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Inland transportation system planning by life-cycle impact assessment: a case study. 2nd report: single comparison index

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Abstract: A model to estimate and compare the ecological impact and economic feasibility of a land transportation system (trucks) and a marine transportation system (cargo ships) was developed and presented in a previous report.[1] Three different comparison indices—environmental, economic, and customer service—were used to evaluate and compare their ecological impacts and determine their economic superiority. In this article, a single comparison index is proposed and assessed for the two transportation systems. The estimates were made for nine different routes in Japan. A simple mathematical model of the whole methodology is given. The sensitivity of the weighting factors used in the comparison method was analyzed. The social cost saving in monetary terms through a modal shift is also presented.

Key words: Transportation · Environment · Modal shift · Life-cycle impact assessment · Kyoto Protocol

List of symbols

LCIA	life-cycle impact assessment
RFR	required freight rate
RTPA	round trips per annum possible by a single transport
RTRA	round trips required per annum for a transportation task
P	price of the transport or first cost (yen)
C	annual cost (yen)
L	amount of cargo carried (ton/year)
i	rate of return (%) on investment
t_{trip}	trip time
t_{load}	loading and unloading time
t_{delay}	time delay (%)
R	route distance
D	days in operation per annum
v	velocity (km/h)
C_{ap}	capacity of transport (ton)
δ	loading condition (%)
W	cargo to be carried (ton/day each way)
F_c	amount of fuel consumption per annum
A_t	annual transportation task in ton–kilometers
g	specific gravity of fuel used
f	fuel consumption rate (km/l)
EP(j)	total potential contribution from the impact category j
Q_i	emissions of compound i
EF(j)$_i$	characterization factor of compound i related to the impact category j
I_E	environmental index
ω_j	weighting factor for impact category j
I_F	economic index
I_S	service index
t_{accum}	cargo accumulation time
I	total comparison index
α_1	weighting factor for environmental index
α_2	weighting factor for economic index
α_3	weighting factor for service index

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1 Introduction

The climate of the earth is changing. Land near the coast is disappearing under water, fierce hurricanes and typhoons occur more frequently, and heat waves, melting polar ice caps, shifting agricultural zones, and coral bleaching are some of the signs confirming climate change. Scientists believe that in all of human history the climate has never changed as fast as it is changing today. There are many reasons for this change, some of which are natural and some of which are human induced.[2] Ever-increasing human activity is having a negative effect on the climate.

The transport system is a major source of greenhouse and other harmful emissions. Special attention is being paid to the transport sector to reduce the emissions it causes. Measures being considered include increases in excise duties, stricter enforcement of speed limits, and finding alternative transport modes and infrastructure. A modal shift of cargo from trucks to cargo ships can be one way of finding a less polluting means of transport.[3] A discouragingly small number of articles is available which quantify the benefits of this modal shift. Fet et al.[4] compared the environmental impact of different transport systems in Europe. A model has been proposed[1] to compare the environmental impact, economic aspects, and customer service of the truck transportation system with the marine transportation system, and three different comparison indices have been described. This article describes a single comparison index, which includes the environmental impact, economic benefit, and customer service factors. The estimation was made for nine different transport routes in Japan. The simple mathematical model used for these estimations is given in this article. The emission data in the inventory table in the first report were collected from various Internet resources. In this report, a more reliable inventory list was used for the operational phase of the transport.

In this article, characterization factors have been used to estimate the environmental impact from emissions, whereas in the previous paper the emissions were directly divided into the impact categories for which they were responsible. The sensitivity of the weighting factors is also analyzed here.

Social cost saving was also analyzed, which showed the total amount of social cost in monetary value that would be saved if a certain amount of cargo was transfered from truck to cargo ship on the Yokohama–Fukuoka route, as well as on eight other specific routes.

2 Methodology

For a transportation model between Yokohama and Fukuoka, Japan, a life-cycle impact assessment (LCIA), and the freight rate and service time required were estimated for both road and inland water transport to determine their impact on the environment, their economic cost, and their customer service quality, respectively. By comparing these characteristic parameters, the benefits of a modal shift from truck to cargo ship were analyzed. A similar analysis was conducted for eight other routes in Japan. The whole comparison methodology is shown in Fig. 1.

2.1 Transportation model

A transportation system model similar to the inland courier service in Japan was considered for this comparison. The two alternative transportation systems are shown in Fig. 2. For this comparison, only the transportation task between the stock points was considered, because the other parts of the system were similar. An average of 1500 tons of break bulk-type cargo was as-

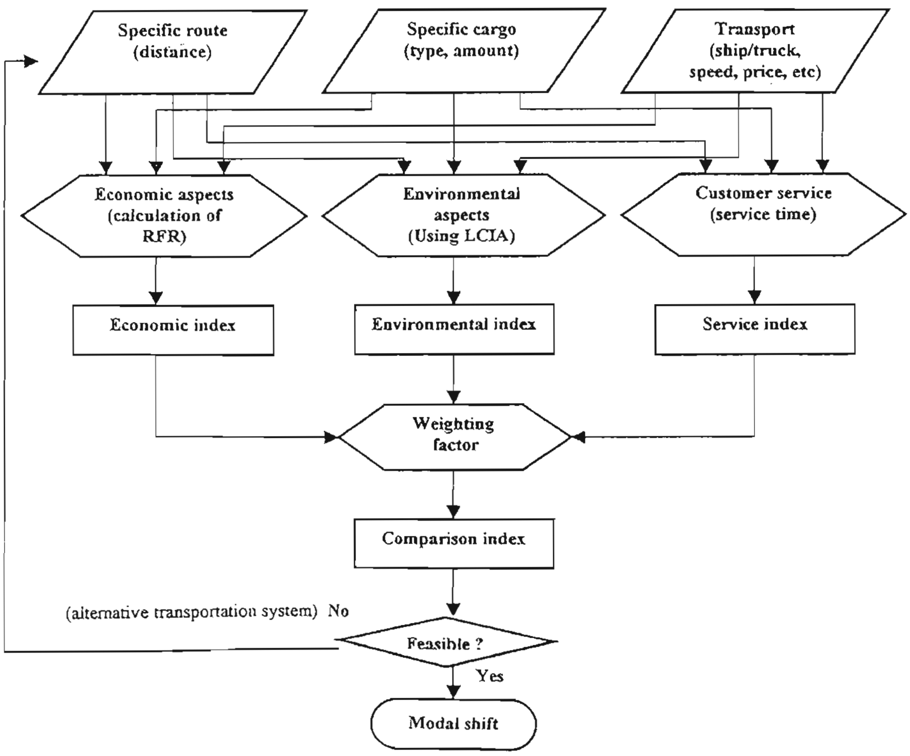

Fig. 1. The comparison methodology. *RFR*, required freight rate; *LCIA*, life-cycle impact assessment

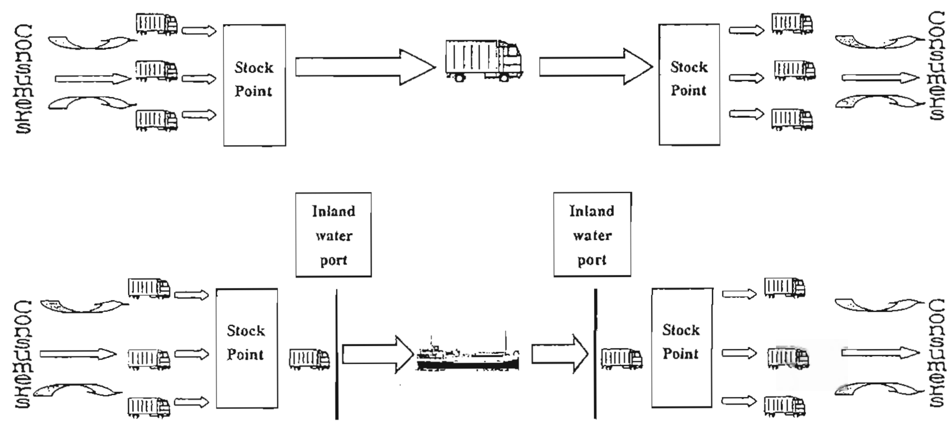

Fig. 2. Alternative transportation system. *Top*, transportation system for the usual courier service in Japan; *bottom*, proposed alternative transportation system

Table 1. Route distances

Route	Distance by road (km)	Distance by waterway (km)
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

sumed to have been shifted from truck to cargo ship for shipment from Yokohama to Fukuoka, and same amount from Fukuoka to Yokohama, every day. This Yokohama–Fukuoka route was chosen for the primary calculation. The comparison was then extended to the other eight routes shown in Table 1. The particulars of the Yokohama–Fukuoka route and the transport systems considered for the comparison were given in the first report.[1] The number of crew members was taken to be six for a ship and two for a truck.

The route and trip particulars were calculated according to the equations given below. The trip time,

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

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

The maximum possible number of round trips per annum (RTPA) per type of transport was calculated from the trip time and the total number of hours available for operation in a year according to the equation

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

where D is the operating days per annum (= 365 – off-hire days).

Round trips required per annum (RTRA) is the minimum number of round trips required to perform the whole transportation task.

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

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

The amount of fuel consumption per annum (in kg) is

$$F_{\text{c}} = \frac{(2\text{R})(\text{RTRA})}{(f)(g)}$$

where g is the specific gravity of the fuel used, and f is the fuel consumption rate (km/l).

The annual transportation task in ton–kilometer is

$$A_{\text{t}} = (L)(R)$$

where L = (2)(365)W, and W is the cargo to be carried (ton/day each way).

The number of trucks/ships required to perform the task is

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

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

2.2 Life-cycle impact assessment and environmental destruction index

The flow process followed for evaluating the environmental burden using the LCIA was similar to that shown in Fig. 1 in the first report. Fourteen compounds and substances that were consumed and released during the production and use of the trucks/ships were considered. The data for the construction phase were the same as used in the first report. The relevant inventory list for the operational phase of the transportation is given in Table 2. The data shown in this table were taken from the BUWAL 250 database of SimaPro,[5] a life-cycle assessment (LCA) software. Only the heat radiation values in the operational phase were the same as in the first report, since these were not available on BUWAL 250. The values in the first report were from various Internet sources. For consistent comparisons, it is always better to use data from a single source, which is why SimaPro data were used whenever possible. Moreover, the database in SimaPro was developed through very detailed calculations and is considered as a reasonable source by many researchers[4,6] in the field.

In the estimates of values in the inventory list, it was taken that the load factor of the truck was 50% of 16-ton capacity, and the load factor of the ship was 70% (capacity not mentioned). These values were not the same as those considered in the comparison process, but they were used because this was the most reliable source found, and all the values in the BUWAL 250 database were given on a ton–km basis.

After calculating the total amounts of various substances and compounds released for the transportation task by both transportation systems, the environmental impacts of the systems in six different categories (fossil fuel exhaustion, local warming, global warming, acid rain, eutrophication, air pollution) were estimated by multiplying the total amount of emissions by the appropriate characterization factors according to the equation below.[4]

$$\mathrm{EP}(j) = \sum \left(Q_i \times \mathrm{EF}(j)_i \right)$$

where, $\mathrm{EP}(j)$ is the sum of the potential contribution from the impact category j, Q_i is the emissions of compound i, and $\mathrm{EF}(j)_i$ is the characterization factor of compound i in relation to the impact category j.

The values of the characterization factors are given in Table 3. These values were based on Eco-indicator '95.[5] Only the characterization factor for heat radiation in the local warming impact category was assumed by the author to be 1, because heat radiation is the only substance that is responsible for local warming in this comparison process. This value of the heat radiation characterization factor would not make any significant contribution to the index, as the ratio of a similar impact category for a truck transportation system to a marine transportation system was used to determine the environmental destruction index. Another reason was that the radiated heat, without a change in form, had a direct influence on the development of local warming, the so-called heat island effect.

The environmental destruction index was calculated by taking the ratio of the amount of potential impact by truck transportation to that of marine transportation, and multiplying this by specific weighting factors for each impact category according to the following equation:

$$I_{\mathrm{E}} = \sum \omega_j \frac{\left(\mathrm{EP}(j)\right)_{\mathrm{truck}}}{\left(\mathrm{EP}(j)\right)_{\mathrm{ship}}}$$

where ω_j is the weighting factor for impact category j. The values of the weighting factors (ω_j) for various impact categories are given in Table 4. These values

Table 2. Compounds and substances released during the operation phase of transportation

Compound or substance	Unit	Truck	Cargo ship
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}

Table 3. Characterization factors for various impact categories

Impact category	Responsible substance or compound	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

Table 4. Weighting factors for various environmental 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

were calculated by the analytic hierarchy process (AHP)[7] from the opinions of general consumers and transport users. The AHP is a widely accepted method of establishing hierarchy among parameters that are not directly related to each other. Saaty[7] explained this method in detail.

A questionnaire was used to survey the opinions of people from different walks of life by asking them to assess the weighting factors of various environmental impacts. The people questioned were asked to consider two environmental impacts at a time, and compare their relation to climate change to determine the weighting factor. For example, they were asked to compare "local warming" with "global warming," and to judge which one is absolutely/very strongly/strongly/weakly dominant over the other, or whether both are affecting the environment equally. From the responses of 112 people, the AHP was used to calculate the weighting factors. Of the respondents, 63.4% were Japanese, 19.6% were Bangladeshi, and the rest were from various other countries including Pakistan, Indonesia, Australia, and Canada. Among the respondents, 40% were students, and most were studying naval architecture and environmental engineering. The rest were professionals from various disciplines, including engineers, doctors, transportation experts, academicians, and businessmen. The values of the weighting factors (ω) shown in Table 4 add up to 1.0 when normalized.

2.3 Required freight rate

To assess whether either system was economically superior, the required freight rates (RFR) at a 5% rate of return on investment for both systems were calculated and compared. The 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 time period (N). Here, annual costs include fuel costs, maintenance costs, crew costs, insurance, etc. The RFR was calculated using the equation given in the first report.[1] In both systems; 60% of the direct labor cost was considered to be an overhead cost when calculating the total annual cost.

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

where I_F is the economic index.

2.4 Customer service index

Customer service is an important aspect of transportation planning. The factors usually considered in assessing the customer service quality of a transportation system include time taken for the service, comfort, entertainment, and safety. Among these, comfort and entertainment are considered only in passenger transportation systems. The other two factors are important for both cargo and passenger transportation. The safety of a cargo, i.e., its protection against damage, is an issue of particular importance when shipping over long distances where the cargo moves through changes in temperature, humidity, etc., as is usually the case when shipping internationally. The model case considered here is for inland shipping, and therefore it is logical to exclude the safety factor. Here, the "service time," i.e., the time taken by the transport company to serve their customer, is only considered as "customer service quality" to compare the transportation modes.

When assessing service time, the time required to accumulate the cargo at the stock point should be included in the trip time. The calculation of the trip time was shown in the first report. The accumulation time was estimated on the assumption that the inflow of the cargo for shipment was uniform over time. In reality, the inflow is usually greater in the daytime than at night, but to simplify the estimation, this nonuniformity was excluded here. With this assumption of the uniform inflow of the cargo, the rate of cargo inflow was 62.5 ton/h, since a 1500-ton cargo would be ready for shipment in 24h. Therefore, the amount of cargo required for one trip by ship, i.e., 2250 tons, would be accumulated in 36h. This is the minimum time-gap required between two successive trips by cargo ship. Considering this time-gap, the maximum time required by the transport authority to serve the customer was (36 + 40) 76h, and the minimum was 40h. Taking the average time required for cargo accumulation, the service time for the cargo ship was 58h. For a truck, this value was 32.57h.

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

$$I_S = \frac{\left(t_{\mathrm{accum}} + t_{\mathrm{trip}}\right)_{\mathrm{truck}}}{\left(t_{\mathrm{accum}} + t_{\mathrm{trip}}\right)_{\mathrm{ship}}}$$

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

2.5 *Single comparison index*

To find a single comparison index, the three different indices, i.e., environmental, economic, and customer service, were summed after multiplying them with their respective weighting factor according to the equation

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

where α_1, α_2, and α_3 are the weighting factors for the environmental index, economic index, and service index, respectively, calculated by the AHP in a similar fashion to that described in Sect. 2.2. These factors were calculated from the responses of 56 people to the questionnaire. Among the responders, 28.5% were Japanese, 21.4% were Bangladeshi, and the rest were from various other countries including Pakistan, India, Indonesia, Australia, the United States, Belgium, and Canada. Of these 56 people, 46.4% were students with many of them studying naval architecture, environmental engineering, and social science. About 19.6% of the respondents were engineers or technologists, and the other 34% included doctors, researchers, transportation system consultants, academicians, bankers, businessmen, and computer programmers. The values of these weighting factors (α) are given in Table 5, and the weight distribution according to the percentage of responders is shown in Fig. 3.

Table 5. Weighting factors for different comparison indices

Comparison index	Weighting factor
Environmental index	0.538
Economic index	0.247
Service index	0.215

Figure 4 shows the environmental and total comparison indices for the nine different routes considered. The environmental indices vary from 4.04 for the Nagoya–Sendai route to 6.82 for the Tokyo–Miyazaki route. For the total comparison indices, the lowest value of 4.27 was found on the Kobe–Matsuyama route, and the highest value of 8.41 was on the Tokyo–Miyazaki route. For the Kobe–Matsuyama route, the total comparison index was lower than the environmental index. This is because the economic index for this route was low (7.83), and the economic index is the dominant parameter in the total comparison index. It is clear from Fig. 4, that whatever the route the index is always more than 4, which means that the marine transportation system is at least four times better than the road system from the viewpoint of environmental impact alone, as well as when the economic and service-quality aspects are included.

The differences in the value of the comparison indices were because of the differences in the length of the routes. For this reason, it is better to compare the total performance for some routes rather than the ton–km performance of the transportation systems.

3 Sensitivity analysis

The first report[1] showed the sensitivity of the environmental index to the quantity of emissions. Here, the sensitivity of the environmental and total comparison indices to the weighting factors were analyzed, as shown in Figs. 5 and 6. Since the sum of all the weighting

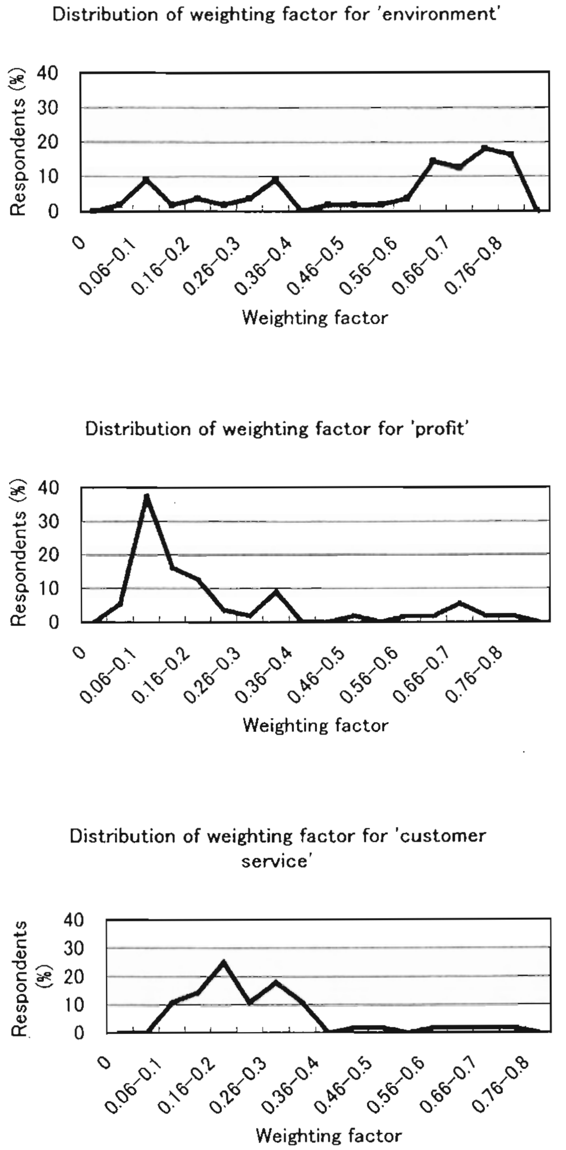

Fig. 3. Distribution of weighting factors according to the percentage of responders

factors in the same category is always 1.0, the values of the other factors were adjusted while one was changed during the sensitivity analysis, as described below.

Weighting factor ω_j was changed to

$$\omega_j' = \omega_j + x$$

where j = any number from 1 to 6, and x is the amount added to the factor (ω_j) to be changed.

$$\omega_k' = \omega_k - \frac{\omega_k}{\left(1-\omega_j\right)}x$$

where k = 1–6, but is not equal to j. The sensitivity of the weighting factors was analyzed with the environmental index and the total index of the Yokohama–Fukuoka route only. Figure 5 shows that the comparison indices have a very low sensitivity to the weighting factors in the environmental impact category. Only the weighting factor for local warming showed slightly more sensitivity. This is because the ratio of the local warming impact category was very low (1.46) compared with the ratio of the other impact categories (5.96–6.15). Therefore, the small increment in the weighting factor for local warming was subsequently adjusted by lowering the values of the other weighting factors, which reduced the total value of the index. As shown in Fig. 6, the total comparison index is highly sensitive to the weighting factors for the indices. The weighting factor for the economic index showed the greatest sensitivity because of the high index value, which dominated the total comparison index.

4 Social cost saving

The social cost saving in monetary value from using an alternative transport mode is another method of demonstrating the superiority of one transportation system over another. In this section, the annual social monetary cost saving for a modal shift of 1500 tons of cargo from truck to cargo ship, every day and in both directions, on the Yokohama–Fukuoka route is estimated. These savings were of three forms: saving from reduced environmental burden, direct monetary saving from a lower freight rate, and time-saving, which was negative in this case.

4.1 Cost saving from reduced environmental burden

There are at least three popular methods of estimating the cost of environmental damage. The first is tracing the direct link between emissions and the damage to human health and the ecosystem, and then placing some economic value on that damage.[8–13] The second is hedonic pricing, where the estimate is done from the observed price differentials of goods and/or services in relation to environmental quality and the cost of meeting any new regulations imposed by the relevant authorities. The third is "willingness to pay," which is a widely accepted principle 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 in their current economic condition.[14,15]

The social cost of air pollutants in Los Angeles, as estimated by Small and Kazimi[9] using the direct damage estimation approach, was used to estimate the annual cost saving due to the reduction of emissions achieved through modal shifting in the model case considered. Romilly[8] also adopted these values in conjunction with

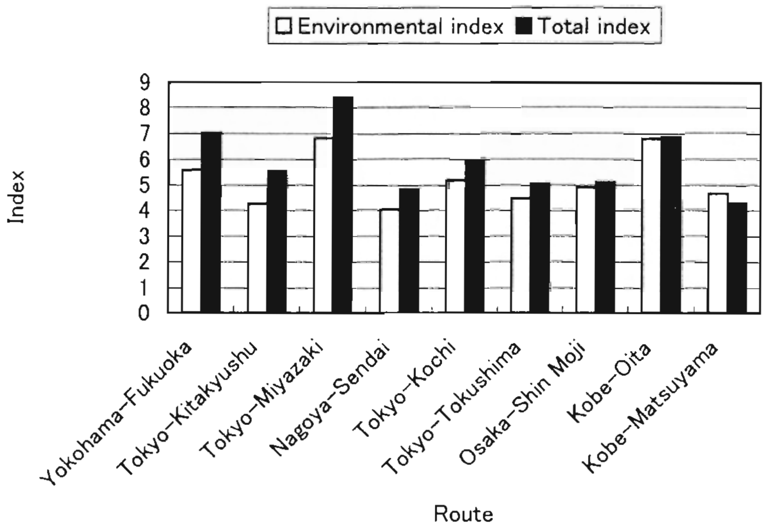

Fig. 4. Comparison indices (truck transportation system/ship transportation system)

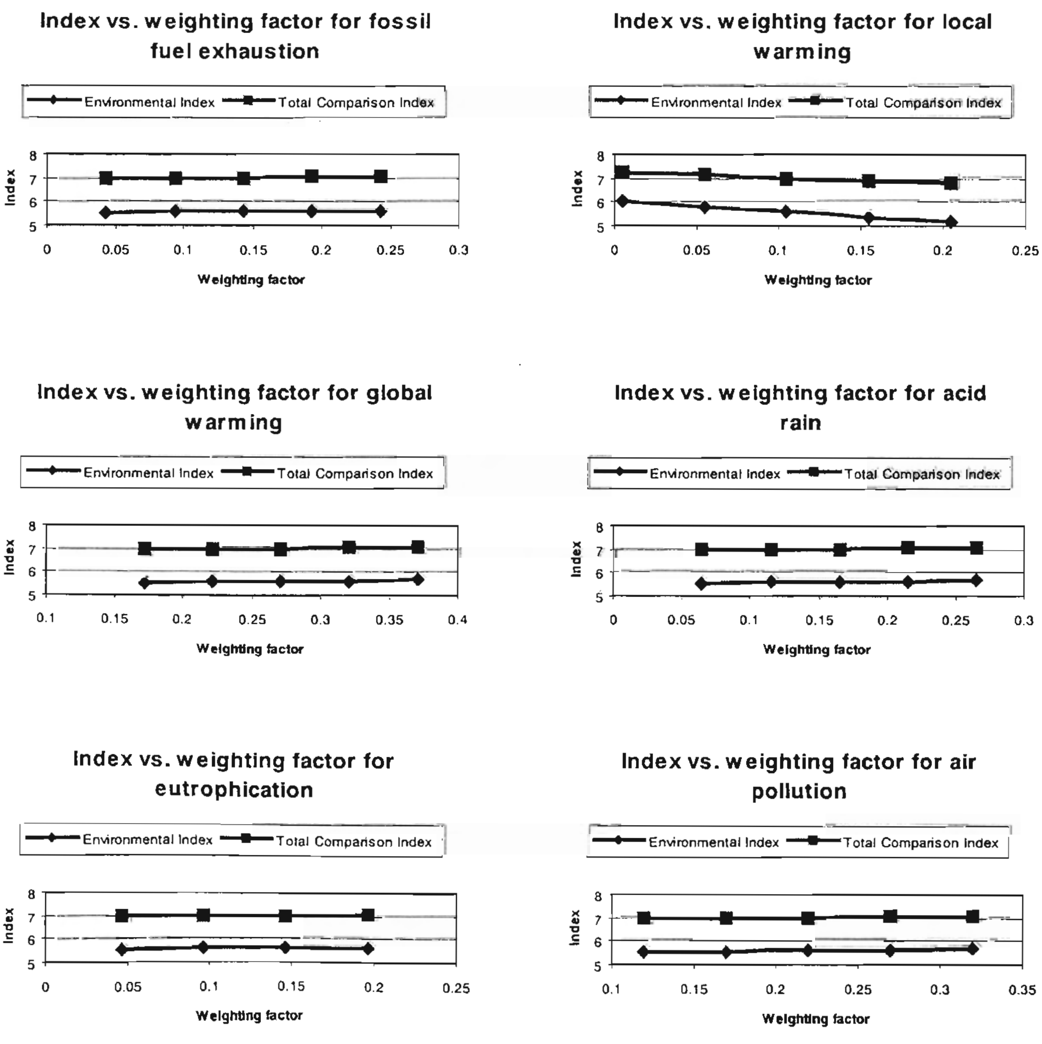

Fig. 5. Sensitivity of the environmental and the total comparison indices to the weighting factors for impact category

some proposed by other authors. Mayeres et al.[10] adapted an approach which was similar to that followed by Small and Kazimi.[9]

The cost of only five pollutants was available in Small and Kazimi.[9] These were VOC, NO_x, SO_x, PM_{10}, and CO_2. The cost of PM_{10} was highest because it caused the most serious health hazards. Originally these values were in US dollars at the 1992 value, and conversion rate of US$1 = ¥120 was used to determine the values in Japan. It would be a better estimate if the conversion were done using the 1992 conversion rate (US$1 = ¥130) and then adjusted for inflation, but for the sake of simplicity this approach was not used. Table 6 shows the annual reduction of pollutants due to the modal shift, the unit cost of the pollutants, and the monetary cost savings. In this table, the social cost of particulate matter was taken to be the same as the value for PM_{10} given by Small and Kazimi.[9]

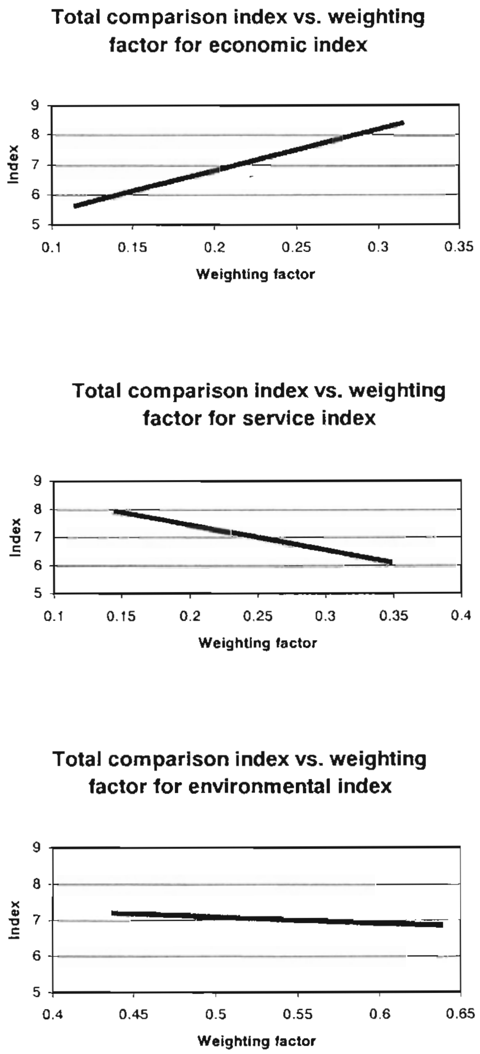

Fig. 6. Sensitivity of the total comparison indices to the weighting factors for various indices

4.2 Direct cost saving from RFR

By considering the monetary saving per ton of cargo movement by ship instead of trucks, i.e., the difference between the RFRs, the total saving was calculated by multiplying this value by the annual amount of cargo shipment. Thus, the monetary cost saving was ¥29.3 × 10^9 if 1500 tons of cargo were shifted from trucks to ships every day and in both directions on the Yokohama–Fukuoka route.

4.3 Cost saving by service time

Mayeres et al.[10] estimated the value of time (VOT) for both passenger and freight transports in Brussels. The VOT for freight transport was ECU 25.9/h at 1991 prices and was adapted from De Jong et al.[16]. With a conversion rate of ECU1 = EURO 1 = ¥107, this value was taken to be ¥2771.3 in this work.

Considering the average service time taken by a ship to be 58 h, and that by truck to be 32.57 h, as estimated in Sect. 2.4, the total time saving through the modal shift of cargo was estimated. On each trip, a ship carried 2250 tons of cargo. When cargo was carried by ship the average waiting time was 18 h, but when cargo was carried by truck the average waiting time was almost negligible. Keeping these times in mind, it was considered that an additional 58 − 32.57 h, i.e., 25.43 h, was required for each trip by ship (i.e., per shipment of 2250 tons of

Table 6. Annual social cost saving from the reduced environmental burden on the Yokohama–Fukuoka route

Compound or substance	Amount of savings	Cost/unit emission (¥)	Cost saving (¥)
CO_2 emission (kg)	2.52×10^8	7.44	1.87×10^9
NO_x emission (kg)	4.51×10^6	1281.6	5.78×10^9
SO_x emission (kg)	3.86×10^5	1632	6.30×10^8
Particulate matter emission (kg)	1.03×10^5	12240	1.26×10^9
VOC (nonmethane) (kg)	1.57×10^6	350.4	5.50×10^8
Total cost saving			1.01×10^{10}

cargo). Thus, the annual cost of time lost due to the use of cargo ships was ¥16.6 × 10^6.

The total annual saving of social costs through the modal shift of 1500 tons of cargo from truck to cargo ship every day, and in both directions, on the Yokohama–Fukuoka route was thus ¥39.4 × 10^9. If there were a similar modal shift on all the nine routes examined, the annual social cost saving would be ¥243 × 10^9.

5 Discussion and conclusions

In 1997, transport in Japan was responsible for about 20% of the CO_2, 54% of the CO, 50% of the NO_X, 23% of the N_2O, and 12% of SO_2 out of the country's total emissions to the atmosphere.[17] In the Kyoto Protocol,[18] Japan made a commitment to cut its emissions to 6% below the 1990 level in the period 2008–2012. A modal shift of 1500 tons of break-bulk-type cargo from trucks to cargo ships on the Yokohama–Fukuoka route will reduce the annual emission by 2.52 × 10^5 tons of CO_2 and 4.51 × 10^3 tons of NO_X if the amount of emissions agrees with the data given here.

A new comparison index to compare marine transport with land vehicles in their environmental, economic, and service quality aspects has been introduced. A simple mathematical model has been proposed for this comparison. The sensitivity of the environmental index as well as of the total comparison index to the weighting factors has also been analyzed. The social benefit in monetary terms of such a modal shift has also been estimated.

The following unsolved problems require further research in this area.

- comparison with other transport modes, including the railway;
- the environmental impacts due to cargo handling systems;
- use of land areas and the effects of exposure to noise;
- cost of congestion due to heavy traffic on the roads or at the inland water ports; and
- cost of traffic accidents.

The outcome of this study can be used by governmental bodies for taxation purposes. It may also be useful for planning inland transportation systems. Convincing people to switch from trucks to cargo ships for their cargo movements will 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. Governments can also promote water transport by introducing high emission taxes and road taxes.

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