Environmental Performance of Land and Marine Transportation in Inland Shipping – Impact of ship speed

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Abstract

It was found that the marine transport is more environmental friendly than land transport in inland cargo shipping[1,2]. Fet[3] also showed the superiority of marine transport in trans border cargo transportation. In all of these cases, the researchers considered moderate operating speeds for ships. But other researches showed that fast ship was not competitive in this respect[4,5]. This paper is to discuss about a methodology to find the critical speed of a ship up to which the marine transport will be favorable for sustainable development to the environment.

1. Introduction

The climate of the earth is changing. Inland and coastline disappearing under water, more frequently occurring fiercer hurricanes and typhoons, heat wave, melting polar ice caps, shift of agricultural zones, coral bleaching in the Pacific Ocean as well as the Indian Ocean and Caribbean Seas are some of the evidences which show the certainty of climate change. Scientists believe that in all of the human history climate has never changed as fast as it is changing today. Plenty of reasons are behind this change. Some of them are natural and some are human induced. Ever increasing human activity is having a negative effect on the climate.

Industrialization and technological development causes people to use ever increasing quantities of gas, electricity, petrol and diesel, and leads to emit increasing volume of CO_2 with some other gases such as methane (CH_4), nitrous oxide (N_2O), CFCs, PFCs, and SF_6 to the atmosphere. These gases enhance the natural greenhouse effect leading to the Earth gradually becoming warmer. Since the industrial revolution, the global mean surface temperature has risen by 0.3^{O} C to 0.6^{O} C[6], which is the effects of increased atmospheric concentrations of various greenhouse gases. It has been found that during this period carbon dioxide (CO_2) concentration in the atmosphere has increased nearly 30%, methane (CH_4) concentration has more than doubled and nitrous oxide (N_2O) concentration has risen by about 15% [6].

The governments of industrialized countries and the countries with economies in transition have been trying to convince those sectors, companies and sources, which are involved in emitting greenhouse gases, so that they adopt new methodologies to reduce these emissions. The Kyoto Protocol[7] has been a turning point in this regard for future economical and environmental policies for both industrialized and developing countries. In this circumstances, environmental friendly and economically feasible transportation system planning has become a very essential subject matter in recent days.

Among the human activities causing the climate change, use of transports and burning the fossil fuel for energy are vital. Table 1 shows some emissions and the share of transport sector in Japan[8]. So especial attention is being paid to the transport sector to reduce the emissions caused by this sector. Measures, which are being considered, include raises in excise duties, stepping up enforcement of speed limit, finding alternative transport modes and infrastructures.

Table 1: A few emissions and the share of transport sector in Japan

Emission	In year	Japan national total ('000 ton)	Japan transport sector (%)
CO_2	1990	1,124,532	18.29
	1997	1,230,831	20.42
CH_4	1990	1,543	4.93
	1997	1,389	3.24
CO	1990	3,873	52.78
	1997	3,751	53.56
N_2O	1990	58	22.41
	1997	66	22.73
NO_x	1990	1,851	49.49
	1997	2,051	49.73
SO_2	1990	900	20.67
	1997	796	12.44

Modal shifting of cargoes from road transports to ships may be an achievement in finding a less emitting alternative transport mode from the existing types[1,2]. One of the significant barrier to attract users to water transport is the speed. Conventional ships sail at speeds much lower than that of road and rail transports. To improve the customer service quality and to attract the user towards water transport, the general trend is to introduce high-speed water-craft or fast ship. But some of the recent research showed that the fast ship is not a better solution as it consumes more energy and emits more gases harmful to the environment compared to the conventional ships and other mode of transports[4,5]. That is why, some researchers including Isensee *et al*[4] and Kristensen[5] suggested not to introduce fast ship, but fast shipping through better cargo/passenger handling and improved navigation. Considering all these, it is logical to believe that there is one certain speed for a certain ship which is critical, that is below that speed that ship is competitive to the land transport. This paper is to find an easy and handy method to find that critical speed for a ship. Hasegawa and Iqbal[1] proposed an easy method to compare the water transport with the relevant road vehicles. In that comparison process, three important factors related to transportation system – environmental impact, economic benefit, and customer service quality, are considered. Using the similar comparison process, a methodology of finding the critical speed for a water transport is discussed here.

2. Methodology

For a specific transportation model, life cycle impact assessment, required freight rate and service time are estimated for both road and inland water transport to find their impact on environment, economic superiority and customer service quality respectively. Then comparing these characteristic parameters, the benefit of modal shifting of cargo/passenger from road vehicles to ship is analyzed. Three different indices – environmental index, economic index, and customer service index, are estimated to find the superiority of one transport type over other in three different fields. Then a single comparison index is found to show the overall superiority. The critical speed will be that speed at which the comparison index will be 1, that is, at that particular speed the road vehicles and the ship will be equally beneficial for the society considering all three mentioned factors.

2.1. Transportation model considered

A transportation system model similar to the inland courier service is considered for the comparison here. Two alternative transportation systems are shown in Fig. 1. For this comparison, the transportation task only between the stock points is considered, because the rest of the systems for both alternatives are similar. A specific amount of cargo is assumed to be carried by both road vehicles and ships for shipment through a particular route.

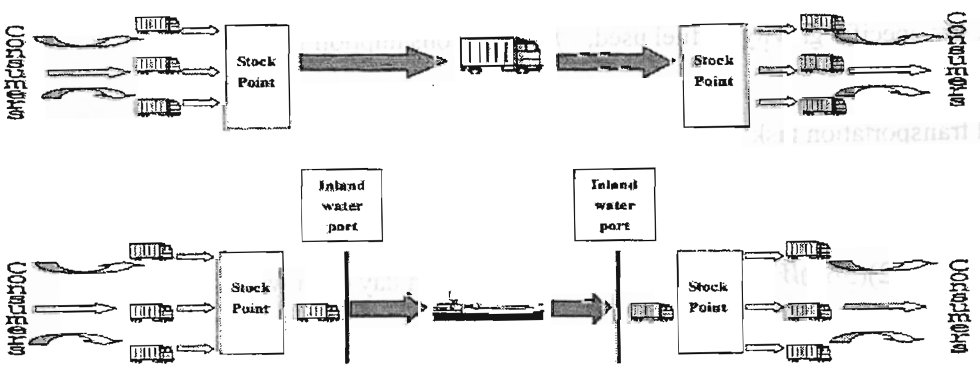

Fig. 1 Alternative transportation model

The route and trip particulars are calculated according to the following equations:

Trip time,

$$t_{trip} = \left(\frac{R}{v} + t_{load}\right)\left(1 + \frac{t_{delay}}{100}\right)$$

where, R = route distance, v = velocity (km/h), t_{load} = loading and unloading time, t_{delay} = delay in time (%)

Maximum possible round trip per annum (RTPA) per transport is calculated from the trip time and total number of hours available in a year for operation according to the following equation,

$$\text{RTPA} = \frac{(24D)}{(2t_{trip})}$$

where, D = days in operation per annum = (365 – off hire days)

Round trip required per annum (RTRA) is the minimum required number of round trip that is required to perform the whole transportation task. It is calculated as follows,

$$\text{RTRA} = \frac{L}{(2C_{ap})\left(\frac{\delta}{100}\right)}$$

where, C_{ap} = capacity (ton), δ = loading condition (%), L = total amount of cargo carried (ton/year)

Amount of fuel consumption per annum (in kg),

$$F_c = \frac{(2R)(RTRA)(g)}{(f)}$$

Where, g = specific gravity of fuel used, f = fuel consumption rate (km/l),

Annual transportation task in ton-kilometer,

$$A_t = (L)(R)$$

Where, $L = (2)(365)W$, W = cargo to be carried (ton/day each way)

Number of transport required to perform the task,

$$T = \frac{RTRA}{RTPA}$$, when $\frac{RTRA}{RTPA}$ is an integer

$$INT\left(\frac{RTRA}{RTPA}\right)+1 \;, \quad \text{when } \frac{RTRA}{RTPA} \text{ is not integer}$$

2.2 Life cycle impact assessment and the environmental destruction index

In considering the life cycle impact assessment of the transportation system, the environmental impact of whole life cycle of the transportation system should be considered. But the data related to the whole life cycle is rarely available. So, on the basis of the available data such assessment is recommended. Calculating the total amount of substances and compounds released for the transportation task by both transportation systems, the environmental impact of the transportation system in different impact categories (for example, fossil fuel exhaustion, local warming, global warming, acid rain, eutrophication, air pollution) are estimated by multiplying the total amount of emissions by respective characterization factors according to the following equation[3].

$$EP(j) = \sum (Q_i \times EF(j)_i)$$

where, *EP(j)* is the sum of the potential contribution from the impact category, Q_i is the emissions of compound *I*, $EF(j)_i$ is the characterization factor of compound *i* related to the impact category *j*

The environmental destruction index is calculated multiplying the ratio of the amount of potential impact by road transportation system to that of the marine transportation system with some specific weighting factors for each impact category according to the following equation.

$$I_E = \sum \omega_j \frac{(EP(j))_{road}}{(EP(j))_{water}}$$

ω_j is the weighting factor for impact category *j*. The values of the weighting factors (ω_j) for various impact categories may be estimated by analytic hierarchy process (AHP)[9] by a survey with a questionnaire.

2.3 Required freight rate

To find the economic superiority, required freight rates (RFR) at a certain rate of return for the investment to the transportation systems are calculated and compared. RFR is the minimum freight rate required to meet the expected rate of return (*i*) on the principal investment or initial price (*P*) and the annual cost (*C*) within a specified length of period (*N*). Here annual cost includes the fuel cost, maintenance cost, crew cost, insurance etc. The RFR is calculated using the following equation[10].

$$RFR = \frac{\left[\frac{P}{spw} + C\right]}{L}$$

where, $RFR =$ Required freight rate, $P =$ Price of the transport or first cost, $C =$ Annual cost , $L =$ Amount of cargo carried (ton/year),

$$spw = \frac{(1+i)^N - 1}{i(1+i)^N}$$

where, $spw =$ Series present worth factor, $i =$ Rate of return (compound interest), $N =$ Number of year in operation

Series present worth factor, also called annuity factor, is the multiplier to convert a number of regular (annual) payments into the present sum[10].

The economic index, $I_F = \frac{(RFR)_{road}}{(RFR)_{water}}$

2.4 Customer service index

Customer service is an important factor to be considered during the transportation system planning. Here only the 'service time', that is, the time taken by the transport company to serve their customer is considered as 'customer service quality' to compare the transportation modes.

In the service time, the time required to accumulate the cargoes/passengers at the stock point should be included with the trip time.

The ratio of this service time of truck transport to the ship transport is taken as the customer service index.

That is, customer service index, $I_S = \frac{(t_{accum} + t_{trip})_{road}}{(t_{accum} + t_{trip})_{water}}$

where, t_{accum} is the average cargo/passenger accumulation time.

2.5 Single comparison index

To find a single comparison index, three different indices i.e. environmental index, economic index and customer service index, are added up after multiplying with respective weighting factor according to the following equation,

$I = \alpha_1 I_E + \alpha_2 I_F + \alpha_3 I_S$

α_1, α_2 and α_3 are the weighting factors for environmental index, economic index and service index respectively may be calculated by AHP in the similar fashion described earlier.

It is generally believed that the water transport is environmentally more friendly than other mode of transports. Hasegawa and Iqbal[2] showed that for inland shipping in Japan, cargo ship is about 4 times less detrimental to the environment compared to truck transportation system.

Most of the factors considered here for this comparison are very much related to the time taken by the transportation system. The customer service index is directly related to it. The speeds of the transports considered play a significant role in the time consumption. For the betterment of the customer service in the water transport, introduction of fast ship in many sectors, specially passenger transportation, is recently become popular. But some recent research works showed that fast ship is not environmentally competitive with land transports. Only the water transports with moderate speed are found competitive from the environmental point of view. It means, there is a critical speed for a particular ship type that shows equally beneficial with other particular land transport. Obviously the speed with the comparison index 1 will be that critical speed. It may easily be found using the comparison index-speed relation. An arbitrary curve of comparison index-speed relation is shown in Fig.2. The ship speed at index 1 in this arbitrary curve is that critical speed at which the ship will be equally beneficial to the society compared to the road transport considered.

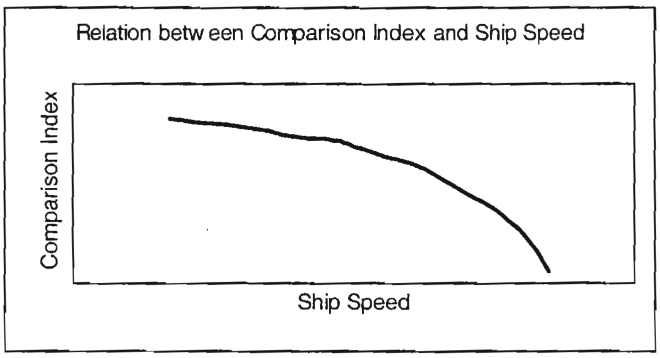

Fig. 2: Relation between comparison index and ship speed

As the ship speed increases, the environmental emissions and energy consumption increase. Though it will improve the customer service quality, the comparison index considering all the factors will apparently go down.

3. Conclusion

A handy method to find the critical speed of ship is shown here. With this critical speed the ship is equally beneficial to the society with particular road transportation system. Shipping is not only carrying by transport, but the whole system involved from receiving the cargo up to delivery to the recipient. So while comparing two transportation systems, the whole systems should be included in the comparison. This method should be studied with real life data of two particular transportation systems to check whether it is acceptable.

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