The Social Benefit through Modal Shifting of Cargo from Truck to Cargo Ship in Inland Shipping *1

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A model to estimate and compare the economical feasibility and the ecological impact of the marine transportation (cargo ships) and land transportation (trucks) in monetary values is presented in this paper. Life cycle inventory analysis, required freight rate and the service time were used to evaluate and compare the ecological impact and find the economical superiority. The estimation was made for nine different routes in Japan. Finally the social cost saving in monetary value through the modal shift of cargo from trucks to cargo ships is presented.

Keywords : *Modal Shift, Transportation, LCA, Environment, Shipping*

1. 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 some recent papers[1, 2], researchers showed some methodologies to compare the existing transportation system from the environmental viewpoint and suggested for modal shifting towards the better one.

Individuals or the regulatory bodies concerned with transport planning policy should use a good deal of judgment to weigh the relative tangible as well as hidden costs of the various modes of transport against some other alternatives. In practice the direct costs involved are usually taken in account for planning, though recently the consideration of other hidden costs, often called external costs, are increasingly drawing the attention.

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Transport activities, like some other economic activities, affect the persons or enterprises those are not directly involved in these activities. These are called external effects. These effects from transport sectors commonly include the effects of pollution, noise, traffic accident, congestion, and land use. The total cost to the society from such activities is thus comprised by the direct costs and the external costs. Recently a number of studies have tried to determine the marginal external costs of the use of transports, mainly road transports. These include the studies by Small[3], Newbery[4, 5], Jones-Lee[6], Mayeres[7, 8], Mayeres *et al* [9], Jansson[10], Peirson *et al* [11], Small and Kazimi[12], Maddison *et al* [13].

In this paper, considering 9 specific routes in Japan, the ecological impact and the economic performance of the marine transports (cargo ships) and land vehicles (trucks) were evaluated and compared. The comparison was made in monetary values. Then the social annual monetary cost savings for modal shifting of a specific amount of cargo from truck to cargo ship have been estimated to show the superiority of one transport mode over other. These savings were in three forms - saving from reduced environmental burden, direct monetary saving from less freight rate, and sav-

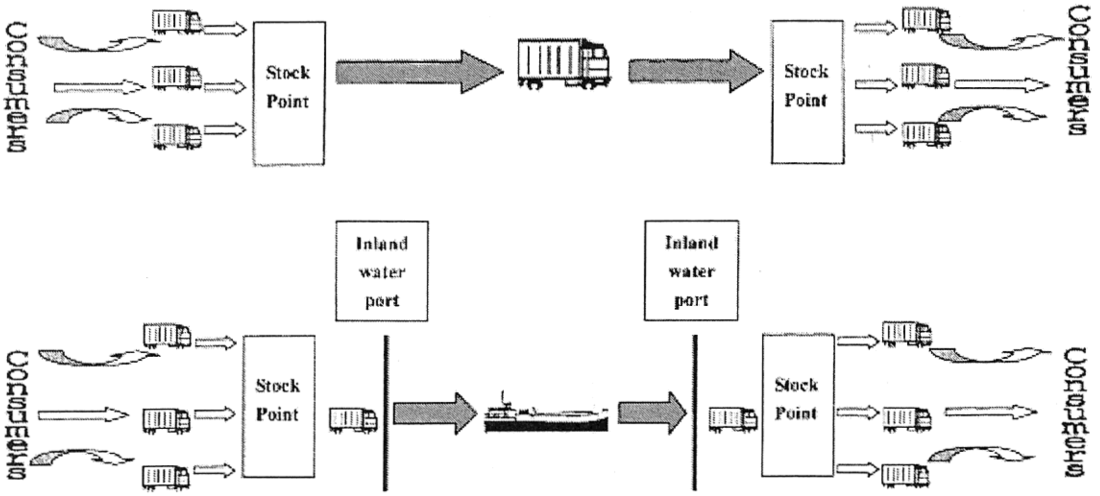

Fig. 1 (top) Transportation system of usual inland courier service,
(bottom) proposed alternative transportation system for inland courier service.

ing in the form of time. Finding these values, the total monetary savings possible to the society through such modal shifting were shown.

For evaluating environmental influence, life cycle inventory analysis was used to find the total amount of substances or compounds those are emitted to the environment by the mentioned two types of transport modes. Assessing the amount of emissions released during the production and operation of the transportation systems considered, the total hidden cost or external cost that the transports impose to the society was estimated. The amount of the emissions released in the different step of life cycle of the transports was collected from a software database and various Internet resources, as it was difficult to avail from the actual field.

Required freight rate (RFR) to attain a prefixed rate of return on the investment was considered for the economic comparison. Using this estimated RFR the total direct cost involved in cargo shipment by the transports were calculated.

For the consideration of customer service, the time taken by the transport authority to serve their customer was estimated for the mentioned transportation systems. Then using specific time value, the cost saving was shown.

2. Methodology

A transportation system model similar to the inland courier service in Japan was 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 was considered, 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, every day and both ways, between each origin-destination pair shown in Table 1. The particulars of the transports considered for the comparison were shown in Table 2.

The trip times required by the transports for shipping the cargoes were calculated according to the following equation:

$$\text{Trip time,}\quad t_{trip} = \left(\frac{R}{\nu} + t_{load}\right)\left(1 + \frac{t_{delay}}{100}\right)$$

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

Table 1 Route particulars.

Route	Distance in Road (km)	Distance in Waterway (km)
Yokohama-Fukuoka	1200	1000
Tokyo-Kitakyushu	1040	1160
Tokyo-Miyazaki	1400	950
Nagoya-Sendai	700	780
Tokyo-Kochi	840	730
Tokyo-Tokushima	650	640
Osaka-Shin Moji	550	460
Kobe-Oita	710	420
Kobe-Matsuyama	320	230

time (%)

With the particulars shown in Table 2, for Yokohama-Fukuoka route, truck requires 32.5 hours for one trip in this route. Considering 30 off-hire days, the maximum round trip per annum (RTPA) per truck was 124. At 90% average loading condition, one 11-ton truck (with 10.7 tons cargo capacity) would carry a total of 1194.12 tons of cargo through one way in one year. To perform the task of carrying 547500 ton of cargo each way in one year, 460 trucks were required. Similarly, with 39.35 hours trip time and 45 off-hire days, the maximum round-trip per annum per ship was 98. Considering the average loading condition as 50% of the 5000-ton ship (4500 ton cargo capacity), the total number of round-trip required per annum (RTRA) was 243, that is, 3 ships were required to perform the same task. The number of trucks or ships required for other routes were also calculated in the similar fashion and shown in Table 3.

Table 2 Transport particulars.

	Truck	Cargo ship
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
RTRA	56854	243
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	1×10^7yen	1.50×10^9yen
Transport tax/year	43600 yen	250000 yen
Depreciation	2.0×10^6yen	7.5×10^7yen
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

3. Consideration and Results

3.1 Transport between Stock- Point and Inland Water Port

The stock point is usually placed in or near the urban area. Truck was considered to be used for shipping the cargo between the stock point and the inland water port, the distance of which was assumed to be 10 km. The average cost of shipping was taken as 25 yen/ton-km, which was nearly the charge estimated in case of road transportation system. Table 4 shows some particulars of this route.

3.2 Cost Saving from Reduced Environmental Burden

The compounds and substances, those were released during the production and use of the transports were considered here. The relevant inventory list for the construction and operation phase of the transports is given in Table 5. The data of the construction phase were taken from various Internet resources and adopted from Hasegawa and Iqbal[1]. The data for the operation phase were taken from BUWAL 250 database of SimaPro[14], a life cycle assessment (LCA) software. Using this inventory table and the transport and route particulars, the total amount of emissions for each transportation system was estimated. The social external costs were then calculated by multiplying these values with respective unit costs.

There are at least three popular methods of estimat-

Table 3 Trip time, RTPA, and the required number of transport for different routes.

Route	Trip time		RTPA		No. of transport required	
	Truck	Cargo Ship	Truck	Cargo Ship	Truck	Cargo Ship
Yokohama-Fukuoka	32.50	39.35	124	98	460	3
Tokyo-Kitakyushu	28.50	44.04	141	87	404	3
Tokyo-Miyazaki	37.50	37.88	107	101	531	3
Nagoya-Sendai	20.00	32.89	201	117	283	3
Tokyo-Kochi	23.50	31.42	171	122	333	2
Tokyo-Tokushima	18.75	28.78	214	133	266	2
Osaka-Shin Moji	16.25	23.50	247	163	230	2
Kobe-Oita	20.25	22.33	199	172	287	2
Kobe-Matsuyama	10.50	16.75	383	229	149	2

Table 4 Transport particulars for the route between stock point and inland water port.

Distance	10 km
Trip time	0.2 h
RTRA	56854
RTPA	1462
Required number of transport means (truck)	39

Table 5 The inventory table.

Compound or substance	Unit	Truck	Cargo ship
Construction phase (per transport)			
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
Operation phase			
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}
Methane emission	kg/ton-km	2.77×10^{-4}	4.81×10^{-5}
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}

ing the cost of environmental damage. First, tracing the direct link between the emissions and the damage occur to human health and ecosystem and then placing some economic values on those damages [3,9,12,15-17]. Second, hedonic pricing, where estimation is done from observed price differentials of goods and/or services related to the environmental quality and the cost of meeting some new regulations imposed by relevant authorities.

Third is 'willingness to pay', a widely accepted principles in market economies. In this method the social cost of any change in economic outcome is measured by the sum of individuals' willingness to pay for that change at their current economic condition [6, 18].

In this study the social external cost of emissions from transports were estimated using the costs found by Mayres *et al* [9], Small and Kazimi[12], Pearce[19], and ExternE[20], those considered a number of emissions in the cost estimations.

Pearce[19] estimated the cost of pollutants in GBP in 1991 values and effective in London. This values were converted to JPY with the exchange rate 1 GBP=175 JPY, the current conversion rate. It could be a better estimation if the conversion was done by the 1991 conversion rate (1 GBP=233.81 JPY) and then adjusted for the inflation. But for simplicity, this approach was not followed here.

The social cost of air pollutants in Los Angeles estimated by Small and Kazimi[12] using direct damage estimation approach was also taken in this study to estimate the annual cost saving due to the reduction of emissions achieved through modal shifting in the model case considered. Romilly[17] also adapted this values with some more values proposed by others.

Only the cost of 5 pollutants was available in Small and Kazimi[12]. Those were VOC, NO_x. SO_x, PM_{10} and CO_2. The cost of PM_{10} was most high as it caused most serious health hazards. Originally these values

Table 6 Unit cost of pollutants.

Compounds or substances	Unit cost of pollutants in JPY				
	Pearce (1993)	Small & Kazimi (1995)	Mayeres *et al* (1996)	ExternE (1999)	
				Truck	Ship
CO_2 Emission (kg)	2.33275	7.44	8.27×10^{8}	0.2568	0.2568
NO_x Emission (kg)	33.25	1281.6	1.48×10^{12}	428	428
SO_x Emission (kg)	38.62075	1632	1.02×10^{13}	N/A	N/A
Methane emission (kg)	12.25	N/A	N/A	N/A	N/A
Particulate Matters (Dust) emission (kg)	1711.297	12240	8.90×10^{12}	6795570	7853800
VOC (non methane) (kg)	N/A	350.4	3.16×10^{11}	N/A	N/A

Table 7 Social environmental costs saving estimated by different valuations.

Route	Social environmental cost saving (JPY)			
	Pearce	Small & Kazimi	ExternE	Mayeres
Yokohama-Fukuoka	9.36×10^{8}	1.01×10^{10}	6.84×10^{11}	1.21×10^{19}
Tokyo-Kitakyushu	7.61×10^{8}	8.22×10^{9}	5.50×10^{11}	9.84×10^{18}
Tokyo-Miyazaki	1.13×10^{9}	1.22×10^{10}	8.31×10^{11}	1.46×10^{19}
Nagoya-Sendai	5.05×10^{8}	5.46×10^{9}	3.65×10^{11}	6.54×10^{18}
Tokyo-Kochi	6.45×10^{8}	6.96×10^{9}	4.70×10^{11}	8.34×10^{18}
Tokyo-Tokushima	4.82×10^{8}	5.21×10^{9}	3.49×10^{11}	6.24×10^{18}
Osaka-Shin Moji	4.18×10^{8}	4.52×10^{9}	3.05×10^{11}	5.41×10^{18}
Kobe-Oita	5.74×10^{8}	6.20×10^{9}	4.22×10^{11}	7.41×10^{18}
Kobe-Matsuyama	2.40×10^{8}	2.60×10^{9}	1.76×10^{11}	3.11×10^{18}

were in US Dollar in 1992 price. A conversion rate of 1 USD = 120 JPY was taken to find the values in Japan. In this study, the social cost of particulate matter was taken the same as the value of PM_{10} given in Small and Kazimi[12].

Mayeres *et al* [9] estimated the external costs using external cost functions computed for a given economic equilibrium. The costs were estimated for 1990 and 2005 to be effective in Brussels. In this study only the 1990 values were taken with the conversion rate 1 ECU = 1 EURO = 107 JPY. In Mayeres *et al* [9] the cost of carbon was given. This value was converted to the cost of CO_2 in this study, considering that all of the carbon would be transformed into CO_2.

The cost estimation using the values proposed by ExterE[20] was described in Iqbal and Hasegawa[21] and was adapted from Bickel *et al* [22]. The same costs of three pollutants (CO_2, NO_x and PM) are used here to find the social cost savings from the reduced emission.

Table 6 shows the unit cost of the pollutants measured by different researchers. These values were considered in this study. Table 7 shows the social cost saving due to reduced environmental burden through the proposed modal shift estimated by 4 different valuations.

3.3 Direct Cost Saving from RFR

Considering the monetary saving per ton cargo shipment by ship in place of truck, that is the difference between required freight rates (RFRs), the total saving was calculated multiplying this value by the annual amount of cargo shipment. The RFR is the level of freight rate, which produces equal present worth of income and expenditure, that is, zero net present value (NPV)[23].

The RFR was estimated as follows[23],

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

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.

Thus the estimated monetary cost saving was 2.93×10^{10} yen, if 1500 tons of cargo was shifted to ship from truck, everyday and both ways, in Yokohama-Fukuoka route. Similarly the savings in other routes were calculated and shown in Table 8.

3.4 Cost Saving by Service Time

Mayeres *et al* [9] estimated the value of time (VOT) for both passenger and freight transport in Brussels. The VOT in freight transport was 25.9 ECU/h in 1991 price and was adapted from De Jong *et al* [24]. With the conversion rate 1 ECU = 1 EURO = 107 JPY, this value was taken as 2771.3 JPY in this study.

In the service time, the time required to accumulate the cargoes at the stock point should be added 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 not considered 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 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, in Yokohama-Fukuoka route, the maximum time required by the transport authority to serve there customer was (36+40) h or 76 h and the minimum was 40 h. Taking the average time required for cargo accumulation, the 'service time' for the cargo ship was 58 h in this route. For the truck this value was 32.58 h.

Considering the average service time taken in Yokohama-Fukuoka route by ship as 58 h and by truck as 32.57 h, the total time saving through the modal shift of cargo was estimated. In each trip, ship carried an amount of 2250 tons of cargo. In case of cargo carrying by ship the average waiting time was 18 h, but in case of truck the average waiting time was almost negligible. Keeping these in mind, it was considered that additional (58-32.57) h that is 25.43 h was taken for each trip by ship, that is, per shipment of 2250 tons of cargo. Thus the cost of annual time loss due to the shipment by cargo ship was 16.6×10^6 yen in Yokohama-Fukuoka route. The cost savings from the time saved in all specified routes are shown in Table 8.

Table 8 Cost saving from the freight rate and the time saved.

Route	Cost saving from (JPY)	
	Freight rate	Time
Yokohama-Fukuoka	2.93×10^{10}	-1.66×10^{7}
Tokyo-Kitakyushu	2.52×10^{10}	-2.25×10^{7}
Tokyo-Miyazaki	3.43×10^{10}	-1.23×10^{7}
Nagoya-Sendai	1.71×10^{10}	-2.07×10^{7}
Tokyo-Kochi	2.06×10^{10}	-1.74×10^{7}
Tokyo-Tokushima	1.59×10^{10}	-1.88×10^{7}
Osaka-Shin Moji	1.36×10^{10}	-1.69×10^{7}
Kobe-Oita	1.76×10^{10}	-1.34×10^{7}
Kobe-Matsuyama	8.07×10^{9}	-1.62×10^{7}

3.5 Total Cost Saving

The total annual saving of social cost through modal shifting of 1500 tons of cargo from truck to cargo ship would thus vary because of the different valuations of air pollutants. Considering the minimum costs, that is, the costs measured by Pearce[19], to show the lower limit of the social costs, this saving in Yokohama-Fukuoka route was 3.02×10^{10} yen. In case of similar modal shift in all the 9 routes mentioned earlier, the annual social cost saving was 18.72×10^{10} yen.

4. Conclusion

In 1997, transports in Japan were responsible for about 20% CO_2, 54% CO, 50% NO_x, 23% N_2O and 12% SO_2 of the country's total emissions to the atmosphere[25]. According to the Kyoto Protocol[26], 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, 4.51×10^3 tons of NO_x, if the amount of emissions agrees with 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 comparison was made with the monetary values of these impacts to ease the understanding. The social costs saving through modal shifting of 1500 ton of break bulk type cargo from truck to cargo ship in certain routes in Japan were estimated. The cost saving in environmental burden, freight rate and time used were estimated separately and the total saving in 9 routes was then calculated and found as 18.72×10^{10} yen.

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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