【Article】

Evaluation of Environmental Emissions for Optimization of Highway Improvement Programme

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Abstract

This paper describes a method to evaluate the environmental impact due to highway improvement with a newly proposed inconsistency minimization model and development of a highway improvement programme for minimizing the vehicular emissions by explaining a case study. Scenario analysis is carried out using User Equilibrium Assignment method with modified BPR function based on Wardrop's equal travel time principle and simple vehicular exhaust emission formula. The new consideration in this study is that capacity of link and parameter of BPR function are changeable according to maintenance level. The amount of user cost and environmental emissions savings due to highway improvement or maintenance is estimated by using International Roughness Index (IRI) which is one of the indicators for highway service level. Finally the priority of highway links under budget constraint for maintenance will be evaluated according to the amount of savings. Optimum amount of maintenance budget is also estimated by trading off between total user cost and highway maintenance cost.

1. Introduction

The highway related factors such as steep upgrades and poor road surface conditions reduce fuel/environmental efficiency. On steep upgrades, vehicles require a heavy power output from their engines, consuming more fuel than under normal conditions. Also, rough roads can lead to significant increase in fuel consumption by influencing the rolling resistance and aerodynamic drag generated. At typical highway speeds, a vehicle tested on a rough road increased its fuel consumption by five percent over a vehicle tested on a normal quality road (Baker, 1994).

Well maintained roads increase speeds and reduce the quantity of fuel, spare parts and tyres consumed. Potential savings of scarce foreign currency now expended on importing fuel and spare parts would be significant in Bangladesh. On the contrary, poor road surface conditions reduce fuel/environmental efficiency. Prediction of road traffic emissions and fuel consumption is therefore becoming increasingly important for evaluation of environmental policies for infrastructural developments. So, economic and environmental evaluation of highway improvement has been carried out by scenario analysis using user equilibrium traffic assignment with modified BPR (Bureau of Public Road) function to prioritize links for maintenance under budget constraint. However, solving any traffic assignment or other transportation planning problem requires the transportation demand information in the form of Origin-Destination (O-D) trip matrix.

An O-D trip table is a two dimensional matrix of elements whose cell values represent the travel demand between each given origin (row) and destination (column) zone. An O-D trip table can be obtained by conventional surveys such as license plate surveys, home interviews, roadside surveys etc. Such surveys are time consuming, expensive and labor intensive. In addition, many of these approaches involve sampling errors. These conventional approaches also suffer from other drawbacks, such as an inability to reflect changes in influencing factors. For instance, if the land use characteristics change, so will the trip table. Hence the previously measured trip table may quickly become outdated, and one needs to repeat these surveys in order to obtain new trip tables, which is cost prohibitive.

Excessive development of the road network was undertaken without any real understanding of subsequent maintenance requirements and the financing involved. And despite the upsurge of traffic in most developing countries, road maintenance has only been of secondary importance in their budgets. However, priority is increasingly being given to maintenance and most developing countries need an effective method of monitoring the condition of their roads and bridge facilities, assessing maintenance needs, and prioritizing those needs to optimize benefits from constrained budgets (World Bank, 1998). Highway improvement programme in this study means selection of highway links for improvement or maintenance under budget constraint and optimum maintenance scheduling to maximize economic efficiency in traveling, which is similar to a Road Network Design problem.

This study, at first, estimates transportation demand in the form of O-D trip matrix from easily available inconsistent traffic count data by using a inconsistency minimization model. These estimated O-D trip matrices will be used to solve user equilibrium traffic assignment on small and disaggregate highway networks in Bangladesh. Then scenario analysis will be performed to estimate user cost and environmental emission savings due to highway maintenance by using the International Roughness Index (IRI), which is one of the indicators for highway service level. Finally selection of highway links under budget constraint and prioritization of highway links for maintenance will be made according to the amount of savings. Optimum amount of maintenance budget is also estimated by trading off between total user cost and highway maintenance cost.

2. Literature review

Decisions regarding road network improvements are increasingly made within spatial planning processes. To be rational, these processes must include several stages. One crucial stage, possibly the most important one, consists of defining a development strategy for the territory under consideration. On the basis of comprehensive regional or urban development indicators, the strategy establishes the major guidelines for public intervention in sectors like agriculture, employment, environment, education, culture and transport, and specifies a provisional budget for each sector. Once the strategy has been defined, the next stage consists of preparing a plan for each sector. The plan details the strategic guidelines to be implemented, thus transforming the general, often vague, ideas coming out in the previous stage into precise actions consistent with the provisional budget. Within spatial planning processes, road network improvements therefore will be defined taking into account previously defined budget conditions (Antunes et al., 2003).

Yang and Bell (1998) have recently reviewed a considerable amount of research devoted to road network design models over the past 40 years. In the past two decades, a vast, growing body of research focused on formulations and solution procedure for the Network Design Problem, which deals with the selection of either link improvement or links additions to an existing road network with given demand from each origin to each destination. Most of these research objectives were to make optimal investment decision in order to minimize the total travel cost in the network, while accounting for the route choice behavior of network users. Asakura and Sasaki (1990), Ortuzar and Willumsen (1991) and Yang (1997) proposed demand performance equilibrium model considering a general framework for optimal transport systems planning with integrated supply and demand. They assume that the transport system has a simple structure with three major components: economic activity *(E),* transport systems capacity *(Q)* and traffic flow *(F),* under a management system *(M).* The performance (or supply) function, which describes the level of service (*L*) of the transportation system, is defined by the revealed transport demand or traffic flow, the system capacity, and the traffic management scheme.

An O-D trip table is required for traffic assignment to evaluate highway improvement considering driver's route choice behavior. Since the early 1970's several techniques have been explored to obtain the trip table without the need for expensive surveys. Early approaches to the O-D problem relied primarily on linear (Low, 1972; Holm et al., 1976; Gaudry and Lamarre, 1979), or non-linear (Robillard, 1975; Hogberg, 1976) regression analysis to construct demand models assuming gravity-type flow patterns. These models required data on zone-specific variables such as, population, employment, and average income etc. A later group of models based their estimation of trip matrices on a network traffic equilibrium approach (Nguyen, 1977; Gur, 1980; Kurth et al., 1979), with the main aim of including the effects of congestion. Another group attempted to extract the most likely O-D trip matrix, consistent with measured link volumes, by maximum entropy or minimum information approaches (Van Zuylen and Willumsen, 1980). Another group of models utilizes the statistical techniques (Carey et al., 1981; McNeill and Hendrickson, 1985) to produce future estimates, based on prior information. Recent research has attempted techniques such as neutral networks (Muller and Reinhardt, 1990) and fuzzy weights (Xu and Chan, 1992) to solve this problem. The continued interest in this problem is evident by recent reports of further enhancements and refinements to these solutions and the wide array of techniques that are used to try to solve the problem.

Smit (2006) used two different types of emission models in his study: an average speed model and a traffic situation model. These models differ in the way in which emission factors are predicted: either continuously as a function of average speed or discretely as a function of several variables. Both types of models are used extensively in emission modeling of large road networks around the world. The average speed emission model COPERT IV (Samaras and Geivanidis, 2005; LAT, 2006) is (and has been) extensively used for network emission modeling in Europe and other parts of the world (e.g., Zachariadis and Samaras, 1999; Corvala'n et al., 2002).

Mobile-6 is a program designed by the U. S. Environmental Protection Agency (EPA) that estimates current and future emissions from highway vehicles. Integrated with a couple of air pollution models, it allows the planner to calculate emissions based on vehicle types, average traffic speeds, temperatures, etc. The Caliper Mobile-6 application provides an interface to prepare data layers and to configure various parameters needed to run the Mobile-6 program, and display emissions results geographically using chart themes. It requires a highway network and associated flow/ speed table as a result of traffic assignment to the network. Survey and investigations of methodologies for monetary evaluation of environmental impacts have been accumulated all over the world but the estimated values of unit cost themselves can be hardly said to be stable.

After reviewing the existing literature, this paper originally attempts to propose a new model to estimate relatively reliable O-D trip matrices and by using these matrices a new method is described with a case study to evaluate the maximum possible reduction of environmental emissions from vehicular traffic by programming the highway maintenance work in Bangladesh. This type of evaluation of environmental emissions for optimizing the highway improvement program in this study will contribute to reducing the negative environmental impact or loads of the highway network in Bangladesh in terms of sustainability. The most important and new consideration of this study is as follows:

1) In O-D estimation, the unknown variable is O-D volume (not the link volume)
2) In traffic assignment, capacity of highway link and parameter of BPR function are changeable according to maintenance level (road condition or more specifically IRI)

3. Transportation network and data

In view of constraints, like computational facilities, time and information resources, the study is dedicated only to simple and small regional highway networks of Bangladesh named Chittagong region (Figure1). The highway network consists of 21 links including a centroid connector and 6 nodes or districts as origin or destination points from where trips are generated. Traffic count data has been collected by the Roads and Highways Department (RHD) from 16 stations located at the middle of links of the highway networks. There are two types of highway used in this study: national highway and regional highway.

Manual Classified Count (MCC) procedures have to be rigorously followed in all counts. The MCC involves counting all the vehicles passing a selected location on a road for a pre-determined period of time. The count can be for any duration, but is usually conducted for sixteen or twenty four hours in a day, and for three or four days consecutively. The count is conducted by persons standing at the roadside and recording passing vehicles on a form, hence the term "*manual traffic count*". This distinguishes it from counts by machines that can record passing vehicles automatically, which are known as "*automatic traffic counts*". The count records individual vehicles by categories (i.e. a truck or car) and the direction they are travelling in. This is the reason for being *"classified count"*. Most MCC take place in November/December as part of the Roads and Highways Department's annual nation-wide traffic census in Bangladesh.

Maintenance of roads is dependent on several factors, one of which is the condition of the pavement surface.

To determine what treatment is necessary the condition of the surface is to be known. Roughness is the measurement of riding quality, which in turn is the effect of total surface deterioration. Roughness of roads in terms of IRI has the greatest influence in the priority listing of the annual highway maintenance programme. So, correct measurement of roughness is a prerequisite for doing the correct annual highway maintenance programming. Roughness measurement is done annually preferably from October to December (to avoid rain) by the Roads and Highways Department.

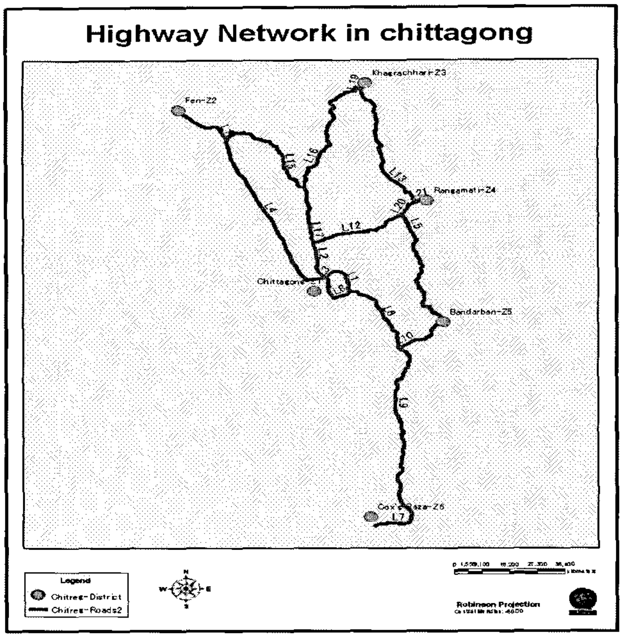

Figure 1: Transportation network.

4. Methodology

A road network is a complex thing and to optimize spending over the total network is a major task. It is certainly beyond the power of an individual or group of people but modern computers and systems have made it possible to analyze complex road maintenance operations. Any road planning exercise whether manual or computerized requires information on the construction, location and condition of the roads and bridges, information on traffic and information on existing and planned projects. The optimum road maintenance strategy is determined based on the economic and environmental evaluation, which is calculated with link volume and link speed both of which are obtained from the traffic assignment procedure. However, since the O-D demand data is required to conduct the traffic assignment procedure, we firstly estimate the O-D demand from traffic count data and load network data. The flowchart of the procedure is described in Figure 2 and each procedure is explained from the next section.

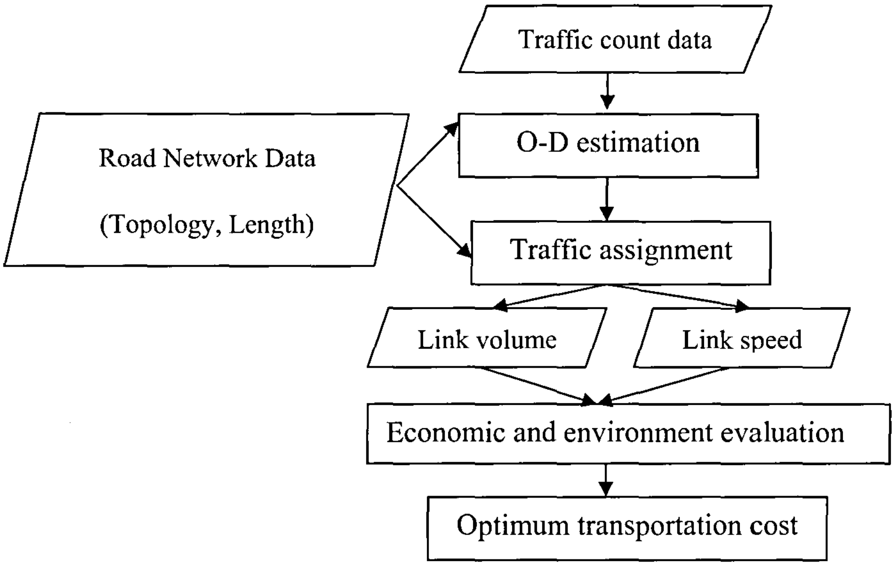

Figure 2: Flow diagram for evaluation.

4.1. O-D trip demand matrix estimation

4.1.1. Problem specification

A network representation of the transport system of the region has been considered in this study. The transportation system consists of a number of directed transport links that are connected to each other at nodes. The different parts of the region are represented as zones, with centroids in which traffic originates and terminates. The centroids constitute a subset of the nodes of the region. From the assignment of the O-D matrix one thus obtains the traffic volume on each transportation link: the flow according to the selected assignment procedure. One may, however, pose the inverse of the assignment problem: find an O-D matrix which, when assigned to the transportation network, reproduces the observed traffic counts.

The estimation of O-D matrices from link count data has the following property, with the basic equation expressing the relationship between O-D traffic volume and traffic link flow:

$$V_a = \sum_{i \in I} \sum_{j \in I} T_{ij} p_{ij}^a \qquad \forall a \in A \tag{1}$$

Where A is a set of links, V_a is the traffic flow of the link a, T_{ij} is a traffic volume of an O-D pair going from origin i to destination j, and p^a_{ij} is the proportion of link a used by O-D traffic volume going from i to j. In this case p^a_{ij} is assumed to be independent of traffic volumes, i.e. congestion. In other words, the proportion of drivers choosing each route depends on uncongested travel time of each route but not on flow levels. Equation (1) holds for all links a ; thus the number of equations is equal to the number of links comprising the network. The estimation of the O-D matrices from link traffic count finds $n \times n$ unknown O-D Traffic volume T_{ij}, where n is the number of centroids. Even though the inner-traffic volume of each zone is eliminated, there remains $n \times (n-1)$ unknown O-D traffic T_{ij} to be determined. But for general road or highway networks, the number of O-D variables is usually more than the number of the links comprising the road or highway network of a region.

The above problem is an under defined problem in which we cannot find a unique O-D traffic pattern $\{T_{ij}\}$ using only link traffic count data and is a characteristic of estimating an O-D matrix from link count data. We cannot estimate the O-D matrices using only link traffic counts because information contained in the link traffic counts is insufficient. Some other information or constraints like traffic behavior must be added in order to find unique O-D matrices.

The estimation problem is further complicated by the fact that often traffic counts are obtained on different occasion (hours, days, weeks) are likely to have inconsistencies in the flow. In other words, the expected flow continuity relationship will not be met. It should be possible to write, for each node m, flow continuity equations of the type:

$$\sum_{l \in In(m)} V_{lm} - \sum_{k \in Out(m)} V_{mk} = 0 \qquad \forall m \in I \tag{2}$$

Where I is a set of nodes and $In(m)$ and $Out(m)$ is the set of nodes going into node m and the set of nodes going out from node m respectively.

It is possible to indentify several sources for inconsistencies in the link flows. The first one is simply the fact that errors in the counts may lead to situations in which the total flow into a node does not equal the total flow out of the same node, thus not meeting link flow continuity conditions. The second source is a mismatch between the assumed traffic assignment model and observed flows. For example, an assignment model may allocate no trips on a link having observed (perhaps small) flow. In these conditions, there will be no trip matrix capable of reproducing the observed link flows using that route choice model.

4.1.2. Inconsistency minimization model

In most study areas, the problem of estimating the O-D trip matrix is underspecified and it is therefore impossible to uniquely determine a trip matrix by using link traffic count data only. However, assumptions about trip making behaviour may help to reduce the number of unknown variables. The different techniques which have been proposed differ on the nature of assumption. One of the alternative approaches to estimation of a trip matrix from traffic count is utilization of quadratic programming with inconsistency minimization as an objective function in an optimization model. In this way the number of unknown variables is dramatically reduced and the problem now becomes determined.

Proposed inconsistency minimization model is as follows:

$$\underset{T_{ij}}{Min}\ S = \underset{T_{ij}}{Min} \sum_{a \in A} \left(V_a - \sum_{i \in I} \sum_{j \in I} T_{ij} p_{ij} \right)^2 \tag{3}$$

Subject to

$$V_r - \sum_{i \in I} \sum_{j \in I} T_{ijr}\, p_{ijr} = 0, \quad \forall r \in R \tag{4}$$

Where T_{ij} is the O-D trip pairs to be estimated, V_a is traffic volume at link a, V_r is traffic volume at reliable link $r \in R$, p_{ijr} is the proportion of O-D trips ij using link a. Since some of the traffic count data in the study area includes considerable error, we classify the set of links as reliable $r \in R$ and $u \in \{A\text{-}R\}$. The reliable links are those links (national highway) where every vehicle type is counted by a different person and the unreliable links are those links (regional highway) where all vehicle types are counted by only one person.

4.2. Traffic assignment

The O-D trip matrix estimated from traffic count data is used to solve user equilibrium assignment based on Wardrop's equal travel time principle. The user equilibrium assignment can be expressed by mathematical problem of optimization as follows:

$$\underset{T_a}{Min} \quad Z = \underset{T_a}{Min} \sum_{a \in A} \int_0^{x_a} t_a(w)\,dw \tag{5}$$

Subject to

$$\sum_{k \in K_{rs}} f_k^{rs} - Q_{rs} = 0 \tag{6}$$

$$x_a = \sum_{rs \in W} \sum_{k \in K_{rs}} \delta_{ak}^{rs} f_k^{rs} \quad , \forall a \in A \tag{7}$$

$$f_k^{rs} \geq 0 \tag{8}$$

Where f^{rs}_k is the traffic flow on the route k between the O-D pair rs, Q_{rs} is O-D trips r and s estimated from traffic count using previously described model, x_a traffic flow, δ^{rs}_{ak} dummy variable, which is 1 when route k between O-D pair rs contains link a, 0 otherwise, t_a is link cost function which is assumed to be below BPR formulae.

$$t_a(x_a, y_a) = t_{a0}\{1 + \alpha\left(\frac{x_a}{c_a + y_a}\right)^{\beta}\} \tag{9}$$

Where t_{a0} is free flow speed, α and β is parameter estimated by interpolating using the values from Table 1 (http:sierrafoot.org/local/gp engineering.html). x_a is traffic volume, y_a is improvement of capacity of link due to the road maintenance which increases the free flow speed as a result of decreasing IRI, since free flow speed is related to road roughness (IRI) (RHD Road user cost report 2004-5). In Eq. 9, improvement of road roughness increases free flow speed and thereby increases the capacity of the link.

Table 1: Updated BPR parameter using HCM procedure.

Co-efficient	Freeways			Multilane		
	70 mph	60 mph	50 mph	70 mph	60 mph	50 mph
α	0.88	0.83	0.56	1.00	0.83	0.71
β	9.80	5.50	3.60	5.40	2.70	2.10

Maintenance does have an effect on the operation level of the highway network, since pavement roughness has been connected to vehicle speed, thus affecting traffic volume (Karan and Haas, 1976). In this study, capacity of a link is assumed to be changeable with respect to maintenance and therefore determined by Free Flow Speed of the link (according to its IRI). The value of Table 2 has been estimated from Table 1, Table 11.10a in Highway Capacity Manual (2000), and Table 3.22 in RHD Road User Cost Report (2004).

Table 2: Estimated value by interpolation.

IRI	Speed(km/h)	Speed(mph)	Capacity	alpha	Beta	QV type
4	55	34.155	19000	0.57	1.95	5
6	54	33.534	18000	0.56	1.95	4
8	50	31.05	16000	0.54	1.94	3
10	47	29.187	15000	0.52	1.93	2
12	45	27.945	14000	0.5	1.92	1
2	65	40.365	22000	0.62	1.97	6

Environmental impacts were calculated with formulae listed in Table 3. The value closest to the link travel speed, obtained from the user equilibrium traffic assignment estimation, should be selected as the vehicle speed mentioned in Table 3, because estimated link travel speed would usually be different from the value mentioned in Table 3.

Table 3: Emission estimation formulae.

Speed(Km/hr)	NO_x emission volume (g/km/day)	CO_2 emission volume (g/km/day)
10	$(0.34a_1+3.79a_2)Q$	$(99a_1+237a_2)Q$
20	$(0.29a_1+3.33)Q$	$(67a_1+182a_2)Q$
30	$(0.24a_1+2.87a_2)Q$	$(54a_1+155a_2)Q$
40	$(0.20a_1+2.41a_2)Q$	$(46a_1+137a_2)Q$
50	$(0.21a_1+2.16a_2)Q$	$(42a_1+127a_2)Q$
60	$(0.23a_1+1.90a_2)Q$	$(40a_1+122a_2)Q$
70	$(0.25a_1+2.10a_2)Q$	$(39a_1+123a_2)Q$
80	$(0.27a_1+2.29a_2)Q$	$(40a_1+129a_2)Q$

Q= Traffic volume(Vehicle/day), a_1=Share of small vehicle in traffic, a_2=Share of large vehicle ($a_1+a_2=1$) in traffic.

Note that the link volumes obtained from the traffic assignment might not be consistent with the input of O-D estimation procedure, but we don't consider the inconsistency hereafter.

4.3. Scenario analysis

In this study scenario analysis has been selected for highway maintenance or improvement planning. Scenario analysis is a process of analyzing possible future events by considering alternative possible outcomes (scenarios). The analysis is designed to allow improved decision-making by allowing consideration of outcomes and their implications. Scenario planning (or scenario thinking or scenario analysis) here means the strategic planning method that some organizations use to make flexible long-term plans. The original method was that a group of analysts would generate simulation games for policy makers. Scenario planning excels especially if it includes systems thinking, which recognizes that many factors may combine in complex ways to create sometimes a surprising future (due to non-linear feedback loops). The method also allows the inclusion of factors that are difficult to formalize.

Economic and environmental evaluation has been made by estimating the economic benefit and environmental emissions savings. Economic benefit has been calculated by deducting total user cost produced by the scenario with an individual link with maintenance effect from total user cost produced by the base scenario (no maintenance). Traffic assignment without maintaining the highway has been considered as a base scenario. Similarly environmental emissions savings have been calculated by deducting total emissions produced by the scenario with an individual link maintenance effect from total emissions produced by the base scenario.

An algorithm to solve the user equilibrium is described in chapter 10 of the user's manual of JICA STRADA version 3.0. Methods and algorithms to estimated time cost, Vehicle Operating Cost (VOC), environmental emissions, and environmental cost have been mentioned in chapter 18 of the above manual. The user cost is defined as the summation of VOC, Travel Time Cost (TTC) and Environmental Cost (EC). Each cost component can be formulated as below;

1) VOC calculation: Fixed demand type-evaluation per link:

$$VOC = \sum_{m} . \sum_{l} Q_l^m . L_l . \beta_m \tag{10}$$

Where Q_l^m: the Traffic volume of the mode m on the link l (Vehicle/day), L_l : the distance of the link l , β_m is the Cost unit per road type and velocity rank for the mode m (currency unit/ vehicle-km).

2) Travel Time Cost calculation : Fixed demand type- evaluation per link:

$$TTC = \sum_{m} . \sum_{l} Q_l^m . T_l . \alpha_m \tag{11}$$

Where Q_l^m is the Traffic volume of the mode m on the link l (Vehicle/day), T_l is the travel time on the link l, α_m is the Time value unit for the mode m

3) Environmental Cost=Emission* unit environmental cost

The unit environmental cost is defined for converting a unit of the environmental impact to the monetary value so that environmental impact can be consistently included in any evaluation task *(Guidelines for the Evaluation of Road Investment Project).*

We adopt the periodic maintenance cost as another indicator for deciding whether or not to maintain the roads. The maintenance cost (*MC*) is defined as below;

MC = Unit maintenance cost* length of the link

where the unit maintenance cost is uniformly assumed as 20 million Yen per kilometre of highway that does not depend on state of roughness of the highway and the traffic demand is irrelevant to the link LOS determined by the link improvement level as well. α_m, β_m and unit environmental cost have been assumed as the default value of JICA STRADA version 3.0.

5. Result

The origin-destination matrix has been estimated for two types of vehicle: large and small, because environmental emissions from vehicular traffic primarily depends on these two types. So bus, truck and minibus have been considered as large vehicles and other motorized vehicles have been considered as small vehicles. Table 4 shows the O-D trip matrix for large vehicles estimated by a inconsistency minimization model.

Table 4: O-D matrix for large vehicle.

Zone	Chittagong	Feni	Khagrachari	Rangamati	Bandarban	Coxbazar	Total
Chittagong	0	2768	1570	1375	1128	726	7567
Feni	2830	0	0	0	16	0	2846
Khagrachari	1713	0		0	0	0	1713
Rangamati	1506			0	0	0	1506
Bandarban	1098	157	462	0	0	0	1717
Coxbazar	977	69	0	0	0	0	1046
Total	8124	2994	2032	1375	1144	726	16395

The O-D trip demand matrix estimated from traffic count data has been used as an input to solve the user equilibrium traffic assignment problem because this data is not available from home or road side interview surveys. The environmental impacts can be estimated quantitatively from vehicle type shares (mixing ratio), vehicle speed and traffic volume. A series of formulae in Table 3 can imply the non-linear dependence of environmental impacts on these three factors. Table 5 shown below is the output of the base scenario.

Table 5: Base scenario without maintaining the highway.

No of Links	21		
Total length	571		
capacity-km	57,100,000		
	All Vehicle Types	Large Vehicle	Small Vehicle
Vehicle-km	2,488,107	1,407,639	1,080,468
Vehicle-hour	47,282.2	26,922.1	20,360.1
Time Cost(Yen/year)	8.17E+10	4.27E+10	38,988,233,608
Running Cost(Yen/year)	2.55E+10	8.31E+09	17,211,599,886
All Vehicle Types			
NO_x(g/day)	2,625,298	1,522,673 Yen/day	
Carbon Dioxide(g-c/day)	1.96E+08	450,940 Yen/day	
Noise(dB(A))	34,291	6,908,130 Yen/day	

Table 6 shows the result of economic and environmental evaluation and the first and third column of this table gives economic and environmental priority respectively for maintenance scheduling based on the amount of the economic cost and environmental emission savings.

In Table 6, the economic benefit and the environmental savings can be calculated as below:

Economic Benefit = User cost without maintenance - User cost with maintenance

Environmental Savings = Emission produced without maintenance - Emission produced with maintenance

Table 6: The result of economic and environmental evaluation.

Link	Economic Benefit (Yen/year)	Link	Emission Saving (g/day)
L4	5,998,325,387	L9	57,117
L14	2,999,162,693	L6	33,507
L16	2,772,064,205	L12	28,229
L9	1,949,212,326	L16	26,122
L6	1,714,589,211	L2	15,218
L17	1,571,392,595	L7	12,692
L12	1,361,932,254	L17	12,538
L2	1,085,310,030	L10	10,364
L10	542,377,656	L8	8,377
L13	455,023,594	L20	6,649
L7	433,158,295	L5	6,017
L8	428,659,994	L13	6,017
L5	353,216,456	L21	2,823
L20	326,363,953	L19	1,868
L19	161,248,385	L4	0
L21	136,193,225	L14	0
L15	0	L15	0

From Table 6, the economic priority of L4 and L14 is higher although the environmental priority of these links is the worst. On the other hand, not only the economic priority, but also the environmental priority of L16, L9 and L6 are relatively higher.

Next, let us find out the optimum maintenance level using Table 6. System objectives can be defined by reference to the objectives of the road administration. A typical objective in the area of road user costs might be:

Highway will be maintained, so far as budgets will allow, to minimize the sum of road user and road maintenance costs in the longer term.

This objective would need to be met by a system designed to minimize the longer-term road user and road maintenance costs in a constrained budget situation. An appropriate planning system would be required to help achieve this objective.

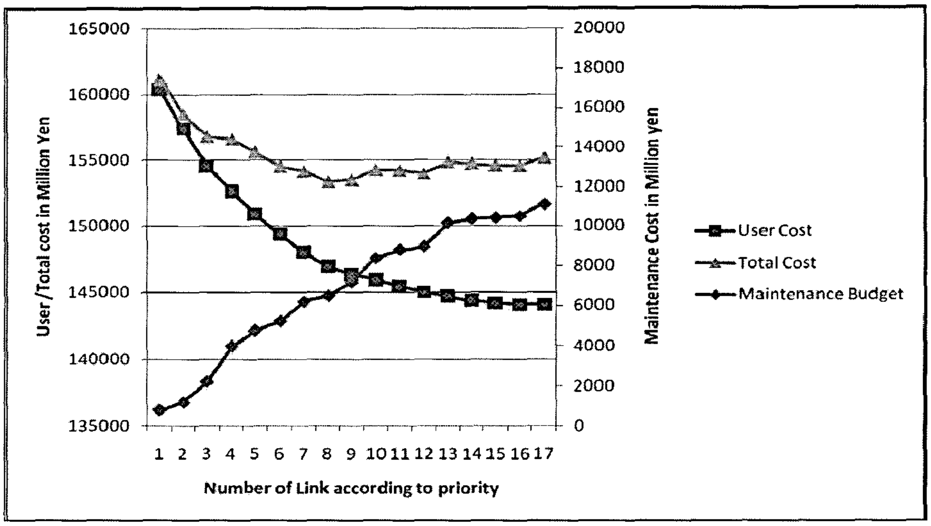

Figure 3: Estimation of optimum transportation cost.

In Figure 3, the links to be maintained (horizontal axis) are sorted by descending order of the user cost. Note that the user cost and the maintenance cost are formulated in the previous section and the total cost is defined as the summation of the user cost and the maintenance cost.

According to the results shown in Fig 3, as the number of maintained links increases, the user cost decreases whereas the maintenance budget increases. As a result, the total cost is convex downward and the optimum maintenance budget is 6300 million Yen per programme and 8 links have been selected for maintenance along with their priority (link 4, 14, 16, 9, 6, 17, 12 and 2) for maintenance scheduling to maximize economic benefit as well as to minimize environmental emissions.

6. Conclusion

Development of a proper highway improvement programme is to enable the network to withstand the damage caused by wear and tear, to prevent substandard conditions from developing, and to ensure that traffic can continue to travel, in a manner which is safe, efficient, and reliable and which causes the least damage to the environment. In order to ensure the least damage to the environment due to highway improvement a comprehensive analysis for evaluation of environmental emissions is very important for highway network design problems including highway improvement or maintenance.

Economic as well as environmental evaluation in highway improvement or maintenance planning is very helpful for making the highway investment more rational in terms of sustainability. The effect of the problem 'high road maintenance costs' can be converted into the objective of achieving 'lower road maintenance costs'. The impact of 'inefficient use of resources' can be converted into the desired result of 'effective use of resources', and the cause of 'lack of resource management' can be converted into the means of 'implementing an operations management system'.

Further study is required on integrating planning modules with vehicle emissions models. The default value offered by JICA STRADA version 3.0 may be difficult to apply to the Bangladesh circumstance. It should be developed for future study, such as re-classifying the vehicle types in Bangladesh, finding the relationship between urban traffic planning and vehicle emissions on real time speed. The number of applications of acceleration and deceleration of a vehicle should also be considered in the future study.

This study will certainly help to develop a simple and low cost planning system for highway improvement programmes in Bangladesh with proper consideration of sustainability and vulnerability issue by using estimated origin-destination trip demand matrices from readily available traffic count (both consistent and inconsistent) data.

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