Schema for Interoperable Representation of Environmental and Social Costs in Highway Construction

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Abstract: Decision makers and designers have utilized various methods for quantifying the environmental and social impacts of highway projects. However, the definition of these impacts, their costs, and their estimation methods lack interoperability. A schema is proposed to support interoperable documentation of relevant knowledge related to the environmental and social costs (E&S) of highway projects. The schema identifies the E&S impacts associated with each project element, lists possible impacted entities, provides access and description to existing methods to estimate associated E&S costs, and provides links to best practices to mitigate such impacts. The schema was encoded into an extensible markup language. The schema was developed based on a synthesis of the different ways for cost estimation, cost estimates, and best practices for managing the E&S costs of highway construction. The schema was evaluated through interviews with domain experts and through analysis of three representative case studies. An interactive Web site was developed to support project teams establish a unified view of the costs, their estimates, and best practices to control them.

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Introduction

The assessment of environmental and social (E&S) costs associated with highway construction/ rehabilitation operations is faced with several challenges as follows:

1. Lack of clear definitions: there is no clear and agreed upon definition of the E&S costs. This could be attributed to the subjectivity of the domain itself and the fact that this is an evolving domain of interest to decision makers;
2. Ambiguity in identifying relevant costs: there is no standard means to identify which costs are applicable to each project. There is also no clear means to link specific project tasks to certain environmental/social impacts;
3. Unclear boundaries: there is no agreement on the geographical extent of the E&S impacts of highway construction. While some researchers have considered the macro/global impacts, others have only considered the micro/immediate impacts; and
4. Inconsistent estimation methods: some methods use socioeconomic approaches, while others use pure technical/ engineering approaches. There is a clear inconsistency in the methods used by researchers and practitioners to estimate these costs. This is not simply due to the subjectivity of the domain, but is also a reflection of the disagreement about the extent of the impacts of a highway project on the surrounding environment.

Projects take place in different physical, legal, and political environments. It is therefore infeasible to develop a universal standard to address the aforementioned challenges—especially that research and implementations in the filed of assessing and mitigating E&S impacts are still evolving. An important step towards establishing more rigorous solutions to the challenges of E&S impacts is to consistently and effectively document knowledge gained by researchers and practitioners in dealing with them. To that end, this paper presents the results of a research project aimed at developing an extensible markup language (XML) schema to support interoperable representation of E&S impacts, costs, and best practices for managing them. The schema describes the main concepts of E&S impacts and costs along with definitions of their attributes and available methods of assessing such impacts and costs. The scope of this schema is limited to modeling existing industry practices and views on the E&S costs of highway construction activities. There is no attempt to provide/ select a standard estimate for any of the costs, or to suggest a universal method for impact mitigation as the most effective.

Developing a common schema for presenting E&S impacts, their sources, and costs in consistent manner serves the following two purposes:

1. Supporting more effective communication between project stakeholders upon addressing the E&S costs of highway construction. This research project worked on the assumption that achieving interoperability (in describing the various views of costs, their values, and impacts) is more beneficial than seeking the development of a single standard in this domain (i.e., creating a single definition and estimation method for each cost item). Using the proposed schema, project teams can collaborate (via the Internet) to select the E&S costs relevant to the project at hand, and then discuss and select the most appropriate method for estimating the costs; and
2. Providing semantic means for documenting and accessing

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knowledge about the E&S aspects of highway construction. Using the proposed schema, stakeholders can access all relevant information about E&S costs, their estimation methods, best practices for optimizing their values, and codes and regulations controlling their assessment. Project teams can use the schema to document their expertise and lessons learned.

The following sections present the research methodology, the proposed schema, a summary of the work done to validate the schema, and the implementation of the schema to support a Web-based system for collaborative identification and tracking of E&S costs. It is not feasible to list all the costs and impacts that are coded into the schema. However, noise impacts and costs will be used as a sample to demonstrate the contents of the schema.

Research Methodology

The main objectives of this research project are as follows:

1. A synthesis of E&S costs and their assessment tools. Reviewing and documenting the different methods for impact identification, cost assessment, and mitigation. Analysis of commonalities and underlying assumptions to discover/identify the interrelationships between different costs and highway features/components;
2. An interoperable schema for E&S costs of highway construction and operations. Developing a common schema for standardizing the description of costs, including their sources, impacts, estimation methods (for their values), and best practices for optimizing their values; and
3. A Web portal to support collaborative analysis and identification of E&S costs among project stakeholders.

The development of an E&S cost model for highway construction included the following five steps:

1. Information gathering: this included reviews of relevant text books, research papers, industry manuals, public records, and interviews with practitioners. The research developed a synthesis of current practices in the identification, assessment, and management of E&S costs;
2. Concept categorization: information gathered was organized into different maps to study/identify overlaps and common themes for the definitions of costs, their impacts, and their estimation methods;
3. Schema development: unified modeling language (UML) diagrams were developed to model the interaction between costs, their attributes, estimation methods, causes, and impacted entities. The model was then encoded into XML;
4. Schema evaluation: three cases studies were conducted to test the relevance of schema concepts to those actually used by practitioners. Eighteen experts were surveyed to test the relevance and adequacy of the proposed schema. Survey participants were chosen based on the relevance and depth of their experience. The survey was carried out in two stages. First round survey responses helped in refining the survey questions for the second round; and
5. Implementation: based on the proposed schema, an interactive Web-based system was developed to support the exchange of knowledge in this domain.

Schema Outline

The basic model for the proposed schema is as follows (see Fig. 1): each *feature/component* of a highway project (such as layout, number of bridges, number of lanes, width of shoulders) is a *source* of an environmental or social *impact*. Impacts can be short term or long term. Impacts affect a set of *entities* in the environment and the social system surrounding it. The *costs* of each *impact* (on relevant *entities*) can be estimated through different *methods*. Based on their accumulated knowledge, project teams can utilize several *best practices* to manage/optimize the impacts and their costs.

The proposed schema includes the following root concepts:

1. E&S impacts: all possible effects or consequences of highway construction on elements of the environment and social system;
2. Impact sources: project elements that may cause or increase the E&S impacts of a highway project;
3. Impacted entity: E&S elements that could be impacted due to the construction work;
4. Estimation method: relevant estimation methods for each cost;
5. E&S costs: definition of the costs associated with each impact;
6. Codes and regulation: a listing of all code sections that are applicable to costs, impacts, or entities; and
7. Best management practices: best strategies for controlling E&S costs.

The following sections provide more details on these root concepts. Throughout the paper, “noise costs” will be used as a sample for illustrating the schema.

E&S Impacts

Road systems produce a mixture of impacts on the environment and surrounding community. These range from the polluting impacts of some materials (i.e., particles and chemicals produced during the construction, operation, and maintenance to noise (sounds due to construction and operation), and urban sprawl. The research team identified over 64 possible E&S impacts of highway construction. These were categorized under nine major classes of impacts as shown in Table 1. Table 1 also shows the relative importance of these impact classes as assessed by industry experts, during the validation interviews. The experts were asked to rate the relative importance based on a scale of 1–6 (where 6=most important).

Sources of Impact

The sources of impacts can be divided into long-term sources and short-term sources. Long-term sources of impacts are those related to and produced by the highway itself. Highway *design features* (such as layout, capacity, and pavement materials) are the first source of impacts. They have direct influence on the production of possibly damaging impacts on the long term (during operation of the highway). Highway *construction activities* are sources of impacts in the short term (during construction). They can produce emissions, noise, and may damage sensitive ecosystems. Proper selection of construction sequence, materials, and equipment could reduce the impacts of construction work on the local environment. Even though construction disturbance is considered a short-term source of impacts, it could produce long lasting impacts such as the erosion effect (if construction waste is not disposed off properly). The research identified 23 impact sources that could be caused by construction activities. These

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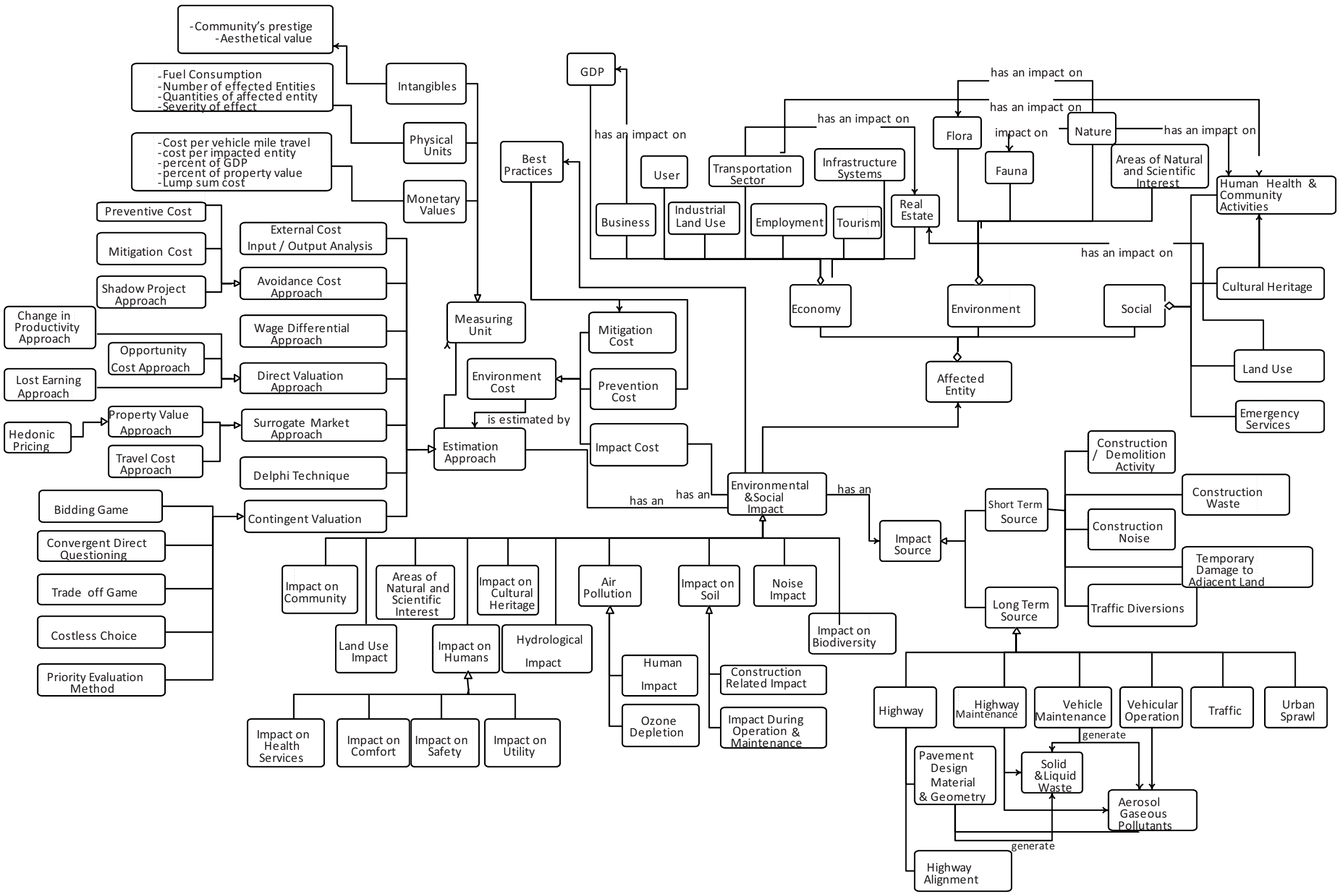

Fig. 1. Abstract view of proposed schema

were clustered under eight major classes as shown in Table 2. Table 2 also shows the relative importance of these sources as assessed by experts during the validation interviews. Construction noise, traffic diversions, congestion, and delays were ranked most problematic. Careful preproject planning and public involvement programs were identified as some of the best practices in addressing these impacts.

The *operation and maintenance activities* of the highway also produce several impacts in the long term. Fifty two long-term sources were included in the schema and are classified into 15 major classes as shown in Table 2 (Sources 9–23). Out of these, the following were ranked highest by the interviewees: urban sprawl, traffic, and vehicular emissions. Urban sprawl is considered by many to encourage greater travel demand and consumption of additional resources. The relationship of highway development and sprawl is complex, and cannot be directly evaluated by cause-effect relations.

Table 1. E&S Impacts and Their Relative Importance

	Impact	Relative importance
1	Air pollution impact	5.21
2	Water quality degradation	4.87
3	Hydrological impact	4.73
4	Impact on soil	4.27
5	Impact on biodiversity	4.73
6	Impact on human health	5.27
7	Impact on human comfort (noise, roadside safety, etc.)	5.27
8	Impact on cultural heritage	4.60
9	Land use impact	4.60

Note: Rating scale is 1–6; 1=insignificant and 6=very important.

Impacted Entities

The schema lists all possible impacted entities. These entities include physical entities such as humans and environmental elements (for example, air, water, fauna, soil) and tacit entities such as local heritage.

To illustrate, the impacts of highway construction on local heritage include:

1. Direct impact: such as structural damage to buildings or encroachment on/fragmentation of sites; and
2. Indirect impact: impact due to improvement in access to site (the impact could be positive or negative depending on the nature of the site), or due to other environmental externalities such as air pollution and noise.

Considering the noise impacts of highway construction, the schema identified the following entities that could be impacted (see Fig. 2):

1. Human welfare: chronic noise exposure can be a source of annoyance, creating communication problems and leading to

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Table 2. Impact Sources

Number	Source	Relative weight
	Construction sources	
1	Side tipping of construction materials	3.20
2	Side tipping of waste materials	3.30
3	Impacts due to the use of heavy machinery	3.50
4	Gaseous emissions from construction machinery	3.30
5	Aerosol emissions from construction machinery	3.20
6	Aerosol emissions from onsite construction related activities	3.20
7	Temporary damage to adjacent land	3.60
8	Construction disruption (e.g., noise, traffic diversions, etc.)	4.30
	Project (extended) sources	
9	Pavement design (materials & geometry)	3.30
10	Highway alignment	4.10
11	Impact due to mining/quarrying (for materials)	3.50
12	Waste from maintenance operations	3.50
13	High turbidity and toxicity of storm water runoff	4.30
14	Pavement markings	2.10
15	De-icing during winters	4.30
16	Leaded fuel	4.70
17	Deposition of Zn and Cd from vehicle tires	4.00
18	Vehicle brakes	3.80
19	Engine wear	3.30
20	Vehicular emissions (CO_2, CO, SO_2, NO_x, VOC, CH_4, CFCs, heavy metals, aerosol)	5.00
21	Vehicle maintenance (lubricants, oils)	3.60
22	Traffic (vehicle noise, road noise, drivers behavior, unregulated traffic)	5.30
23	Urban sprawl	5.67

Note: Rating scale is 1–6; 1=insignificant and 6=very important.

elevated stress levels, as well as associated behavioral and health effects.

2. Structures: the vibrations induced by the resonance of traffic noise can have a diverse effect on structures present near the road—especially historical buildings;
3. Wildlife: noise may prevent the natural/free movement of many animal species resulting in an ecological alteration;
4. Property value: highway noise may contribute to lowering the value of adjacent properties; and
5. Value of recreational spaces: noise reduces the natural feeling of parks and other recreational areas, hence reducing their value to the users.

E&S Costs

E&S costs span a wide spectrum that extends over the life cycle of a highway. To facilitate accurate description of these costs, the schema utilizes a set of main cost types that act as meta concepts. These include the following:

Extent/Control Level Dimension

Costs can be categorized based on their type as follows:

1. Preventive cost: the cost of eliminating an impact completely by incorporating alternative designs, construction methods or operation policies. The cost type has the following subtypes:
   a. Direct asset replacement cost: costs to replace or change a design feature or a construction activity. For example, the cost of realigning a highway (to protect an entity), the cost of treating the waste before disposal, etc.; and
   b. Relocation cost: costs to relocate environmentally sensitive entities (such as a heritage building) from the path of the highway.
2. Damage cost: while preventive cost relates to avoiding any negative impacts, damage cost refers to costs that occur when an impact is not prevented. This cost is further classified into:
   a. External cost: costs that are incurred by an entity to cope with the consequences of the highway construction. This may include expenses to meet the health consequences of noise, pollution, or a reduction in real estate value; and
   b. Compensation cost: in cases where a clear impact can be identified, compensation costs could be paid to the impacted entity.
3. Mitigation cost (hybrid of preventive and damage cost): the cost of alleviating the impact to a desirable extent before or after the impact has occurred. The examples of such costs could be the cost of building a noise barrier wall, improved quality of fuels to reduce air emissions, etc.

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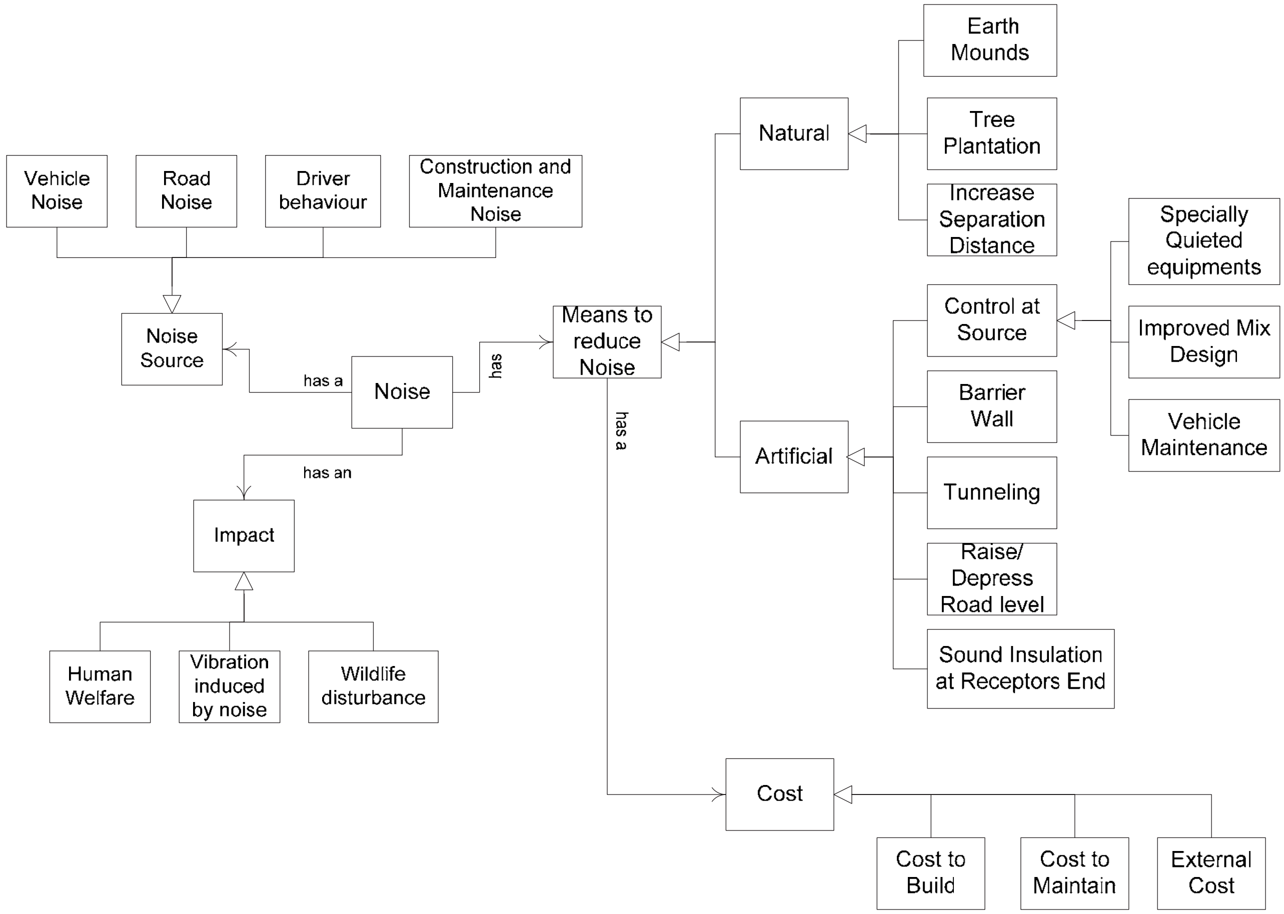

Fig. 2. "Noise" component in proposed schema

Temporal Dimension

This type classifies costs according to their time of occurrence. It includes two main subtypes:

1. Costs during construction: E&S costs associated with the construction phase; and
2. Costs during operation: E&S costs associated with the operation phase.

Highway Element Dimension

E&S costs directly related to a specific design feature. This includes:

1. Costs related to physical features: costs related to the layout and its extent; and
2. Costs related to material use: costs associated with certain materials (concrete versus steel, for example).

Technical Dimension

This represents the main domains for costs sorted by their technical domains, such as noise cost, health costs, user costs, etc.

Entity Dimension

Costs can also be categorized based on the entities that incur them, for example, social costs (costs to the society), environmental costs, and economic costs.

Cost Estimation Methods/Approaches

A set of relevant methods/approaches have been used to estimate E&S costs. The schema classifies these methods into six major classes as shown in Table 3 (compiled from Tsunokawa and Hoban 1997; Dixon and Hufschimidt 1986; Gilpin 2000; King and Mazzotta 2004). Table 3 also lists E&S costs where each method could be applied.

Direct Estimation Method

This method is used to evaluate costs that are fairly explicit and can be estimated based on available data. This method is mainly used to evaluate costs on the local level—for example, the cost to change the layout of a highway, or the cost to stabilize slopes. With some judgment calls, this approach can also be used to estimate less tangible costs such as damage to fisheries and/or wetlands.

Shadow Project Method

This method is also used to estimate costs on the local level. It is used to estimate less tangible issues, such as impacts on habitat, local heritage, and the value of recreational spaces. The method compares the impacts of the current project with a hypothetical (shadow) project that can produce less impacts.

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Table 3. Applicability of Valuation Technique

Method		Applicability of valuation technique
Direct estimation approach		Air pollution Cost of erosion protection and water purification services of wetlands Destabilization of slopes Water/soil contamination (cost to treat drinking water contaminated by highway runoff) Potential physical damage to the property Encroachment on ANSIs[a] Impact on fisheries Valuing noise protection (by measuring the cost of building barrier wall) Property losses, cleaning or painting structural surfaces spoiled by air pollution Plantation, agricultural land, wetland
Shadow project approach		Habitat area degradation Impact on fisheries Cost of supplying alternate recreational facilities
Input-output analysis		Macro impacts on the economy Macro impacts on the environment
Economic valuation approach	Change in productivity approach	Soil erosion (that can also effect downstream water quality) Habitat loss Impact on water supply or impact on groundwater recharge or discharge area Impact on waterways Effect on agricultural output, on fisheries, or on benefits of wetland Water and soil contamination Loss in local businesses Encroachment on ANSIs Impact on cultural heritage
	Opportunity cost approach	Encroachment on ANSIs Impact on cultural heritage Effect on agricultural land and wetland Soil contamination and erosion, and water course contamination Species degradation or species loss Impact on fisheries Impact of uncontrolled highway runoff
	Lost earning approach	Health hazard Businesses' losses
Surrogate market technique	Hedonic price method	Overall environmental quality (air pollution, water pollution, noise pollution, odor) Living condition (housing quality) Visual impact Noise valuation
	Travel cost approach	Restriction of access (increased transportation cost and travel time) Visual impact Elimination of existing recreation site Change in environmental quality at a recreational site Improved access to recreational site
	Wage differential approach	Health impact Visual impact
Contingent valuation approach		Non market goods Overall environmental quality (air pollution, water pollution, noise pollution, odor) Living condition (housing quality) Visual impact Noise valuation Species degradation Reduced water quality Water and soil contamination Impact on community structure Encroachment on ANSIs Impact on cultural heritage Construction disruption Health hazard due to air pollution

[a]ANSIs = areas of natural and scientific interest, and is adopted from the environmental assessment term of reference document of mid-peninsula transportation corridor prepared by MTO (Ontario Ministry of Transportation).

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Economic Valuation Approach

This approach is used in assessing the economic impacts of highways. It uses three production changes that evaluate the economic losses and gains associated with highway construction:

1. Change in productivity approach: direct value changes in output of economic assets due to wasted time or a reduction in productivity;
2. Opportunity cost approach: the lost market value of a physical asset, such as a house, due to proximity to a highway; and
3. The lost earnings approach: reduction in people's output and subsequent loss of earnings.

Input/Output Analysis

This approach deals with the macro impacts/costs of highways on the economy and the environment. The economic input-output analysis accounts for all of the direct and indirect inputs in producing a product or services by using the input-output matrices of a national economy. The environmental input-output analysis complements the economic input-output by linking economic data with resources as an input and environmental degradation as an output. The approach depends on calculating the embodied energy of the road construction and then converting it into environmental load (Horvath and Hendrickson 1998; Hendrickson and Horvath 2000; Matthews et al. 2001; Park et al. 2003; Treloar et al. 2004). The environmental cost can thus be determined by multiplying the environmental load (emission values) with its unit damage cost.

Surrogate Market Approach

This is an indirect method of estimation, which is used when the direct estimation of economic impacts is impossible. The most commonly used techniques are as follows:

1. Hedonic pricing approach: this approach is also referred to as the property valuation approach. This approach is used to estimate the change in property values due to the adverse environmental impacts such as noise, air pollution, quality of surrounding environment, property access, etc. The basic assumption of this approach is that if the quality and character of a house (with a similar cost of construction) are kept constant, then the difference in market price is due to the surrounding environment. However, other controlling factors also exist, such as better schools, shopping centers, recreational facilities, entertainment, law and order situations, having good neighbors and the better reputation of an area (Gilpin 2000).
2. Travel cost approach: this method considers the costs and time spent by system users in accessing areas of interests (ecosystem, landscape, cultural heritage, etc.) (Friedrich and Bickel 2001). "Travel costs from each concentric zone around the site are used as a surrogate for price, the quantity being determined by actually counting the number of visitors from each zone" (Gilpin 2000); and
3. Wage differential approach: this approach is very similar to the Hedonic pricing method; as "it uses wage differentials in place of property prices as a guide to the values that people assign to environmental qualities, and workers are assumed to be able to choose freely between jobs in different areas at wages that will maximize utility for them" (Gilpin 2000). Wage differential approach can also be defined as the "estimation of willingness of workers to trade off wages for improved environmental quality" (Dixon and Hufschmidt 1986).

Contingent Valuation

Also known as "hypothetical valuation," this approach is used in the absence of information about people's preferences or when there is absolutely no direct way of allocating cost value on less tangible items (like visual impact). This approach sets up a hypothetical market through questionnaires or other techniques for soliciting expert input (Friedrich and Bickel 2001). This approach is basically comprised of a survey of willingness to pay (WTP) for benefits or willingness to accept (WTA) as compensation for toleration of annoyance. Experience shows the value of WTA to be several times greater than WTP. This approach has several forms as follows (Gilpin 2000):

1. Bidding game: individuals are directly asked how much they are ready to pay to enjoy or preserve a particular environmental feature. The surveyor could ask for a single bid, or an open-ended bid, and get individual WTP or minimum WTA values;
2. Convergent direct questioning: each individual is given two values, a high value (which is likely to exceed any reasonable WTP) and a low value (which certainly would be paid). The individual is given some reasonable value to find his/her WTP. If the individual's response is yes, then the value is increased until the response turns into no. If the individual response is no for the first given value, then the amount is decreased until the response turns into yes;
3. Trade-off game: each individual is given two items: a certain amount of money, and an environmental feature. The individual is then asked to choose between the items. The point of indifference defines the value of the environmental feature;
4. Costless choice or moneyless choices: this approach is similar to the trade-off game. However, specified commodities are used instead of money. This could be suitable for individuals with better economies. The point of indifference will identify the almost equivalent commodity to the environmental good, and the current market price of the commodity chosen will give the economic value of the environmental good;
5. Priority evaluation method: an individual is given a hypothetical sum of money to spend on conventional goods and environmental amenities at assumed prices. Because the individuals' choice is constrained by the limited budget, it will reflect true preferences. Marginal value can then be estimated from these findings; and
6. Delphi technique: the concept of the Delphi technique is to arrive at an economic value of environmental assets by asking experts' opinions. The technique consists of a series of questionnaires through successive rounds of continuous refinements until the group agrees on a certain value. Experts' knowledge and background, and proficiency in the use of this technique, play an important role, and can affect the quality of outcome to a great extent.

Sample Case: Noise Costs

To illustrate the contents of the schema, this section provides a summary of cost estimation for a sample impact: noise. There is no globally accepted formula of calculating the value of noise

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Table 4. Estimates of External Cost of (Road) Traffic Noise (Adapted from Verhoef 1994)

Country	Year	Percent GDP (%)	Method
Norway	1983	0.22	Property value loss
		0.17	Sleep loss
		0.07	Existing protection
		0.12	Potential vehicle control
Germany	1987	0.15	Productivity losses
France	1986	0.04	Property value loss
The Netherlands	1987	0.02	Government expenditure on abatement
		0.02	Property value loss
General Europe	1983	0.1–0.2	Comparison of studies
The Netherlands	1988	0.03–0.08	Extra prevention and remaining property value loss
The Netherlands	1983	0.03–0.08	Potential insulation program
		0.12–0.24	Potential source control
Germany	1991	0.03	Avoidance cost
		0.52	Willingness to pay
Germany	1986	0.04–0.10	Avoidance cost
		0.02–0.05	Property value loss

impacts. Researchers have mostly used the hedonic price method (HPM) and the contingent valuation method (CVM) for calculating noise costs.

On the micro level (local level), researchers have used reduction in property values as a means for estimating noise costs. This included correlating the increase in noise to property value depreciation. The impacts averaged 0.5% for Organization of Economic Cooperation and Development (OECD) countries and ranged between 0.15% (in North Virginia) and 1.26% (in Basel, Switzerland).

OECD recommends a depreciation of 0.5% in property value per dB increase if levels are above 50 dB. Other researchers have estimated the costs based on the increase, in the number of vehicles using the highway. For example, Bagby (1980), estimated a range of 5–25% reduction in property value for an increase in a few hundred vehicles

Other estimates provide a total impact of noise on all elements (including property values). For example, Bein (1997), represented the impact of noise above 50–65 dB(A) at an average value of Canadian $1,000–$1,500 or more per affected person, per year, for the residences in close proximity to a busy highway. Litman (2003) used vehicle-mile to estimate the overall impacts of noise. He estimated that to be around United States $0.002–$0.06 (1996$) per vehicle-mile based on the various studies on noise cost.

On the macro level, several estimation methods and values have been generated for the impacts of increasing noise on the GDP as shown in Table 4 (adopted from Verhoef 1994). Some estimates (such as that of Lambert 1997) present noise cost as a function of vehicle mode (cars, trucks, and motorcycles) for an increase of 1 dB(A) in noise level. Soguel (1991) estimated road traffic noise cost in Neuchâtel, Switzerland. The cost per dwelling exposed to noise per year was estimated at 362 European currency unit (ECU), (the predecessor of euro). The cost per inhabitant exposed to noise levels exceeding 60 dB(A)/year was estimated to range between 158 and 366 ECU. The costs per 100 vehicle km was estimated at 1.67 ECU for passenger cars (accounting for 75.3% of total noise cost). For motorcycles, lorries, and busses, the cost was 2.1, 2.38, and 2.2 ECU, respectively. Bjørner et al. (2003) studied traffic noise impact in Denmark and estimated the value of noise reduction by the HPM and by the CVM (WTP). The results of their study are shown in Table 5.

The following estimation method is adopted from a research project conducted by Ozbay et al. (2001) for the New Jersey Department of Transportation (NJDOT). The subsequent formulas can be used for estimating depreciation in value of residential units as a result of traffic noise

$$\mathrm{ND} = N_h \,.\, (L_{\mathrm{eq}} - L_{\max}) \,.\, D \,.\, W_{\mathrm{avg}}$$

where ND=house value depreciation due to noise ($); N_h =number of houses affected by noise (number of houses per acre); L_{eq}=equivalent noise level in dB(A); $L_{\max}$=maximum acceptable noise level in dB(A)=50 dB(A) assumed; D =percentage reduction in value of residential unit per dB(A) increase in the ambient noise level [0.40%, as recommended by Nelson (1982)]; and W_{avg}=average house value ($)

Table 5. Impact Valuation for 1 dB(A) Reduction in Noise Level through Contingent Valuation (CV) Method and Dwelling Price Change (HPM) (Adapted from Bjørner et al. 2003)

Noise level dB(A)	WTP from CV [DKK/dB(A)/household/year(Euro)]	P_{HPM} at 2% p.a. [DKK/dB(A)/household/ year (Euro)]	P_{HPM} at 4% p.a. [DKK/dB(A)/household/year (Euro)]
50	9.52 (1.28)	—	—
60	28.65 (3.86)	86.66 (11.63)	173.32 (23.26)
70	62.80 (8.45)	103.84 (13.94)	207.68 (27.88)

Note: DKK=Danish krone; WTP=willingness to pay; P=price; values in bracket are in Euro/dB(A)/household/year.

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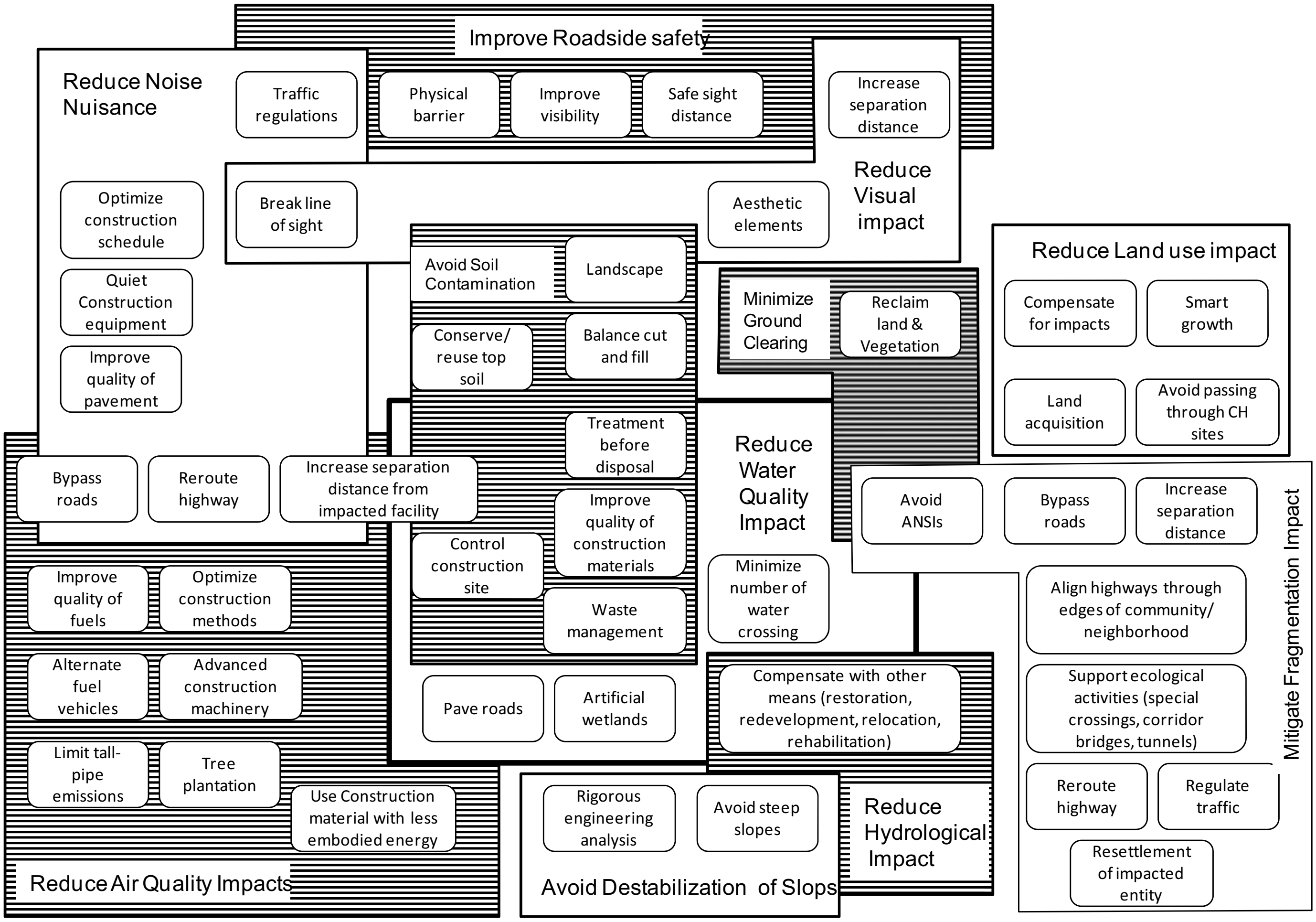

Fig. 3. Map of best practices

$$L_{eq} = 10 \,.\, \log Q - 10 \,.\, \log r_1 + 20 \log V + 20$$

where Q=traffic flow (veh/h); $Q \geqslant 1{,}000$ veh/h; r_1=distance to the highway (ft); and V=average speed of the traffic (mi/h)

$$N_h = 2 \,.\, \mathrm{RD} \,.\, r \,.\, d$$

where RD=average residential density (residential units per mile^2); and d=length of highway section (mil). Note: "d" is multiplied by 2 for calculation of the number of housing units on each side of the highway.

Moreover, an addition of 1, 2, 4, and 8 dB(A) would be added to the noise level L_{eq} for 2.5, 5, 10, and 20% truck traffic contribution to incorporate the effects of heavy traffic.

Therefore the cumulative cost of noise would be

$$C_{\mathrm{noise}} = 2 \,.\, \int_{r1}^{r2} (L_{eq} - L_{\max}) \,.\, D \,.\, W_{\mathrm{avg}} \cdot \frac{\mathrm{RD}}{5{,}280} \,.\, dr$$

where C_{noise}=total noise depreciation cost in house values over their lifetime around a 1 mil long roadway segment ($/mile), D=percentage reduction in value of residential unit per dB(A) increase in the ambient noise level [0.40%, as recommended by Nelson (1982)]; W_{avg}=average house value in ($); RD=residential density around the highway (number of houses/mil^2); r_1=distance of highway from first house (ft); and r_2=maximum distance (ft).

Codes and Regulations

A representative set of relevant codes/regulations have been modeled into the schema. Each section of applicable code is linked to relevant E&S cost elements, impacted entities, and impact sources. This allows schema users to navigate and access related regulations upon planning for new projects. For example, upon considering noise costs, the schema provides a link to US-DOT directive D 22-22 (WSDOT 2002). In this directive, a method was developed for comparing and prioritizing the construction of noise barriers. The evaluation was done on the basis of a three way comparison between the effectiveness of noise abatement techniques, the sensitivity of the affected community to noise, and the actual cost of noise abatement techniques.

Best Practices

The schema provides access to a synthesis of best practices for enhancing and managing E&S costs. These best practices are classified as follows (see Fig. 3):

1. Identification techniques: methods and rules for identifying possible impacts, their extent, and impacted entities;
2. Estimation tips: means for collecting data on impacts and their costs based on project conditions. The tips also include

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a set of rules for classifying the costs incurred by each entity; and
3. Mitigation/management techniques: listing of best practices to reduce E&S costs and benchmarking best practices in this regard. This includes two main categories:
   a. Technical: engineering means to reduce the impacts, such as the optimization of highway layout or the selection of materials; and
   b. Managerial: means to coordinate the work of different project stakeholders to assure a reduced total impact, such as effective information technology (IT) management, team building techniques, and public communication tools.

Sample Case: Noise Impacts

This section illustrates the contents of the schema regarding the noise impacts. Noise generated from construction, operation, or demolition activities of highways can be mitigated either at the source (where it is emerging), or by providing barriers along the transmission path, or at the receptors' end (such as building sound insulation, etc., near residences) (Towers 2001).

Controlling Noise at Source

Noise generated during the construction, maintenance, repair, and demolition (CMRD) phase is normally greater than the noise during the operation phase. During the life cycle of a highway, CMRD is normally of a very short duration as compared to the operation phase. The noise abatement barriers, normally designed for the operation phase, may not be suitable for the CMRD phase. Temporary noise barriers can be constructed if no abatement of noise is required during the operation phase. Limiting noise emissions at all sources during construction provides the most effective means for controlling noise, and should be applied whenever practical. Noise limits for equipment can be included in the construction specifications (Towers 2001). During the operation phase, vehicle and road noise are the two main sources of impact. A study by the Environmental Agency, Bristol, England United Kingdom suggested that tires are responsible for much of the road noise. Road noise is mainly generated by the friction between tires and the pavement, and this depends on many factors. Some of the factors are surface mix design (material selection and their properties) and road geometry.

Asphalt pavement is generally considered to be quieter than concrete pavement. Kandhal (2003) has provided a list of studies showing the comparison of various mix designs with respect to noise reduction levels. Meiarashi and Ishida (1996) showed the relationship of pavement composition and porosity to noise levels. They tested porous elastic road surfaces (PERS) that were composed of rubber granulate combined with urethane, and compared it to drainage asphalt pavement (DAP), and densely graded asphalt pavement (DENAP), based on the concept of sound absorption by the pavement. Results of their study showed that a noise reduction of 10 dB(A) or greater can be effectively achieved by increasing the porosity of pavement as is demonstrated in PERS. Advanced studies in exposed aggregate concrete resulted in a tire noise reduction of 5 dB(A) to about 100 dB(A) measured at the source and at a speed of 100 km/h. The resulting noise level on concrete pavement is approximately equivalent to the asphalt surface and was the result of using a special mix and particular surface texture (Federation Internationale du Beton 2003).

Controlling Noise at Transmission Path

Noise abatement at the transmission path can be achieved either by increasing the distance between source and receptors, or by barriers (natural or artificial). Locating the source (highway) away from the receptors is the most feasible technique for noise mitigation; this approach, however, is often limited by practical constraints and is less effective in an urban environment (Towers 2001). Noise barriers are among the most common mitigation measures used. The types of noise barriers most commonly employed consist of earth mounds (natural) or walls (artificial) of wood, metal, or concrete which form a solid obstacle between the road and roadside communities (Tsunokawa and Hoban 1997). The mitigation techniques also include plantation (already present or planted if there is a chance of future land development in that region) along the roadside, or elevating, depressing, or tunneling the road level.

Concrete (4 in. thick) is the most widely used material for noise barrier walls. It provides excellent sound proofing with low maintenance costs. Earth berms provide a natural appearance with favorable costs. Vegetation can be added to berms or they can be combined with concrete, wood or steel walls. Wood has a favorable cost and is very appealing. However, it has high levels of maintenance costs due to deterioration. Brick and masonry walls have aesthetic advantages too and good acoustical properties. However, they could be expensive to build and maintain. Finally, cold-formed steel sheets could be used as barrier walls. They have low construction and maintenance costs. Their disadvantages include vibration, frequent denting, and ineffectiveness in lower frequencies (Brockenbrough and Boedecker 2003)

Other materials that can be used include aluminum, plastic, glass, composites, and gabions (rock-filled wire baskets). Design for reductions greater than 15 dB(A) is usually not considered to be feasible. It is sometimes possible to take advantage of the local terrain and locate a noise wall on land with higher levels. The wall height ranges between 6 and 25 ft. Generally, the higher the wall, the greater it reduces noise level and the greater the cost (Brockenbrough and Boedecker 2003). However, the sound dampening rate is dependent on the acoustical properties of the material and the density of material used for constructing the barrier wall.

Noise Control at Receptors' End

This is the least desirable technique for dealing with noise abatement. Successful methods include sound insulation of buildings by modifying doors and windows that range from weather stripping, to storm sashes, to full replacement (Towers 2001). Special advance glass is available that produces waves in the opposite direction of noise waves resulting in the reduction of noise level. However, this method can only be useful for a limited time period, as insulation is only effective as long as the windows and doors are closed.

Evaluation and Testing

To test the relevance of the schema concepts on those used by practitioners, the research analyzed three historical case studies of highway construction where E&S analysis was considered substantially. These are as follows:
1. Preliminary design study and environmental assessment for Highway 417 (Ottawa Queensway), from Highway 416 easterly to Anderson Road, Ontario, Canada;

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Fig. 4. Overview of Web portal

2. Highway 99 (Sea-to-Sky Highway) Improvement Project, British Columbia, Canada; and
3. Proposed Route 238 Hayward Bypass Project, California.

The objective was to test the relevance and extent of coverage of the contents of the proposed schema to actual cases. The analysis included comparing the concepts, costs, and impacts, considered in these cases and the elements included in the schema. This covered the following points:

- The extent that each E&S impact is considered;
- The method of integrating E&S impact in highway development/improvement;
- The impacted entities that are considered important in each study;
- Results of assessment; and
- Best practices and lessons learned from each study.

Analysis of the cases showed that the proposed schema has covered most of the E&S concerns that have been considered during environmental assessment studies. It was also found that in each environmental assessment study, the E&S impacts were studied in detail and were assessed qualitatively and quantitatively. Most of the costs considered in the cases were evaluated based on qualitative measures. Finally, the cases presented a valuable source to enrich the lessons learned database.

The schema was further evaluated through interviews with 18 domain experts. The interview involved three sections with the following objectives:

Section 1: understand the needs/practices of E&S impact assessments. This was an open discussion where the research team presented the synthesis and the proposed schema to the experts.

Section 2: evaluate schema contents. Experts were asked to respond to a formal survey to assess the relevance and importance of the proposed E&S impacts, their types, sources, best practices to mitigate the impact, and impact valuation techniques; and assessing the level of importance of E&S impacts and impact sources. Experts were also asked to identify any additional relevant content.

Table 1 shows the relative importance of E&S impacts of highway construction. Table 2 shows the relative importance of impact sources. Finally, Table 3 shows a representation of the consensus of experts on how to classify valuation techniques.

Section 3: overall evaluation. Once the experts became aware of the contents of the proposed schema, they were asked to assess the suitability of the model used to describe costs and impacts and their interrelationships, assess the relevance and coverage of the valuation techniques that were documented in the schema, and assess the importance and benefits of using the proposed schema to document knowledge.

The general outcome of the interviews indicates that a universal standard for describing and assessing E&S costs is not feasible at this stage due to the subjectivity of data and the shear differences in the conditions (physical, legal, and political) of each project. The experts, however, unanimously expressed the need for effective documentation of best practices and sharing of knowledge in the field.

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Web-Based Portal

A Web portal was developed to implement the proposed schema. The portal serves two purposes:

1. Education and knowledge documentation: users can navigate the schema concepts and study the definitions of costs, their estimation methods, and some of the best practices to mitigate the impacts. They can also add new best practices or additional clarification to cost definitions; and
2. Collaborative definition of costs: it is not possible to produce/suggest a universal list of costs or estimation methods. Each project has its unique features and issues that will mandate the relevant costs. Significant variation in stakeholders' composition and attitude toward E&S costs is expected in each project. Therefore, for each project, the stakeholders have to collaborate in analyzing the specific project characteristics and define the relevant E&S costs, and their estimation methods.

The portal was designed to allow a team of designers/contractors/decision makers to collaborate in identifying the sources of E&S impacts, defining the impacted entities, estimating the relevant costs, and sharing best practices for decreasing the E&S impacts of the construction activities. The portal provides access to the schema, where users can select the sources, impacts, impacted entities, and the cost estimation methods (see Fig. 4). Users can drag and drop concepts from the schema to build a common table (map) for the impacts and their cost estimates. During the establishment of the table, users can identify the impacted entities, the relevant costs, their preferences for cost evaluation techniques, cost estimates, and relevant best practices. The resulting table presents means to stir discussions among project stakeholders. Eventually the table could form a blueprint for the costs, and best means to control their values during the design and construction phases.

Summary

It is widely acknowledged that assigning a monetary value to the environmental/social impacts of highway projects can improve the project evaluation process. However such a task is an extremely difficult process due to the nature of the domain. Consequently, researchers and practitioners have used different methods and techniques to identify and measure E&S impacts and costs. In effect, it is believed that a universal standard for assessing E&S costs and impacts is not attainable given the current state of research and implementation.

It is, however, very important to develop means to help researchers and practitioners document and access available knowledge and best practices related to this domain. To that end, this research developed a schema to support interoperability in communicating E&S cost data. This includes: identification of project elements that could produce such costs, identification of entities that are impacted by such project elements, methods of estimation of such costs, and best practices to mitigate and control such costs.

On a project level, the use of such scheme will allow project stakeholders to review existing definition and valuation techniques related to E&S costs and impacts, collaborate on selecting the most relevant costs and valuation techniques to the project at hand, and formally document their expertise for future use.

On an industry level, the use of such schema will help achieve interoperability in representing concepts and best practice related to E&S costs and impacts. It will also help build a repository of consistent representation of knowledge related to the domain from various projects. Such knowledge could be valuable in streamlining some common practices on a national scale.

Notation

The following symbols are used in this paper:

dB = decibel, ratio between two quantities, used in acoustics and electronics;
C_{noise} = total noise depreciation cost in house values over their life time around 1 mi long roadway segment ($/mile);
CFC = chlorofluorocarbon;
CH_4 = methane gas;
CO = carbon monoxide;
CO_2 = carbon dioxide;
d = length of highway section (miles). Note: "d" is multiplied by 2 for calculation of number of housing units on each side of highway;
D = percentage reduction in value of residential unit per dB(A) increase in ambient noise level;
L_{eq} = equivalent noise level in dB(A);
$L_{\max}$ = maximum acceptable noise level in dB(A);
ND = house value depreciation due to noise ($);
N_h = number of houses affected by noise (number of houses/acre);
NO_x = mixture of nitrogen monoxide and nitrogen dioxide;
Q = traffic flow (veh/h); $Q \geq 1{,}000$ veh/h;
r_1 = distance of highway from first house (ft);
r_2 = maximum distance (ft);
RD = average residential density (residential units/mile^2);
SO_2 = sulfur dioxide;
V = average speed of traffic (mph); and
W_{avg} = average house value ($).

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