontovas (2014) made a study to clarify some important factors such as ship speed optimization and investigated the effect of speed reduction on total trip time, fuel consumption, fuel costs, air emissions. They have indicated that slow steaming is the most economical measure in order to minimize the costs and gain more profit.

Psaraftis and Kontovas (2013) presented a taxonomy and survey of speed models in maritime transportation emphasizing that the ship speed is a major determinant for maritime economics and sustainability.

Magirou et. al. (2015) examined the economic speed of vessels operating in the spot market in a tramp transportation utilizing from dynamic programming equations. Fagerholt and Psaraftis (2015) proposed a mathematical model aiming to maximize daily profit and they applied their model to ships that sail in and out of Emission Control Areas (ECAs).

2 Case Study

Investment, fuel/lubricants, operation/maintenance and external costs of a vessel have been considered in order to estimate the unit transportation cost in maritime transportation.

A. Investment cost per unit of cargo (Uc):
Investment, operational and maintenance, fuel and lubricant, external costs per unit of cargo have been designated with the economic model presented by Sahin et. al. (2005, 2009).
The unit cargo investment cost, Uc, calculated with the below equation (2005, 2009):

$$U_c = \frac{\left\{ \sum_{t=1}^{n} I_c \left[(1-\frac{t-1}{n})i + \frac{1}{n} \right] (1+r)^{-t} \right\} \left[2L + V_s Z_{sa} \right]}{2 Y_k Y_d V_s \left(8760 - Z_{bt} - Z_{bk} \right) \sum_{t=1}^{n} (1+r)^{-t}} \tag{1}$$

Investment cost (I_c) of a cargo vessel has been derived subject to DWT by using the sale prices data of recently built cargo ships in Table 1 (Turan, 2014).

Table 1: Sale price for recently built cargo ships

DWT (tons)	**Sale Price (M. USD)**
1,000	2.50
2,000	3.25
2,500	4.00
3,200	5.60
3,300	5.20
4,000	6.50
5,000	8.50
5,500	9.30
5,843	10.00
6,500	9.00
9,200	10.90
20,000	20.30
23,800	26.54

Investment cost subject to DWT is;

$$I_c = 1000000x0.0116xDWT^{0.7621} \tag{2}$$

whereby, unit investment cost is derived with the following expression (Turan, 2014);

$$U_c = \frac{\left\{\sum_{t=1}^{n} 11600DWT^{0.7621}\left[\left(1-\frac{t-1}{n}\right)i+\frac{1}{n}\right](1+r)^{-t}\right\}\left[2L+V_s Z_{sa}\right]}{2\left(Y_k Y_d\right)V_s\left(8760-Z_{bt}-Z_{bk}\right)\sum_{t=1}^{n}(1+r)^{-t}} \tag{3}$$

In (3), I_C represents investment cost, L is route length, V_s is service speed of vehicle, Z_{sa} is waiting time between sequential trips, Y_k is cargo capacity, Y_d represents fullness ratio, Z_{bt} is annual maintenance-repair time, Z_{bk} is annual idle time and i is the interest rate.

B. Operational and maintenance costs per unit of cargo (U_m):

Operational and maintenance costs per unit of cargo (U_m) can be calculated with the following expression (2005, 2009);

$$U_m = \frac{\left\{\sum_{t=1}^{n}\left[C_{mo}(1+e_m)^t + \left(sI_c(1-\frac{t}{n})\right)(1+e_s)^t\right](1+r)^{-t}\right\}\left[2L+V_s Z_{sa}\right]}{2Y_k Y_d V_s(8760-Z_{bt}-Z_{bk})\sum_{t=1}^{n}(1+r)^{-t}} \tag{4}$$

where, C_{mo} is annual operation and maintenance costs, e_m is escalation rate for future operational and maintenance costs, is insurance percentage (% I_c), e_s is the escalation rate for future insurance cost.

C. Fuel and lubricant costs per unit of cargo (U_f):

Fuel and lubricant costs per unit of cargo, Uf, can be formulated as (2005, 2009):

$$U_f = \frac{\left(B_f P_f + B_0 P_0\right)L\sum_{t=1}^{n}\left[(1+e_f)^t(1+r)^{-t}\right]}{\left(Y_k Y_d\right)\left[\sum_{t=1}^{n}\left[(1+r)^{-t}\right]\right]} \tag{5}$$

where B_f is fuel consumption per km (main+aux.), P_f is fuel price, B_o is lubricant consumption per km

(main+aux.), P_o is lubricant price, e_f is escalation rate for future fuel cost.

D. External costs per unit of cargo

The external costs per unit of cargo can be estimated as (2005, 2009):

$$U_{ex} = \frac{\left(c_{ac}+c_p+c_n\right)L\sum_{t=1}^{n}\left(\frac{1+e_x}{1+r}\right)^t}{\left(1+e_x\right)\sum_{t=1}^{n}\left[(1+r)^{-t}\right]}\left(\frac{Y_d^*}{Y_d}\right) \tag{6}$$

According to above expression, c_{ac}, c_p and c_n, are specific cost of accidents, the specific cost of pollution caused by emission and the specific cost of pollution caused by noise, respectively. Y_d^* is reference fullness ratio used for the calculation of specific external costs, ex is the escalation rate in the external costs.

As a conclusion, U_T, is formulated as below;

$$U_T = U_c + U_m + U_f + U_{ex} \quad (\$/\text{ton}) \tag{7}$$

3 Case Study

A cost analysis has been done with the application of the method in Part I. Calculations have been performed in order to obtain the unit transportation costs for 10000 DWT cargo vessel. Interest rate is assumed as 8% according to the information from the banks, discount rate, 10%, escalation rate for future operational-maintenance, insurance, external cost, 3% during calculations. Escalation rate for future fuel cost have been considered fluctuating with the ratios of 2%, 4%, 6%, 8%, 10% and 15% in order to present the effect of fuel prices on the alteration of unit transportation cost in detail.

For specific cost of accident, pollution and noise, data from Sahin et.al.(2009) have been used and given in Table 2. Technical and economic data for 10000 DWT cargo vessel is also given in Table 2.

Table 2. Technical and economic data for 10000 DWT cargo vessel

CARGO VESSEL	Symbol	Unit	
DWT		ton	10000
Investment cost	Ic	\$	12,967,552
Average economic lifetime	n	year	20
Insurance percentage (I_c%)	s	\$	0.00733
Cargo capacity	Y_K	ton	9000
Annual maintenance-repair time	Z_{bt}	hour	300
Daily idle time	Z_{bk}	hour/day	3
Fuel consumption per km (Main+Aux.)	B_f	liter/km	24.07
Lubricant consumption per km (Main+Aux.)	B_o	liter/km	0.11
Fuel price	P_f	\$/liter	0.26
Lubricant price	P_o	\$/liter	1.8
Annual operation-maintenance cost	C_{mo}	\$/year	750,000
Interest rate	i		0.08
Discount rate	r		0.1
Escalation rate for future operational-maintenance cost	e_m		0.03
Escalation rate for future fuel cost	e_f		0.02, 0.04, 0.06, 0.08, 0.1, 0.15
Escalation rate for future insurance cost	e_s		0.03
Escalation rate for future external cost	e_x		0.03
Waiting time between sequential trips	Z_{sa}	hour	9.00
Specific cost of accident	c_{ac}	\$/ton-km	6.00E-05
Specific cost of pollution	c_p	\$/ton-km	3.85E-04
Specific cost of noise	c_n	\$/ton-km	0.00E+00
Reference fullness ratio for specific external costs	Y_d^*		0.7

Unit transportation cost for various escalation rates for future fuel cost (2%, 4%, 6%, 8%, 10%, 15%) of 10000 DWT cargo vessel at 1000 km route length with respect to service speed and fullness ratio (between 30% and 100%) are shown in Fig. 1, 2, 3, 4, 5 and 6. According to these six figures, unit transportation cost increases with the increase in service speed. Speed increase effects specific fuel consumption of a vessel and thereby, fuel costs increase. Total transportation cost is also affected from this alteration directly since fuel costs are a component of total transportation cost. Increase ratio in the unit transportation cost is more in lower fullness ratios (Turan, 2014).

Speed increase also effects the specific fuel consumption of the vessel and directly the emission ratios of the vessel sourced by the fuel. Speed regulations on the vessels should be made not only considering the transportation costs, but also the environmental issues, air pollution and sustainability.

Fullness ratio of the vessel also alters the unit transportation cost. The decrease on the fullness ratio of the vessel causes an increase in the unit transportation cost as seen in the figures. Cost reduction rate is more in lower fullness ratios compared to higher ratios (Turan, 2014).

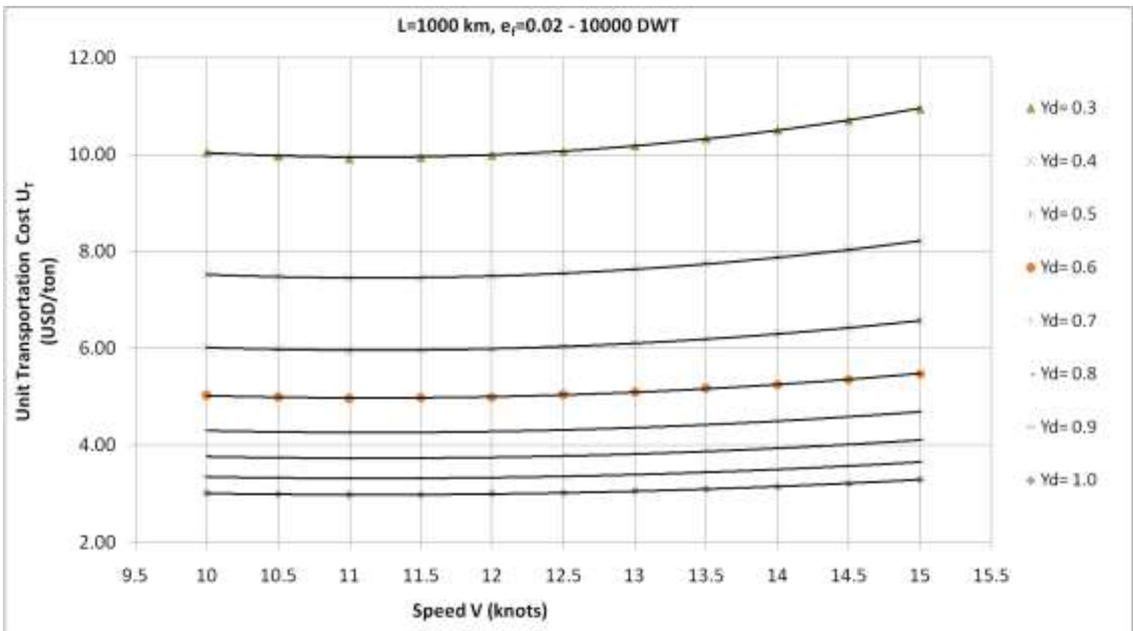

Fig. 1.Unit transportation cost for 2% escalation rate for future fuel cost with respect to service speed and fullness ratio (Turan, 2014)

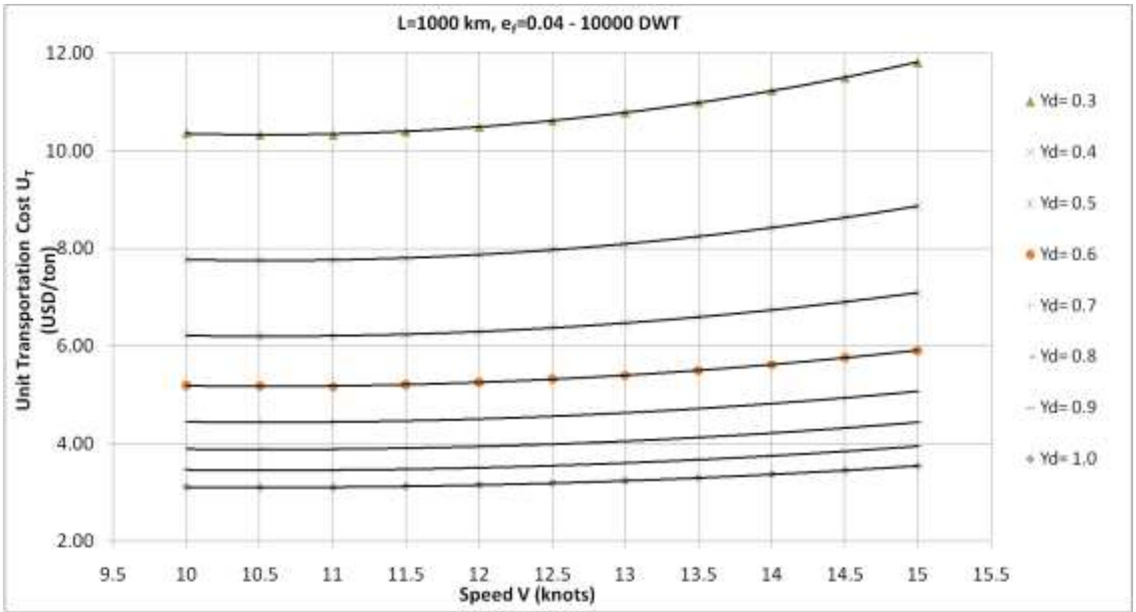

Fig. 2. Unit transportation cost for 4% escalation rate for future fuel cost with respect to service speed and fullness ratio (Turan, 2014)

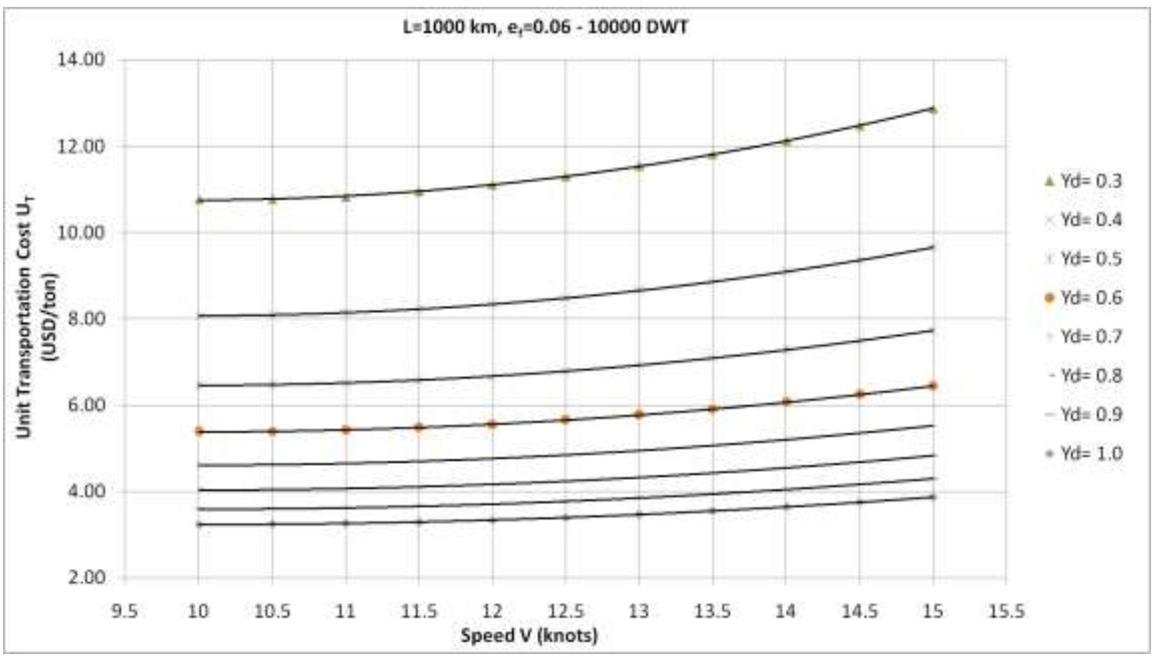

Fig. 3. Unit transportation cost for 6% escalation rate for future fuel cost with respect to service speed and fullness ratio (Turan, 2014)

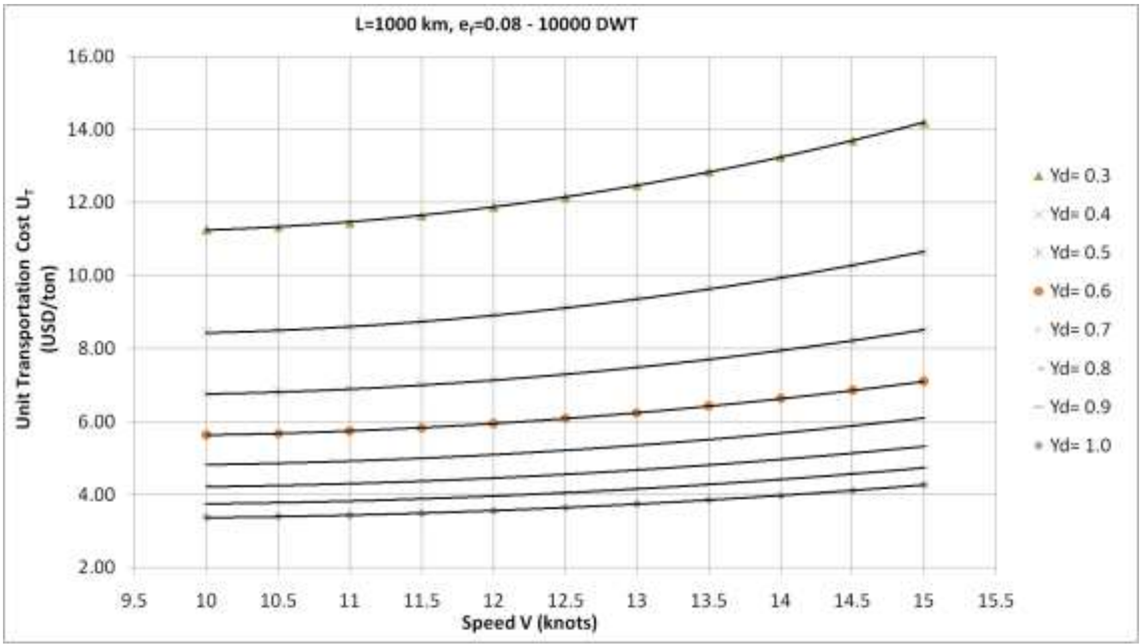

Fig. 4. Unit transportation cost for 8% escalation rate for future fuel cost with respect to service speed and fullness ratio (Turan, 2014)

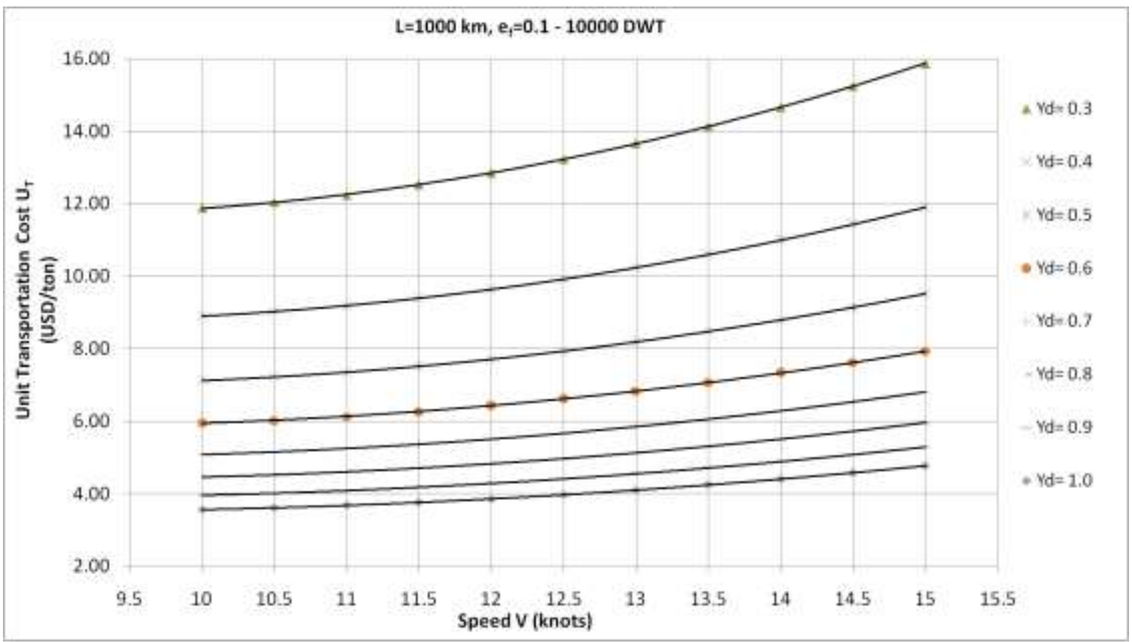

Fig. 5. Unit transportation cost for10% escalation rate for future fuel cost with respect to service speed and fullness ratio (Turan, 2014)

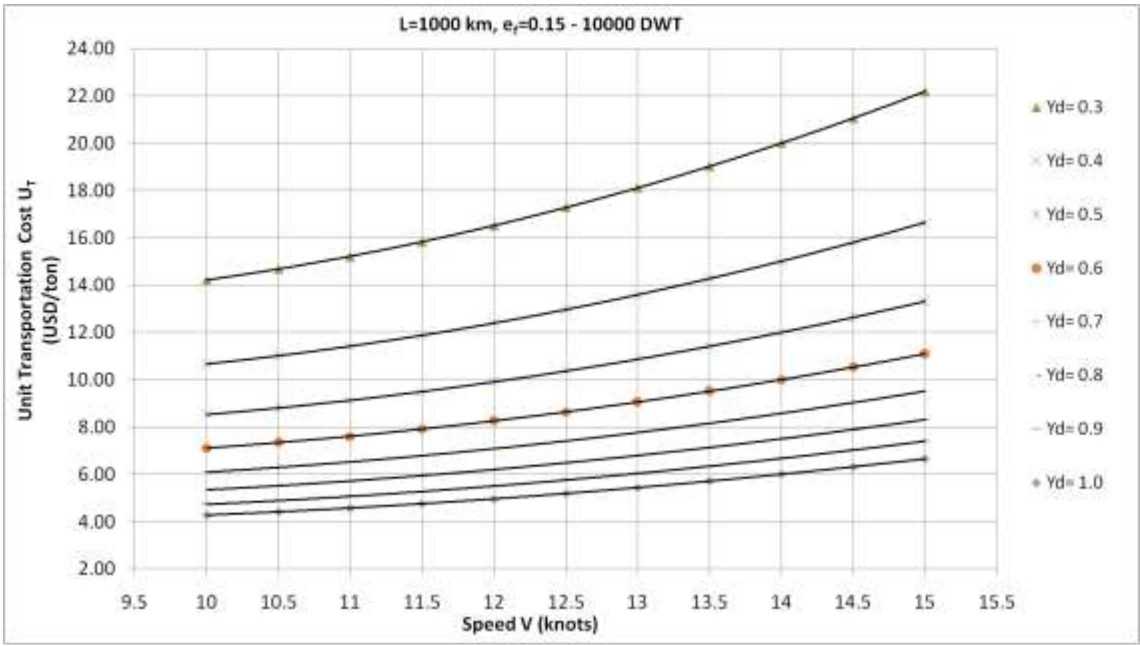

Fig. 6. Unit transportation cost for15% escalation rate for future fuel cost with respect to service speed and fullness ratio (Turan, 2014)

Comparison of unit transportation cost for various escalation rate for future fuel cost ratios (2%, 4%, 6%, 8%, 10%, 15%) with respect to service speed and constant fullness ratio (Y_d=0.7)have also been presented in Fig. 7. As specified for the above six figures, it is clearly reached that the service speed increase causes an increase in the unit transportation cost due to the fuel consumption rates. Moreover, it is figured out that, the more escalation rate for future fuel cost occurs, the more unit transportation cost is calculated. It is also observed from Fig. 7 that alteration of unit transportation cost has sharper increment in the higher rates of fuel escalation.

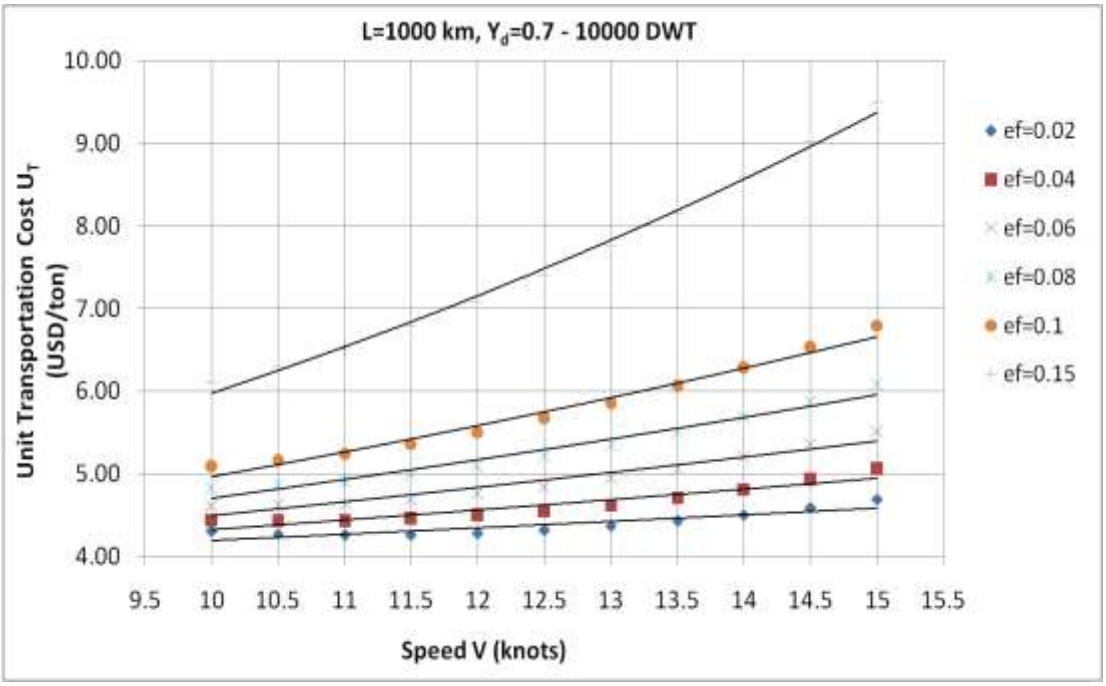

Fig. 7. Comparison of unit transportation cost for various escalation rates for future fuel cost (2%, 4%, 6%, 8%, 10%, 15%) with respect to service speed and fullness ratio

High fuel prices, in parallel with high fuel consumptions due to increasing speed lead to uneconomic situations. Especially, after the global crisis started in 2008 in the shipping industry, some Owners or ship managers selected for slow-steaming alternative or laying up their vessels. Slow steaming is to reduce the speed as well as fuel consumptions in order to reduce transportation costs and thereby operation of vessels in the optimum speed has become a significant point. Optimum speed can be defined as the speed that maintains minimum transportation cost. To illustrate how the optimum speed can vary with respect to escalation rate for future fuel costs, we have run the model for six different ratios and the alteration of optimal speed is shown in Fig. 8. It is clearly seen from Fig. 8 that optimum speed of the vessel alters contrary with the escalation rate for future fuel cost. The vessel should sail slower in the case of having high fuel escalation rates. The optimal speed has been calculated around 11 knots during the conditions of 2% fuel escalations, whereas it is around 8 knots for 15% escalation rates. This result is a significant output of this study since it could be improved within the scope of capacity or fleet optimization in the future studies by using the proposed cost model.

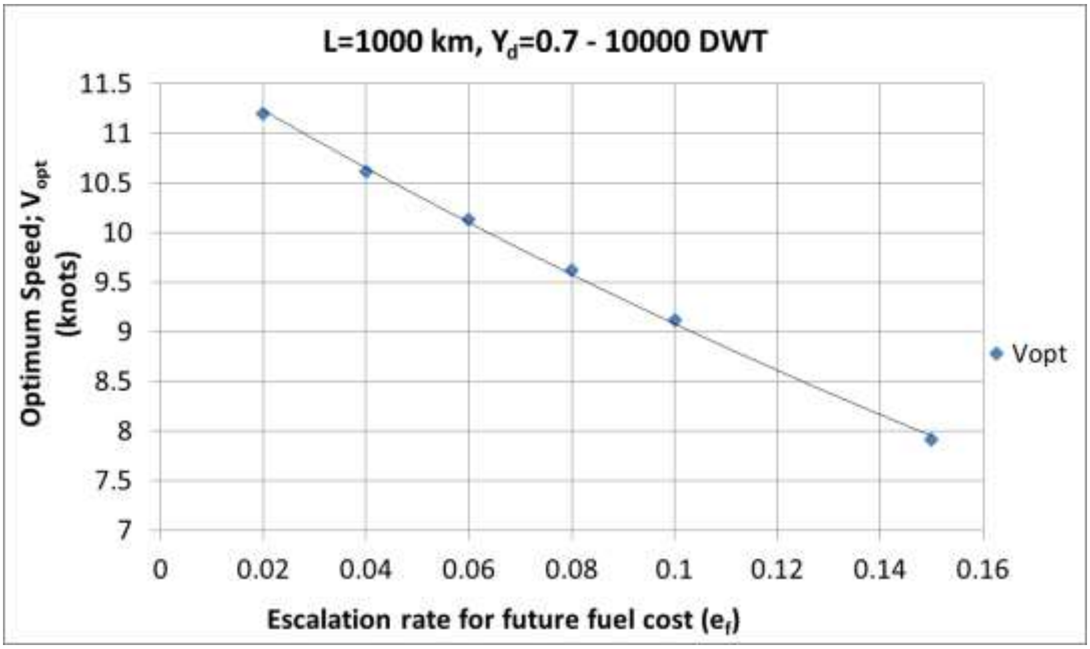

Fig. 8. Alteration of optimum speed with respect to escalation rate for future fuel cost

4 Conclusion

Unimodal cost calculation approach has been presented for Unimodal cost calculation approach has been presented for maritime transportation and parameters effecting the transportation costs have been considered. As a case study, 10000 DWT cargo vessel has been considered and unit transportation cost of this vessel have been calculated considering technical and economical parameters by using levelised cost method in this study. Alterations of unit transportation cost have been investigated with the alteration of service speed, fullness ratio and escalation rate for future fuel cost ratios. Route length has been assumed as 1000 km in the calculations. The study has a novelty due to the presentation of an economic model for unimodal transportation, speed optimization and consideration of the significant parameters for cost estimations during analysis.

It is pointed out that fullness ratio and service speed of a vessel, which are the significant determinants for shippers, alter the transportation cost. These parameters have an important value especially in the depressed market conditions as today.

It is also observed that increment of service speed increases the unit transportation cost of the vessel. However, increase in fullness ratio of a vessel decreases the same cost. Therefore operating the vessel with more cargo is significant. In order to prevent high fuel consumptions and as well as high fuel costs, operators adopt slow-steaming applications in the maritime transportation in order for energy efficiency and cost reductions.

Escalation rate for future fuel cost ratios which is a prominent factor for transportation cost analysis have also been considered in the study. It is presented that unit transportation cost of a vessel increases with the increment of this escalation rate considerably.

The main purpose of observing the effect of fuel escalation rates was the determination of optimal speed and its alteration subject to fuel price fluctuations. The study has a significant result for clearly indicating the optimal speeds by using proposed cost model. It is emphasized in the study that the vessel should sail slower at high fuel escalation rates in order not to increase transportation costs. The study could also lead to future studies for the point of investigating emission ratios for a specific route and calculating the environmental hazards by using proposed method.

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