Comparison of Land and Marine Transportation System from the View Point of Life Cycle Impact Assessment *1

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To achieve a sustainable development to the environment the scope of modal shift from truck to ship is discussed. Considering some environmental impacts, the environmental effects conducted by truck and ship for an assumed model case are calculated and compared. The calculations are carried out for four different scenarios. The superiority of marine transports over road vehicles from ecological viewpoint is shown by environmental index estimated using life cycle impact assessment.

Keywords : *Transportation, LCA, LCIA, Environment, Modal Shift, Kyoto Protocol*

1. Introduction

Since 1979 scientists of the world have been agreed upon to focus careful attention to the Global Climate Change[1]. It has been believed that since the industrial revolutions, atmospheric concentrations of carbon dioxide (CO_2) have increased nearly 30%, methane (CH_4) concentrations have more than doubled and nitrous oxide (N_2O) concentrations have risen by about 15%, which caused the global mean surface temperature rise by 0.3 ° to 0.6 ° C[2]. This temperature rise has already started showing its devastating effect like coral bleaching[3] and long-lasting flood in various parts of the world. The emission from various transports is one of the reasons behind the climate change.

For example, motor vehicles are responsible for about two-thirds of the carbon monoxide, one-thirds of the nitrogen oxides and one-fourths of the hydrocarbons emission to the atmosphere[4]. Modal change to inland shipping could be one of the effective measures to reduce such emission[5]. It is found that the inland shipping is about 600% cleaner than the road transport and compared to the diesel train it is still 150% cleaner[6]. But very often this modal change is considered as contradictory to economical development. A solution would have to be found out to satisfy both the requirements, which is usually termed as sustainable development[5].

In this paper the authors compared the ecological burden of road vehicles with that of inland water transports. Considering 7 environmental impacts which have influence on 6 different types of effects (showed in Figure 2), the environmental indices for trucks with respect to water transports were estimated for an assumed model case. Different weight coefficient for each different environmental effect were used for this calculation. Before comparing the environmental influence, the economic feasibility of modal shift from road to water was examined.

2. Methodology

Considering a model system the economic scenario of various surface-transports was compared. Four transport types included in that model were truck, ferry, medium cargo ship and small cargo ship. The cargoes were considered as the small cargo usually consumed by general consumer and transported regularly by trucks, ferries and ships including the courier services. The cost required to carry the cargoes across 9 different routes were calculated and compared.

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In this comparison some important assumptions were made. Those were

(1) Stock-point was situated at the convenient place for the trucks.

(2) In case of ferry transport, the loaded trucks were considered to be carried as cargo, so no stock-point was required.

(3) In case of medium and small cargo ship, the cargoes were considered to be carried by trucks from the stock-point to the ship.

Considering this comparison, attractive transport types for road and water were considered for the evaluation of their influence on environment change.

Seven different impacts, which have immense influence on climate change, were taken into account while calculating the environmental index. Those impacts were energy consumption, heat radiation, CO_2, NO_x, SO_x, phosphorus, and particle matter. Then the environmental effects in 6 different categories by these 7 impacts for trucks with both the medium and the small cargo ships were calculated. Finally the environmental index were calculated multiplying these effects with a specific weight coefficient for each effect category.

To evaluate this environmental influence another model case was studied where it was assumed that 1500 ton of cargo to be carried in a day by trucks and ships. Thirty percent loading condition was considered for cargo ships, where 1 medium ship or 2 small ships were required to carry the mentioned amount of cargo. At 60% loading condition 500 trucks were required to serve the purpose. The estimation was made for 4 different scenarios considering 500 km or 1000 km distance with 10 years or 20 years operation. The environmental impact of the material itself by which the trucks and ships were made was not considered during this evaluation.

The flow diagram of the whole analysis is shown in Figure 1.

3. Transport System Considered

The particulars of various transport types are shown in Table 1.

The names of 9 routes considered for the economic analysis and the time required to cover them are shown in Table 2.

The amounts of environmental impacts released during the production and operation of truck and ship

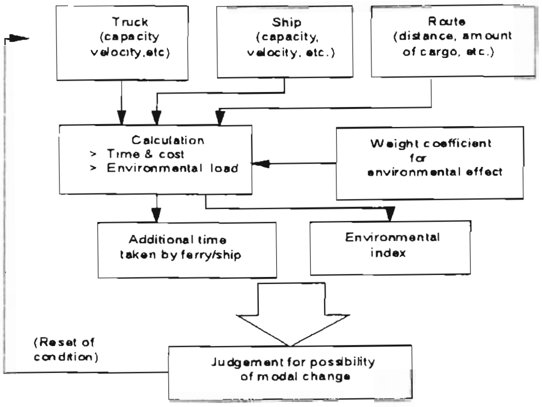

Fig. 1 Flow diagram

Table 1 Transport characteristics

	Truck	Ferry	Cargo Ship	
			Medium	Small
Eng. Power [PS]	350	15,000	12,000	9,000
Capacity [TEU]	0.5	120	500	250
Velocity	50 [km/h]	23 [knot]	23 [knot]	25 [knot]
Fuel type	Light Oil	Heavy Oil		
Fuel consumption	4.0 [km/l]	150 [g/PSh]		
Fuel unit cost	70 [yen/l]	15 [yen/l]		
Harbor Charge [in 1000 yen]			130	120
Loading /unloading (hour)		1.5	4	2
Labor cost	22,000 [yen/man-hour]			

are shown in Table 3. The calculation of the environmental impact and their influence is very difficult. Hence these data were collected amongst internet resources[7)8)9)10)]. However the amount of heat and particle matter released during the phase of production and phosphorous during the phase of operation were not available.

Table 2 Time required

Route	Distance (road /water) (km)	Truck (hour)	Ferry (hour)	Cargo Ship Medium (hour)	Cargo Ship Small (hour)
Tokyo ~ Kitakyushu	1,040 /1,160	21	30 (42.9)	32 (55.0)	28 (34.9)
Yokohama ~ Fukuoka	1,200 /1,000	24	26 (6.3)	28 (18.7)	25 (2.5)
Tokyo ~ Miyazaki	1,400 /950	28	25 (-11.4)	27 (-2.5)	24 (-16.0)
Nagoya ~ Sendai	700 /780	14	21 (48.7)	23 (66.5)	20 (41.8)
Tokyo ~ Kochi	840 /730	17	20 (16.9)	22 (31.8)	19 (11.7)
Tokyo ~ Tokushima	650 /640	13	18 (34.8)	20 (54.0)	17 (29.4)
Osaka ~ Shin-Moji	550 /460	11	13 (20.9)	16 (43.6)	13 (17.6)
Kobe ~ Oita	710 /420	14	12 (-13.0)	15 (4.6)	12 (-15.0)
Kobe ~ Matsuyama	320 /230	6	8 (23.4)	10 (62.5)	8 (24.5)

( ) shows additional hours required in percentage.

Table 3 Unit load of environmental impact

(a) During the phase of production (per truck/ship)

	Truck	Cargo Ship Medium	Cargo Ship Small
Energy [MJ]	3.62x105	1.39x108	9.27x107
Heat [MJ]	-	-	-
CO2 [ton]	29.4	1.07x104	7.13x103
NOx [kg]	43.6	4.85x104	3.23x104
SOx [kg]	152	1.32x104	8.87x103
Phosphorus [kg]	34	9.65x103	6.45x103
Particle Matter [kg]	-	-	-

(b) During the phase of use

	Truck	Cargo Ship
Energy	3.93 [MJ/ton-km]	0.62 [MJ/ton-km]
Heat	42.7 [MJ/l]	40.7 [MJ/l]
CO2	188 [g/ton-km]	58.4 [g/ton-km]
NOx	1.49 [g/ton-km]	0.810 [g/ton-km]
SOx	4.20 [kg/ton of fuel]	48.3 [kg/ton of fuel]
Phosphorus		
Particle Matter	0.205 [g/ton-km]	0.2 [g/ton-km]

4. About LCIA

As a method for quantitative evaluating environmental influence of a product, Life Cycle Assessment (LCA standardized as ISO 14040)[11] is now widely used. Through a product's life from raw material acquisition through production, use and disposal, LCA studies the environmental aspects and potential impacts of that product. Nagata *et al* have proposed approaches for valuation of LCA impacts including distance-to-target and panel aggregation[12].

Life cycle impact assessment (LCIA standardized as ISO 14042)[13] is one of the tool to evaluate LCA. Each factor which has influence on the environment is called impact in LCIA. There exist various kinds of methodologies and procedures for considering the LCIA method. The calculation process for environmental burden using LCIA is shown in Figure 2.

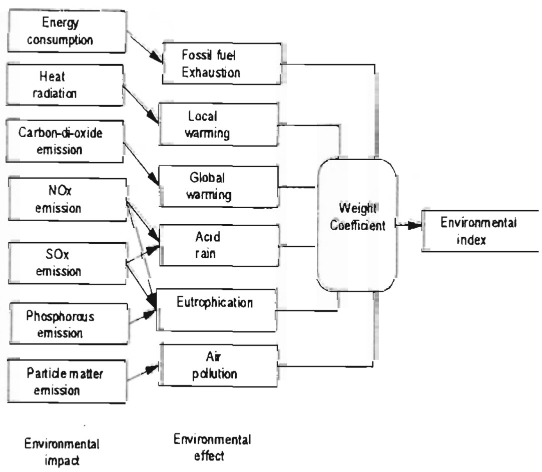

Fig. 2 Calculation process of environmental index

5. Results and Findings

5.1 Economic Aspect

A comparison of cost required to carry the cargoes across the 9 different routes are shown in Figure 3.

The index line 100 corresponds to the cost by trucks. From the figure it is clear that in the case of Nagoya-Sendai route the cost by ferry significantly exceeds the cost by truck. The ferry cost is also a little higher in the route Tokyo-Kochi. Even in all other routes the ferry costs are not so attractive with respect to the costs by truck. But in all of the routes the costs by ships are considerably low in comparison with the costs by trucks and by ferries. It may be a very important factor in choosing the mode of transport. It is to be mentioned here that in this analysis neither the construction cost nor the depreciation cost of the transports were taken into account.

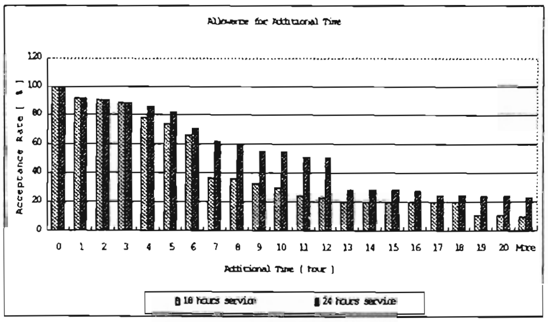

Fig. 4 Acceptance for additional time taken

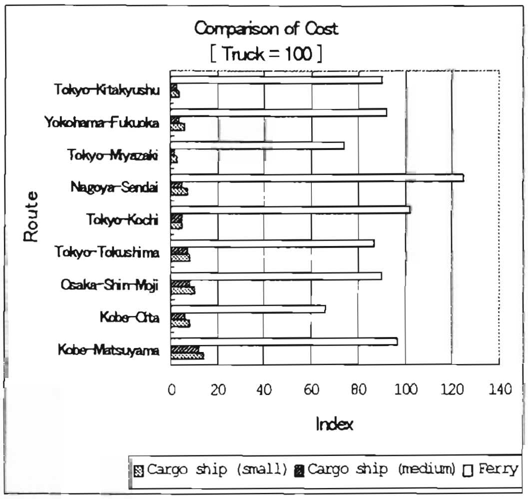

Fig. 3 Comparison of cost

According to Figure 3 the medium cargo ship with 23 knot speed may be the best choice. Full-loaded conditions were considered in all cases for economic analysis. If the cargo is not enough for full-loaded condition of medium cargo ship, then the small cargo ship may be a better choice.

It was found in the practice that the truck takes about 18 hours to carry cargo at a distance of 500 km and 24 hours in case of 1000 km. This duration includes the rest and delay times. A survey was carried out by the authors among some naval architects, shipbuilding related personnel and students to find if they could allow any additional wait for their cargo. The findings are shown in Figure 4.

Figure 3 shows how cheap the inland water transports are than trucks. Of course the equivalent value of time was not considered in the analysis. But it has been shown in Figure 4 that how much additional delay might be allowed by the consumer while shifting the cargoes from one point to other.

5.2 Environmental Aspect

Life cycle impact assessment of the truck and the ships was conducted considering the previously mentioned conditions and the amounts of environmental loads are shown in Table 3. Table 4 shows the environmental effects of truck compared to ships. Since the ferry was not economically attractive in comparison with truck, it was not considered here. The weight coefficients for each category of environmental effects are shown in Table 5. A questionnaire was used for a survey among some naval architects, shipbuilding related personnel and students asking to put weight factor to various environmental effects. Then analytic hierarchy process (AHP) was used to calculate the weight coefficients.

Finally the environmental indices for four different scenarios are summarized in Table 6.

According to Table 5 global warming got the highest weight coefficient and air pollution was the next. It is clear from Table 6 that the influence of truck transport on the climate change is about 3.5 times of that of the cargo ship for 20-year operation. This influence is about 4～4.5 times for 10-year operation.

Adopting the Kyoto Protocol (1997), Japan has decided to reduce its CO_2 level by 2012 to 94% of the level measured in 1990. According to available esti-

Table 4 Environmental effect by truck
(a) For 10-year operation
[Cargo ship = 100]

Effect	In case of 500 km		In case of 1000 km	
	Truck /medium ship	Truck /small ship	Truck /medium ship	Truck /small ship
Fossil fuel exhaustion	592	574	614	604
Local warming	448	299	448	299
Global warming	308	300	315	311
Acid rain	110	103	110	103
Eutrophication	132	112	132	113
Air pollution	807	538	807	538

(b) For 20-year operation
[Cargo ship = 100]

Effect	In case of 500 km		In case of 1000 km	
	Truck /medium ship	Truck /small ship	Truck /medium ship	Truck /small ship
Fossil fuel exhaustion	620	610	629	624
Local warming	448	299	448	299
Global warming	320	316	321	319
Acid rain	111	104	111	104
Eutrophication	192	157	192	157
Air pollution	807	538	807	538

Table 5 Weight coefficients for environmental effects

Effect	Weight coefficient
Fossil fuel exhaustion	0.145
Local warming	0.078
Global warming	0.26
Acid rain	0.185
Eutrophication	0.099
Air pollution	0.233

Table 6 Environmental index of truck
[Cargo ship = 100]

	Truck / Medium cargo ship		Truck / Small cargo ship	
	10 years	20 years	10 years	20 years
500 km	422	340	436	354
1,000 km	427	347	437	357

mated data[10], to achieve this level in 2000, the emission of CO_2 will have to be reduced by 1.07×10^7 ton in that year. But still it is not clear how to achieve this. It was found that only by modal shifting from truck to cargo ship in 10 routes of 500 km, it would be possible to reduce the CO_2 emission by about 7% of the target in 2000.

6. Conclusions

A new environmental index to compare the marine transports with land vehicles in LCIA consideration has been introduced. The following conclusions may be made in favor of ships:

1. Cheaper than road vehicles.
2. To some extent slower but acceptable by the general consumers.
3. About 4 times better than truck in comparison of CO_2 and other harmful emission to the environment from the view point of LCIA.
4. Modal shift from truck to ship could be one of the effective measures for sustainable development to the environment and helpful to implement the Kyoto Protocol.

The following future works are to be carried out:

1. Infrastructures necessary for inland shipping and land transport, that is harbor facilities, road network, effects of deforestation due to the extension of road, etc., should be considered in these comparisons.
2. Time value should be included in the economic comparison.
3. A single comparison index should be established to consider both the economic aspects and the environmental aspects.

The economic development is sometimes considered contradictory to such modal shift to inland shipping as this mode is to some extent slower than the other modes, even though it is the cheapest. So it is now an important issue to discuss how far we may allow the environment to be fatal for the existence of lives like coral, and of course at the end the human beings.

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Discussion

[Discussion] (Osaka Sangyo University) Shinsuke Akagi

A shipper will consider total cost taking account of the time value of the charge for modal shift. How do the authors deal with the time value in the present study?

[Author's Reply]

In the present study the equivalent value of time was not considered. But the cargo considered was general cargo usually consumed by the daily user. The additional time required in case of modal shift from truck to ship was calculated. According to the result of the questionnaire on the allowance of additional time taken, the excess time required was always within the allowance limit imposed by most of the consumers. In this sense, the allowance of additional time can be evaluated as zero in the value by general consumers.

[Discussion] (Osaka Prefecture University) Yoshiho Ikeda

In Table 1, the difference between the figures of car ferry and cargo ships is doubtful. The capacity of car ferry is 120 TEU, while in case of small cargo ship it is 250 TEU, more than double of the ferry capacity. Besides, the small cargo ship is only two knots faster than the car ferry. However, the engine power of the small cargo ship is quite small. The discussing person doesn't believe that there was big difference in their structure. Explain the reason of the big difference of propulsion performance between the ferry and the small cargo ship.

[Author's Reply]

All the data mentioned in Table 1 were collected from the particulars of real ship. The authors cannot comment on the difference.

[Discussion] (Hitachi Shipbuilding Co. Ltd.) Yoshiaki Sezaki

(1) Who are the responders of the questionnaire? It may affect the result.

(2) In Table 3(b) we may find the value of SOx. It is said that the only way available to reduce it is to improve the quality of the fuel based on the present technique. The discussing person guesses that the authors have assumed diesel oil for trucks and type-C heavy oil for cargo ships. Do the authors consider this fact?

[**Author's Reply**]

(1) The authors agree that the result might be a little affected if the responders were from some other sectors. But they feel that since the responders to the questionnaire, that is naval architects, shipbuilding related personnel and students, were from the daily consumers, the results showed the consumers' views.

(2) Yes, the author considered diesel oil for trucks and type-C heavy oil for cargo ships and the discussing person is right on this point. That is the reason why the value of SO_x in case of cargo ship is much higher than that of the truck. In the present study, the authors didn't consider the improvement of the fuel quality, but it is clear that if the fuel quality is improved, the superiority of marine transport will be overwhelming. Moreover if only the quality of fuel for truck is improved, the cost by this mode will increase significantly which may make the user reluctant to use this mode.