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SUSTAINABLE PLANNING FOR INLAND WATER TRANSPORTATION SYSTEM IN BANGLADESH

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ABSTRACT

For a sustainable planning, using life cycle impact assessment, required freight rate and the customer service time, the ecological impact, the economic performance, and social acceptance of minibus and water taxi were evaluated and compared for the Dhaka – Narayanganj route in Bangladesh. Then the superiority of the water transport to minibus service is shown. The results are shown as three different comparison indices. The sustainability indicator was used to show the overall performance in the said transportation system. The water taxi showed clear superiority in environmental and economic aspects. Only the 'service quality' went to the favor of minibus. Overall performance was significantly in favor of water taxi.

KEYWORDS

Water transportation planning, life cycle assessment, sustainable design

NOMENCLATURE

t_{trip}	trip time (hrs.)
v	velocity of transport (km/h)
t_{delay}	delay in time (%)
RTPA	round trip per annum
RTRA	round trip required per annum
C_p	capacity (passengers)
L	total number of passengers carried (passenger/year)
$EP(j)$	sum of the potential contribution from the impact category j
$EF(j)_k$	characterization factor of compound k related to the impact category j
Q_k	emissions of compound k
I_E	environmental destruction index
P	price of the transport or first cost (Tk.)
C	average operating and maintenance cost per annum (Tk.)
spw	series present worth factor
N	number of year in operation
I_F	economic index
R	route distance (km)
t_{load}	loading and unloading time
D	days in operation per annum
δ	average load factor (%)
T	number of transport vehicles
RFR	required freight rate (Tk./passenger)
ω_j	weighting factor for impact category j
i	rate of return (compound interest)
I_S	service index
Tk.	Taka (Bangladesh currency, 1USD=Tk.65)
$I_{eco\text{-}eff}$	eco-efficiency indicator
I	sustainability indicator
α_i	weighting factors for comparison indices

INTRODUCTION

Sustainability in planning is the future trend considering all estimated economic, environmental, and social performance in the planning stage of all projects concerning product and/or service. It is replacing the traditional way of taking only the economic benefit into consideration and even the current trend of considering eco-efficiency performance. So is for the planning of water transportation system including the water transport means.

In this paper the environmental and economic performance of a proposed water-taxi (small sized water transport) to be operated between Dhaka and Narayanganj, two nearby cities in Bangladesh, were estimated. The similar performances of minibus service, that is currently in effect, were also estimated. Since the quantified value of social performance or impact was not easy to find, a simple service quality performance was taken here as indicator. The performances of both the services were then compared to find the better one using environmental indicator, eco-efficiency-indicator, and sustainability indicator.

Dhaka is the capital city of Bangladesh. The population of metropolitan Dhaka is already over 10 million. Narayanganj is another large city at a distance of 43 km by water and 49 km by road to the south of Dhaka. It is a port city and another important commercial location. Every year almost 9.4 million people shuttle between Dhaka and Naryanganj for their job and business purposes.

In this paper, considering the Dhaka-Narayanganj route, the ecological impact and the economic performance of bus and river transport were evaluated and compared. For comparing environmental impacts, life cycle assessment (LCA) with different weighting factors for the impact categories were considered. The required freight rate (RFR) or transport fare to attain a pre-determined rate of return on the investment was considered for the comparison of economic performance. For the consideration of social service or customer service, the time taken by the carrier to serve their customers was estimated and compared for the different transportation system types.

Using an ideal case of meeting the demand of passenger transport between Dhaka and Narayanganj, indices for environmental burden, economic benefit and customer service quality were estimated.

TRANSPORTATION MODEL CONSIDERED

A transportation system model of two alternative forms of transport were considered and compared to find the better one that would improve environmental, economic, and social conditions: a bus transportation system that would connect two cities through a road network of 49 km in length and a water transportation system that would be operated on a river route of 43 km. The particulars of these two systems are shown in Table 1.

The provisions for routine renovation of the vehicles have been made on the 3^{rd}, 6^{th} and 9^{th} year of the operation. It was assumed that the vessel acquisition was 100% covered by commercial loan.

Table 1: Particulars of transport systems

	Road transport (minibus)	**Water taxi**
Route distance	49 km	43 km
Capacity	25 persons	100 persons
Transport velocity	50 km/h	8 knots
Loading & unloading time	0.5 h	0.5 h
Time delay	25%	25%
Off hire days per annum	15	35
Operating hours	5 am to 10 pm	5 am to 10 pm
Fuel type used	Diesel oil	Diesel oil
Fuel consumption	4.5 km/l	2.2 km/l
Fuel cost	25 Tk./l	25 Tk./l
Fuel specific gravity	0.85	0.85
Engine power	103 hp	100 hp
Average loading condition	0.9 %	0.9 %
Life time	10 years	10 years
Price of transport	2.00×10^{6} Tk.	3.20×10^{6} Tk.
Hull and machinery depreciation rate	5%	5%
Crew wages/month	3500 Tk.	3500 Tk.
Number of crew/drivers	2	5

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

Trip time,

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

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

$$RTPA = \frac{(17D)}{\left(2t_{trip}\right)} \tag{2}$$

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

$$RTRA = \frac{L}{2C_p\left(\frac{\delta}{100}\right)} \tag{3}$$

Where, C_p = capacity (passengers), δ = average load factor (%), L = total number of passengers carried (passenger/year)

Number of transport vehicles required to perform the task,

$$T = \frac{RTRA}{RTPA}, \text{ when } \frac{RTRA}{RTPA} \text{ is an integer} \tag{4}$$

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

The estimated RTRA, trip time, RTPA and the required number of transport vehicles for the transport systems between Dhaka and Narayanganj are shown in Table 2.

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

RTRA		**Trip time (hrs)**		**RTPA**		**No. of transport vehicles required**	
Minibus	Water taxi	Minibus	Water taxi	Minibus	Water taxi	Minibus	Water taxi
417778	104444	1.85	4.25	1608	660	260	160

ENVIRONMENTAL INDICATOR OR ENVIRONMENTAL DESTRUCTION INDEX

Eleven compounds and substances, among those released during the production and use of the transport, were considered here. 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 five different impact categories (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 following equation (Fet, 2000).

$$EP(j) = \sum (Q_k \times EF(j)_k) \qquad (5)$$

where, $EP(j)$ is the sum of the potential contribution from the impact category, Q_k is the emissions of compound k, and $EF(j)_k$ is the characterization factor of compound k related to the impact category j.

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

$$I_E = \sum \omega_j \frac{(EP(j))_{Bus}}{(EP(j))_{water}} \qquad (6)$$

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

ECONOMIC INDEX

To find the economically superior option, required freight rates (RFR) assuming 10% rate of return on investment to the bus and the water transport 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 equation (7) (Buxton, 1987).

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

Where, $RFR =$ Required freight rate (Tk./passenger), $P =$ Price of the transport or first cost (Tk.), $C =$ Average operating and maintenance cost per annum (Tk.), $L =$ Number of passenger carried (Passenger/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 (Buxton, 1987).

The economic index,

$$I_E = \frac{(RFR)_{Bus}}{(RFR)_{water}} \tag{8}$$

SOCIAL OR CUSTOMER SERVICE INDEX

It has always been difficult to quantify any social benefit or destruction by any service or product. In this study customer service quality was considered as a service to the society. 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. Here only the 'service time', that is, the time taken by the carrier to serve their customer is considered as 'customer service quality' to compare the transportation modes. The other factors for the service quality were excluded as it was a short distance travel.

Here the trip time was taken as the service time. The ratio of this service time of bus transport to the water transport was taken as the customer service index.

So, customer service index,

$$I_S = \frac{(t_{trip})_{bus}}{(t_{trip})_{water}} \tag{9}$$

ECO-EFFICIENCY INDICATOR

Eco-efficiency indicator was calculated according to the equation (10).

$$I_{eco-eff} = \frac{RFR_k}{\sum \omega_j (EP(j))_k} \qquad (10)$$

Where, k is for the mode of transport.

SUSTAINABILITY INDICATOR

As already discussed the sustainability indicator will include all the performances regarding environment, economy and social service. A similar comparison index was proposed by Iqbal and Hasegawa (2001), later it was called *econoserv index* by them Iqbal (2001).

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 specific weighting factors according to the following 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 environmental index, economic index and service index respectively.

THE VALUES OF INPUT PARAMETERS

The amount of steel material used and the electricity consumption for the construction of each vehicle is given in Table 3. These figures were found through interview of relevant personnel of a local bus company and a shipyard. Other materials and energy were not considered as the data was not available.

Table 3: The materials / energy used in the construction of one unit of minibus and one unit of water taxi

Material/energy	Unit	Minibus	Water taxi
Amount of steel used	tons	6	23
Amount of electricity consumed	kw-h	1200	4600

The emissions for the production and use of a unit amount of some materials/energy are shown in Tables 4 to 7. Here only the available emission data that were used in this analysis were given. It was difficult to find reliable data for this analysis. For the construction phase of such transports, Hasegawa and Iqbal used data collected from various Internet resources (Hasegawa and Iqbal, 2000). In this analysis the data were mostly collected from SimaPro, a life cycle assessment (LCA) database software, developed by Pre Consultants of Amersfoort (Pre Consultants, 1999). In SimaPro the sources of data were mentioned as BUWAL 132, BUWAL 250, Chalmers 1991, etc. Only the heat radiation values in the operational phase were taken as shown by Hasegawa and Iqbal (Hasegawa and Iqbal , 2000).

Table 4: Emissions during the production of 1 kw-h electricity (taken from BUWAL 132 of SimaPro)

CO_2 (gm)	NO_x (gm)	N_2O (gm)	C_xH_y (gm)
201.96	0.684	0.018	0.0216

Table 5: Emissions for the production of 1 ton electrolytic chrome coated steel (taken from BUWAL 250 of SimaPro)

CO_2 (gm)	NO_x (gm)	SO_x (gm)	N_2O (gm)	HF (gm)	HCl (gm)	Methane (gm)	Ammonia (gm)	C_xH_y (gm)	Suspended Particulate Matter (gm)
2.95×10^6	4540	6180	9.52	11	86.30	1.08×10^4	1.97	5.23	1410

Table 6: Emissions through burning of 1 kg diesel (3% Sulpher content) by an engine (Hasegawa, 2000 and Chalmers 1991 of SimaPro)

Heat Radiation (MJ)	CO_2 (gm)	NO_x (gm)	SO_x (gm)	C_xH_y (gm)	Suspended Particulate Matter (gm)
40.70	322.55	3.15	5.45	4.26	0.468

Table 7: Emissions for the production of 1 kg diesel (taken from BUWAL 132 of SimaPro)

CO_2 (gm)	NO_x (gm)	SO_x (gm)	N_2O (gm)	Ammonia (gm)	C_xH_y (gm)	Suspended Particulate Matter (gm)
312	1.90	3.86	0.048	0.02	6.79	0.22

The estimated total annual emissions from the fleet are shown in Table 8. The total emissions were estimated using the number of transports and the number of trip required to perform the transportation task mentioned in the model system as given in Table 2.

Table 8: The annual emissions from the fleet construction and operation

Compound or substance	Unit	Minibus	Water taxi
Construction phase			
CO_2 emission	kg	2.87×10^5	1.10×10^6
NO_x emission	kg	7.30×10^2	1.72×10^3
SO_x emission	kg	9.64×10^2	2.27×10^3
N_2O emission	kg	2.05	4.83
Methane emission	kg	1.68×10^3	3.97×10^3
Ammonia emission	kg	3.07×10^{-1}	7.25×10^{-1}
HCl emission	kg	1.35×10	3.18×10
HF emission	kg	1.72	4.05
Particulate matter emission	kg	2.20×10^2	5.19×10^2

Table 8: The annual emissions from the fleet construction and operation (continued)

Compound or substance	Unit	Minibus	Water taxi
Operation phase			
Heat radiation	MJ	3.11×10^8	1.40×10^8
CO_2 emission	kg	4.85×10^6	2.18×10^6
NO_x emission	kg	3.86×10^4	1.73×10^4
SO_x emission	kg	7.12×10^4	3.19×10^4
N_2O emission	kg	3.67×10^2	1.65×10^2
Ammonia emission	kg	1.53×10^2	6.86×10
C_xH_y emission	kg	8.44×10^4	3.79×10^4
Particulate Matter (PM) emission	kg	5.25×10^3	2.36×10^3

The values of the characterization factors are given in Table 9. These values were according to Eco-indicator '95 of SimaPro (Pre Consultants, 1999). Only the characterization factor for heat radiation in the local warming impact category was assumed as 1 by the author. 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 make any significant contribution to the index, as the ratio of a similar impact category for the bus transportation system to the water transportation system was taken to find the environmental destruction index. Another reason was that the radiated heat, without changing in form, had a direct influence on the local warming and in developing the so-called, 'heat island.'

Table 9: Characterization factors

Impact category	Responsible compounds or substances	Characterization factor	Unit
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	1.60	kg
	NO_x	0.70	kg
	SO_x	1	kg
Eutrophication	NO_x	0.13	kg
	Ammonia	0.33	kg
Local air pollution	Particulate matter	1	kg
	SO_x	1	kg
	C_xH_y	0.398	kg

The values of the weighting factors for various impact categories are given in Table 10. These values were calculated by analytic hierarchy process (AHP) (Saaty, 1980) using the opinions of general transport users.

A questionnaire was used to survey the opinions of people from different disciplines of society including students, engineers, doctors, carriers, academicians and businessmen, asking them to assess weighting factors for various environmental impacts. From the responses of 112 persons, AHP was used to calculate the weighting factors

Table 10: Weighting factors for impact categories

Impact category	Weighting factor
Local warming	0.1225
Global warming	0.3162
Acid rain	0.1925
Eutrophication	0.1120
Local air pollution	0.2567

The values of the weighting factors for various comparison indices to get a single comparison index or sustainability index (α) are given in Table 11.

Table 11 The weighting factor for indices

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

These factors were also calculated by AHP from opinions of some responders. These factors are calculated from the responses of 56 persons in the questionnaire. Among the responders 28.5% are Japanese, 21.4% are Bangladeshi and the rest are from various countries including Pakistan, India, Indonesia, Australia, America, Belgium, and Canada. Professionally 46.4% of them are student of various major including Naval Architecture, Environmental Engineering and Social Science. About 19.6% are Engineer and Technologist. The rest 34% are of various professions including doctor, researcher, transportation system consultant, academician, banker, businessman, and computer programmer.

The economic assessment was carried out assuming 10% rate of return on the investment. The escalation rates considered for the projected economic analysis are shown in the Table 12.

Table 12: Annual escalation rate

Heads	Annual escalation rate (%)
Hull Maintenance	5.00
Engine and Machinery	10.00
Fuel and lub. oil cost	5.00
Insurance, Registration, Port charges etc.	5.00
Passenger fare	2.50
Crew wages	10.00

In both cases of bus and water transport, 100% of the direct crew/labor cost was considered as overhead cost while calculating the total annual cost. The insurance and other overhead were taken as 1% of the vehicle price.

RESULTS AND DISCUSSION

The potential contribution to the environmental impact categories by minibus and water taxi are given in Table 13.

Table 13: Potential contribution to the impact categories

	Minibus	**Water taxi**
Local warming	3.11×10^{8}	1.4×10^{8}
Global warming	5.25×10^{6}	3.37×10^{6}
Acid rain	9.99×10^{4}	4.77×10^{4}
Eutrophication	5.16×10^{3}	2.50×10^{3}
Local air pollution	16.60×10^{4}	7.86×10^{4}

The passenger fare found for the bus was 0.44 Tk./passenger/km and for the water transport, it was 0.37 Tk./passenger/ km. So, the RFRs for the specified route were 21.61 Tk./passenger by bus and 16.20 Tk./passenger by water transport.

The service time for the bus and the water transport were 1.85 hrs. and 4.25 hrs. respectively.

The three estimated comparison indices are shown in Table 14. Eco-efficiency indicator for both minibus and water taxi are given in Table 15.

Table 14: The indices

Environmental destruction index or Environmental indicator	**Economic index**	**Service index**
1.94	1.33	0.44

Table 15: Eco-efficiency indicator for minibus and water taxi

	Minibus	**Water taxi**
Eco-efficiency indicator	5.43×10^{-7}	8.90×10^{-7}

The sustainability indicator or *econoserv index* was found as 2.94.

The environmental index shows that the water transport is 1.94 times less detrimental than the bus from the viewpoint of life cycle assessment on that particular route. The economic index, that is, the comparison of direct passenger fare is 1.33. The results show that from both the environmental and economic point of view, water transport would be a better option. The superiority of water transport in these regards is very significant. Yet this mode of transport is getting insufficient support from the general transport users. This is because of the lower service quality involved in this mode. Here the service index is 0.44. Moreover the ease of traveling by bus from and to the center area of the city attracts transport users more easily towards the bus. By developing the navigation on the said route, and also by emphasizing the environmental superiority of water transport, it should be easier to convince users that they have a moral obligation to use this mode in place of other surface vehicles. This modal shifting of passengers from road to water will also be very helpful in solving the traffic congestion problem on the road. Concerning the eco-efficiency indicator the water taxi has showed 1.6 times better economic performance compared to their environmental destruction capability. If sustainability indicator is of concern, the water taxi performs 2.94 times better compared to the minibus. This finding is expected to assist decisions makers in deciding what services they should promote to preserve the environment while maintaining commercial viability. Government can also promote water transport by introducing higher emissions tax and road tax.

CONCLUSION

The results found in this study are highly uncertain because of the uncertainty involved in the data used. There are differences among the characterization factors proposed by various persons/organizations. Iqbal and Hasegawa used a few different characterization factors to evaluate social benefit that can be achieved through modal shifting of cargo from truck to cargo ship (Iqbal and Hasegawa, 2002).

The waiting factors used in this study to assess the environmental destruction index and sustainability indicator were estimated by AHP from the responses of people to a particular questionnaire. The AHP is often used to establish hierarchy among the matters, which are not directly comparable. The responses may differ depending on the responders social environment, awareness, economic condition, etc. So, one should be aware of these uncertainties while using these results, though the environmental destruction index was found not much sensitive to the weighting factors except to the weighting factor for local warming (Iqbal and Hasegawa, 2001).

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