Modal shifting from truck to cargo ship in inland shipping: an effective measure towards sustainable development to the environment

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ABSTRACT
Using life cycle impact assessment, required freight rate and the customer service time, the ecological impact and the economical performance of land and marine transportation systems were evaluated and compared. Then the benefit of modal shifting of certain amount of cargoes from land transport to marine transport in a specific route in Japan is shown. The results are shown by three different comparison indices.

KEYWORDS: transportation planning, life cycle impact assessment, sustainable development, Kyoto Protocol

INTRODUCTION
Besides the research for improving the technology, searching for environmental friendly and economically feasible alternative transport modes from the existing types has become a very interesting field for researcher.

In this paper, considering the Yokohama-Fukuoka route in Japan, the ecological impact and the economic performance of land vehicles (trucks) and the marine transports (cargo ships) were evaluated and compared. For comparing environmental impacts, life cycle impact assessment (LCIA) with different weighting factors for the impact categories were considered. These weighting factors were estimated by analytic hierarchy process (AHP), getting opinion from the general consumers of goods and users of transports including environmentalist, technologists and transporters. Assessing the amount of emissions released during the production and operation of the transportation systems considered, the impact of each system was estimated and compared to find the environmental destruction index.

Required freight rate (RFR) to attain a prefixed rate of return on the investment was considered for the comparison of economic performance. For the consideration of customer service, the time taken by the transport authority to serve their customer was estimated and compared for the mentioned transportation system types.

Using a model case of transporting specific amount of cargo between two origins/destinations, indices for environmental burden, economic benefit and customer service quality were estimated. Finally comparing these indices, the benefit of modal shifting from truck to cargo ship in inland shipping was shown.

TRANSPORTATION MODEL CONSIDERED
A transportation system model similar to the inland courier service in Japan was chosen for the comparison here. Two alternative transportation systems are shown in Fig. 1.

For this comparison, the transportation task only between the stock points was taken, because the rest of the systems for both alternatives were similar. An average of 1500 tons of break bulk-type cargo was assumed to be shifted from truck to cargo ship for shipment from Yokohama to Fukuoka and same amount from Fukuoka to Yokohama everyday. The particulars of Yokohama-Fukuoka route and the transports considered for the comparison were shown in Table 1

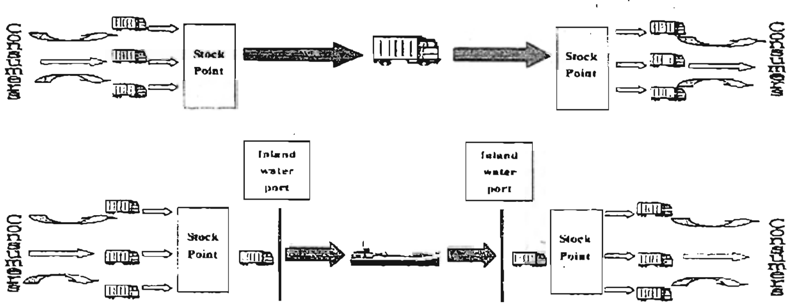

Fig. 1: Alternative transportation system: (top) usual inland courier service in Japan, (bottom) proposed alternative transport system

The trip time, maximum round trip per annum (RTPA) per transport, total round trip required per annum (RTRA) to perform the transportation task and the required number of transport means were calculated according to the following equations.

Trip time,

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

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

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

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

$$RTRA = \frac{L}{(2C_{ap})\left(\frac{\delta}{100}\right)} \quad (3)$$

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

Number of transport means required to perform the task,

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

$$INT\left(\frac{RTRA}{RTPA}\right) + 1, \quad \text{when } \frac{RTRA}{RTPA} \text{ is not integer} \quad (4)$$

The calculated RTRA, trip time, RTPA and the required number of transports for the mentioned transportation task in Yokohama-Fukuoka route are shown in Table 2.

The average distance between the stock point and the inland water port was taken as 10 km. With 50 km/h speed of truck, the RTPA was 1462 and the number of truck required was 39 for carrying the goods between stock point and the cargo ship.

LIFE CYCLE IMPACT ASSESSMENT AND THE ENVIRONMENTAL DESTRUCTION INDEX

Fourteen compounds and substances, among those consumed and released during the production and use of the transports, were considered here.

The relevant inventory list is given in Table 3. The data of the construction phase were adapted from Hasegawa and Iqbal[1]. These data were collected from various Internet resources. The data of the operation phase were taken from BUWAL 250 database of SimaPro[2], a life cycle assessment (LCA) software. But the heat radiation values in the operation phase were taken from Hasegawa and Iqbal[1]. The required data were taken from these sources, as these were difficult to get from the actual field.

In the estimation of the values in the inventory list of BUWAL 250, it was considered that the load factor of the truck was 50% of 16 tons capacity and the load factor of the ship was 70%, capacity was not mentioned. These values were not the same of those considered in this comparison process. Yet, the authors took these values in consideration because this was the most reliable source found by the authors and all the values in this database were given in the ton-km basis.

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 6 different impact categories (fossil fuel exhaustion, local warming, global warming, acid rain, eutrophication, air pollution) were estimated by multiplying the total amount of emissions by respective characterization factors according to the equation (5)[3].

Table 1: Particulars of transport systems

	Truck	Cargo ship
Route distance	1200 km	1000 km
Capacity	11 tons	5000 tons
Transport velocity	50 km/h	23 knots
Loading & unloading time	2 h	8 h
Time delay	25%	25%
Off hire days per annum	30	45
Fuel type used	Light oil	Heavy oil
Fuel consumption	4 km/l	150 g/PS-h
Fuel cost	70 yen/l	15 yen/l
Fuel specific gravity	0.85	0.9
Engine power	600 PS	12000 PS
Average loading condition	0.9	0.5
Harbor charge/trip		20000 yen
Life time	10 years	20 years
Price of transport	1×10^7 yen	1.50×10^9 yen
Transport tax/year	43600 yen	250000 yen
Depreciation	2.0×10^6 yen	7.5×10^7 yen
Maintenance cost/year	100000 yen	2000000 yen
Other cost/year (Weight tax, insurance, etc.)	192000 yen	2000000 yen
Labor cost/man-hour	2500 yen	2500 yen
Number of crews/drivers	2	6

$$EP(j) = \sum (Q_i \times EF(j)_i) \quad (5)$$

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

Table 2: Calculated RTRA, trip time, RTPA, and the number of transport required

RTRA		Trip time		RTPA		No. of transport required	
Truck	Cargo ship	Truck	Cargo Ship	Truck	Cargo Ship	Truck	Cargo Ship
56854	243	32.50	39.35	124	98	460	3

Table 3: The inventory table

Compound or substance	Unit	Truck	Cargo ship
Construction phase			
Energy consumption	MJ	7.25×10^5	1.39×10^8
CO_2 emission	kg	58.79×10^3	1.07×10^7
NO_x emission	kg	87.11	4.85×10^4
SO_x emission	kg	3.03×10^2	1.32×10^4
Phosphorous	kg	68	9.65×10^3
Operation phase			
Energy consumption	MJ/ton-km	2.88	0.499
Heat radiation	MJ/kg fuel	42.7	40.7
CO_2 emission	kg/ton-km	0.228	3.95×10^{-2}
NO_x emission	kg/ton-km	4.10×10^{-3}	7.11×10^{-4}
SO_x emission	kg/ton-km	3.43×10^{-4}	5.95×10^{-5}
N_2O emission	kg/ton-km	5.50×10^{-6}	9.54×10^{-7}
Methane emission	kg/ton-km	2.77×10^{-4}	4.81×10^{-5}
Ammonia emission	kg/ton-km	6.19×10^{-9}	1.07×10^{-9}
HCL emission	kg/ton-km	4.66×10^{-7}	8.07×10^{-8}
HF emission	kg/ton-km	4.87×10^{-8}	8.44×10^{-9}
C_xH_y emission	kg/ton-km	1.36×10^{-6}	2.37×10^{-7}
Benzene emission	kg/ton-km	8.18×10^{-6}	1.42×10^{-6}
Particulate Matter (PM) emission	kg/ton-km	9.39×10^{-5}	1.63×10^{-5}

The values of the characterization factors are given in Table 4. These values were according to Eco-indicator '95[2)]. Only the characterization factor for heat radiation in local warming impact category was assumed as 1 by the authors. It was so assumed because heat radiation is the only factor that was responsible for local warming in this comparison process. This value of characterization factor would not impose any significant contribution to the index, as the ratio of similar impact category for truck transportation system to the marine transportation system was taken to find the environmental destruction index. Another reason was that the radiated heat, without changing in the form, had direct influence on the local warming and developing the so called, 'heat island.'

Table 4: Characterization factors

Impact category	Responsible compounds or substances	Characterization factor	Unit
Fossil fuel exhaustion	Energy consumption	1	MJ
Local warming	Heat radiation	1	MJ
Global warming	CO_2	1	kg
	N_2O	270	kg
	CH_4	11	kg
Acid rain	Ammonia	1.88	kg
	HCL	0.88	kg
	HF	1.6	kg
	NO_x	0.7	kg
	SO_x	1	kg
Eutrophication	NO_x	0.13	kg
	Ammonia	0.33	kg
	Phosphorous	3.06	kg
Local air pollution	Particulate matter	1	kg
	SO_x	1	kg
	C_xH_y	0.398	kg
	C_6H_6	0.189	kg

The environmental destruction index was calculated multiplying the ratio of the amount of potential impact by truck transportation system to that of the marine transportation system with some specific weighting factors for each impact category according to equation (6).

$$I_E = \sum \omega_j \frac{(EP(j))_{truck}}{(EP(j))_{ship}} \quad (6)$$

Where, ω_j is the weighting factor for impact category j.

The values of the weighting factors for various impact categories are given in Table 5. These values were calculated by analytic hierarchy process (AHP)[4] from the opinions of general consumers and transport users.

A questionnaire was used to survey the opinions of people from different disciplines of society including student, engineer, doctor, transporter, academician and businessman, asking them to assess weighting factors to various environmental impacts. From the responses of one hundred and twelve persons, AHP was used to calculate the weighting factors.

ECONOMIC INDEX

To find the economic superiority, required freight rates (RFR) at 5% rate of return on the investment to the truck and the cargo ship were 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 was calculated using the equation (7)[5].

$$RFR = \frac{\left[\frac{P}{spw} + C\right]}{L} \tag{7}$$

Where, RFR = Required freight rate (¥/ton), 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[5].

In both cases of truck and ship, 60% of the direct labor cost was considered as overhead cost while calculating the total annual cost.

The economic index,

$$I_F = \frac{(RFR)_{truck}}{(RFR)_{ship}} \tag{8}$$

CUSTOMER SERVICE INDEX

Customer service is an important factor to be considered during the transportation system planning. The factors usually considered in the customer service quality for a transportation system includes time taken for the service, comfort, entertainment and safety. Among these factors comfort and entertainment are considered only in passenger transportation system. The other two factors are important for both cargo and passenger transports. But the safety of the cargoes, that is, protection from being damaged is an issue to be considered while shipping through long distance where the cargoes move through changing temperature, humidity, etc., which is an usual case while shipping internationally. The model case considered here is for inland shipping, and it is logical to exclude the factor 'safety'. Here the 'service time', that is, the time taken by the transport company to serve their customer is only considered as 'customer service quality' to compare the transportation modes.

Table 5: Weighting factors for impact categories

Impact category	Weighting factor
Fossil fuel exhaustion	0.143
Local warming	0.105
Global warming	0.271
Acid rain	0.165
Eutrophication	0.096
Local air pollution	0.22

In the service time, the time required to accumulate the cargoes at the stock point should be included with the trip time. The accumulation time was estimated with assumption that the inflow of the cargo for shipment was uniform over the span of time. In reality the inflow is usually more in the daytime than in the night. But for the simplicity of the estimation this non-uniformity was excluded here. With this assumption of uniform inflow of cargo, the rate of cargo inflow was 62.5 ton/h, since 1500 tons of cargo would be ready for shipment in 24 h. So, the required amount of cargo for one trip by ship, that is, 2250 tons of cargo would be accumulated in 36 h. This is the minimum required time gap between two successive trips by cargo ship. Considering this time gap, the maximum time required by the transport authority to serve there customer was (36+40) h or 76 h where the minimum was 40 h. Taking the average time required for cargo accumulation, the 'service time' for the cargo ship was 58 h. For the truck this value was 32.57 h.

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

That is, customer service index,

$$I_S = \frac{(t_{accum} + t_{trip})_{truck}}{(t_{accum} + t_{trip})_{ship}} \quad (9)$$

Where, t_{accum} is the average cargo accumulation time.

RESULTS AND FINDINGS

The ratios of potential environmental impacts (land transportation system/marine transportation system) in various categories are given in Table 6. The ratios are very much similar in all impact categories except in the case of local warming. The three estimated comparison indices are shown in Table 7.

Table 6: Ratios of potential environmental impacts

Fossil fuel exhaustion	Local warming	Global warming	Acid rain	Eutrophication	Local air pollution
6.03	1.46	6.03	6.15	5.96	6.15

Table 7: The indices

Environmental index	Economic index	Service index
5.59	17.97	0.57

Here the environmental index shows that the cargo ship is 5.59 times less detrimental than the truck transportation system from the view point of life cycle impact assessment in that particular route. The economic index, that is, the comparison of direct freight cost shows that the cargo ship is very much attractive. Yet this mode of transport is not getting enough support from the general transport users. This is because of the lower service quality involved in this mode. Here the service index is 0.57. Moreover the ease of door-to-door service by truck transportation system and the lose involved in the marine transportation system due to cargo handling attract the transport users easily towards the truck transports. Through the development of cargo handling and navigation system the service quality of marine transportation system should be improved to attract the transport users. The environmental index will also help convincing the users to use the marine transports.

CONCLUSION

In 1997, transports in Japan were responsible for about 2.51×10^8 tons of CO_2, 4.50×10^4 tons of CH_4, 1.02×10^6 tons of NO_X, 1.50×10^4 tons of N_2O and 9.90×10^4 tons of SO_2 emissions to the atmosphere[6]. According to the Kyoto Protocol[7], Japan made a commitment to cut its own emission by 6% below the 1990 level in the period 2008-2012. Only modal shifting of 1500 ton of break-bulk type cargo from truck to cargo ship in Yokohama-Fukuoka route in Japan will reduce the annual emission of 2.52×10^5 tons of CO_2, 3.06×10^2 tons of CH_4,

4.51×10^3 tons of NO_X, 6.06 tons of N_2O, and 3.89×10^2 tons of SO_X, if the amount of emissions are according to the data considered here.

The benefit of modal shifting of cargo from truck to cargo ship was discussed with the comparative evaluation of the ecological and economic characteristics of these two modes of transports. The results of the comparisons were shown by indices.

The results found in this study are highly uncertain because of the uncertainty involved in the data used. One should be aware of these uncertainties while using these results.

The following unsolved problems are still left for further research in this area.

- Comparison with other transport modes including railway.
- The environmental impacts due to cargo handling systems.
- The use of land area and the effects of noise exposure.
- The cost of congestion due to heavy traffic in the road or at the inland water port.

The outcome of this study can be used for governmental bodies for taxation. It may also be useful for planning inland transportation systems. Convincing people to switch from truck to cargo ship for their cargo shipment can reduce primary energy use and harmful emissions to the environment. A vital part of encouraging this transition is providing safe and efficient inland water transport systems. Government can also promote water transport by introducing high emission tax and road tax.

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