A REVIEW AND CLASSIFICATION OF THE EXISTING METHODOLOGIES FOR ENVIRONMENTAL IMPACT ASSESSMENT*

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In the last two decades several techniques have been developed for Environmental Impact Assessment (EIA) of development activities. These have proliferated to more than a hundred in number due to the growing concern in the world about environmental deterioration and the possible mitigation strategies.
This paper presents an extensive classification, according to logical steps in an EIA, of the available methods along with their merits, demerits and requirements for application in the EIA of public transportation projects. The paper also discusses the development of systems for EIA, which are combinations of several methodologies, and provides evaluation from the point of view of the application to public transportation projects, based on an extensive set of criteria. In addition, this paper also demonstrates the development of a computer-aided system for the EIA of public transportation projects.

1. INTRODUCTION

Environmental Impact Assessment (EIA) of transportation projects is a comprehensive and important task. The implementation of almost of any public transportation project brings with it a series of both positive and negative impacts on the related environment. A typical EIA involves many tasks such as, careful and objective examination of the project data, review of the existing environmental parameters and regulations that may affect the project, appropriate calculation of impact, comparison of values against acceptable criteria and recommendation of necessary mitigation strategies.

The variety of methods used to assess environmental impacts are very large in number and project specific. A nominal listing and description of the methods have been included in many previous reviews by different authors (Jain & Urban, 1975; Bisset, 1980; Shopley & Fuggle, 1984). Recently, the application of computers, particularly, their graphics oriented capabilities, have very distinctly influenced the conventional methodologies that call for new approaches in their classification and evaluation. Nevertheless, the various logical steps involved in an EIA is agreed upon by several authors without much argument (Conover, 1985).

1.1 Classification of the Methods for EIA

In this review, we have classified the methods incorporated in an EIA system into methods used to perform each of the different steps in the preparation of an EIA (Warner & Preston, 1973; Munn, 1979) such as:

1) identification of impacts
2) measurement and prediction of impacts
3) assessment of significance of impacts
4) communication with concerned parties and reporting

as given in Table 1. In the Sections 2 through 5, this review clearly identifies the distinct features of the different methods under the four major classes and the criteria for their evaluation. The performance of the methods relative to these criteria is also discussed. It may be useful to comment that when a system is cited to explain a particular sub-classification of methods, the system itself may not be

Table 1 Classification of Methodologies for EIA

STEPS IN EIA	METHODS
Identification of Impacts	Environmental Impact Indicators Cause & Effect Pairs Chains of Causality Project Alternatives
Measurement & Prediction of Impact	(Methods have not been classified)
Assessing the Significance of Impacts	Display Individual Values for Impact Indicators Rank Alternatives on Selected Impact Types Weighting Systems for Evaluation of Impacts Treatment of Uncertainty
Communication with Concerned Parties & Reporting	Participation after the Completion of EIA Participation during the EIA

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classified exclusively under that particular class.

1.2 Review Criteria

Review criteria have been defined for analyzing the various methods, according to their role in accomplishing the tasks in the EIA, and determining their strengths and weakness. These are presented in Table 2. In the following sections, the methods are rated for their degree of compliance with the criteria discussed. The rating characteristics are suggested as follows: (Jain et al., 1977)

s = Substantial compliance, low resource needs, or few replicability-flexibility limitations.
p = Partial compliance, moderate resource needs, or limitations.
n = No compliance or minimal compliance, high resource needs, or major limitations.

2. METHODS FOR IDENTIFICATION OF IMPACTS

These methods are addressed particularly to the identification of the characteristics of the environment, activities in the project and also alternatives to the action proposed.

2.1 Environmental Impact Indicators

One of the simplest methods in EIA is to provide a comprehensive documentation, in the form of either a list or map, of the environmental effects and impact indicators. With these the analyst can think broadly about possible consequences of completed actions. The documents are very comprehensive, but could become very voluminous if all environmental characteristics are to be detailed. There is also a weakness of bias that the analyst may ignore those factors not included.

For example, the Dee et al.(1973) method identifies a comprehensive list of seventy eight environmental parameters. The impacts are measured for each parameter for assessment. The approach particularly covers social impacts, but does not deal with economic or secondary impacts, since the parameters are chosen within the categories of ecology, environmental pollution, aesthetics and human interest. The McHarg (1968) approach maps eleven to sixteen environmental and land use characteristics. These maps are made on transparencies which can be overlaid on a regional based map to screen alternatives and project sites.

2.2 Cause & Effect Pairs

These methods display the interactions, in the form of cause-and-effect pairs, between a list of project actions and environmental characteristics. They can be represented in many ways - short descriptions, symbols, numerical values, for the magnitude and severity of the impacts. A large number of primary impacts are easily understood although secondary impacts are not considered adequately. The category of methods have the same weakness as the previous one, that they could be biased towards only certain aspects of the environment. Nevertheless, the methods provide helpful initial guidance in designing further detailed studies.

The EIA approach developed by Leopold et al.(1971) is the best known review for the use of this methodology. The approach identifies 100 project activities and 88 environmental characteristics and list their interaction in a matrix on a basis of cause and effect. The analyst can evaluate impact of each action of the project on every environmental character.

2.3 Chains of Causality

These methods trace the linkages between a project action and the affected environmental characteristic to their fuller extent, in the form of action-effect-impact relationship, thus making it possible to investigate higher order impacts. These methods are best suited for single-project assessment (Munn, 1979). They are often disadvantageous when quantitative information should be assessed. The flow diagrams developed in the application of the methods become so extensive that they are of little practical value, particularly when several actions must be examined.

The approach of Sorenson (1971) is a very useful guide to identify impacts and the pathways by which both primary and secondary impacts are produced.

2.4 Project Alternatives

There are many consultative techniques available to identify the possible alternatives to a project action. The manner in which possible alternatives are initially identified depends on the choice of the consultative techniques. Internal workshops, use of consultants and communications with interested parties are some of the techniques useful to develop project alternatives. The process by which these alternatives may be narrowed down to a smaller set of feasible ones may involve a range of techniques, varying in sophistication from fairly informal reviews, based on structured data gathering exercises, to the more formal reviews, based on simulation modeling studies of the alternatives initially identified. Nevertheless, the underlying concept can be summarized in the following manner.

First, the set of objectives of the proposed action are clearly identified and classified into higher and lower ones. Then, several alternatives that are generated for the higher objectives, are narrowed down to a feasible set of alternatives after testing against the

Table 2 Criteria for Evaluating the Methods for EIA

CRITERIA	DESCRIPTION
Methods for Identification of Impacts	
1-1) Comprehensiveness	A full range of impacts should be addressed, including: ecological, physical-chemical pollution, social-cultural, aesthetic, resource supplies, wealth redistribution, and induced land-use and energy patterns.
1-2) Selectivity	The system should identify specific parameters, under the different impact types, to be examined.
1-3) Isolating the impacts	The system should include methods to identify project impacts, as distinct from the future environmental changes caused by other factors.
1-4) Double-counting	A methodology should be provided in the system not to include the same impact more than once although it may be reflected in alternative forms in the environment.
1-5) Distribution Effects	The system should distinguish how the different affected communities will receive the predicted impacts. This is crucial in communicating the impacts.
Methods for Measurement and Prediction of Impact Magnitudes	
2-1) Explicitness	Specific measurable indicators to be used for quantifying impacts upon parameters should be suggested.
2-2) Data Accessibility	A system should clarify how to use the existing data and perform sampling and other methods to obtain addition data.
2-3) Objectivity	Objective rather than subjective impact measurements should be emphasized.
2-4) Dynamic Changes of Socio-economic Conditions	The prediction methods should take into account in the analysis, the absence of a static equilibrium in the environmental system.
2-5) Uncertainty of Estimates	The system should provide the uncertainties attached with the predictions.
Methods for Assessing the Significance of Impacts	
3-1) Process of Simplification	The criteria and assumptions employed to determine impact significance should be explained.
3-2) Aggregation System	The methodology for aggregation of impacts should as much as possible employ an acceptable weighting system, so that the net total estimate is meaningful for the decision-maker, and later, the general public involved in the communication.
3-3) Qualitatative Information	The system is required to clearly indicate, if there is an objective basis for the qualitative information, and provide a clear indication of the difference between the alternatives in the critical impact categories to perform a trade-off analysis.
3-4) Adaptive to Uncertainties	The system should include methods to assess uncertainties in the significance of impacts.
Methods for Communication	
4-1) Link to the Affected Parties	A mechanism for linking impacts to the specific affected social groups or geographical areas should be suggested.
4-2) Non-technical Documentation	The project setting should be described to aid statement users in developing an overall perspective. The key issues and impacts identified in the analysis should be highlighted in the summary.
Resources and Application Requirements	
5-1) Data	What is the volume of data required?
5-2) Manpower	What is amount human resources required to conduct the EIA using this system?
5-3) Time	How much time is required to learn to use and apply the system?
5-4) Costs	Costs of using the system in comparison with other tools.
5-5) Replicability	To what degree will different impact analysts using the system tend to produce widely different results?
5-6) Adaptability	How readily can the system be modified to fit project situation other than those for which it was designed.

lower order objectives.

In most of the earlier applications, the methods for identifying project alternatives have been of limited use other than minor modification of the action proposed (Lee, 1982).

2.5 Criteria and Evaluation

The review criteria 1-1 through 1-5 in Table 2 correspond to the methods in this section. A general evaluation of the sub-classification of methods is given Table 3.

Table 3 Evaluation of Methods for Identification of Impacts

METHODS	CRITERIA 1 1 1 1 1 / 1 2 3 4 5
E.I INDICATORS	‖s‖s‖p‖n‖n‖
CAUSE & EFFECT PAIRS	‖s‖s‖s‖s‖n‖
CHAINS OF CAUSALITY	‖s‖p‖p‖p‖p‖
PROJECT ALTERNATIVES	‖s‖s‖p‖p‖p‖

3. METHODS FOR MEASUREMENT & PREDICTION OF IMPACT MAGNITUDES

Methods for measurement and prediction cover a wide spectrum and cannot be readily categorized (Munn, 1979). In some cases writers have preferred to treat them as "techniques" falling outside the subject of EIA (Lee, 1982). The tasks of these methods can be summarized as:

1) determining base-line environmental conditions and the expected changes in these, assuming no alternation in socio-economic conditions;
2) predicting the changes in the future environmental conditions expected to result from predicted changes in general socio-economic circumstances;
3) predicting the changes in future environmental conditions expected to result from a proposed action, given predicted changes in general socio-economic circumstances.

The methods consist of conceptual models identifying the interactions between environmental characteristics and economic systems. The responses of the environmental system for the predicted changes in the economic system are determined using techniques that vary in complexity from those totally intuitive to those based on explicit assumptions and derived equations. Of course, the environment is never as well behaved as assumed in models, and therefore models will be specific for each project.

Modeling approaches have attracted increasing attention in the last decade due to their potentials to present the dynamic changes of the environment impacted by the project, mostly due to the availability of the GIS based computer systems that can enhance the presentation of the spatial distribution of such results, which offer much better visual effects and input for decision-making. Further, such methods offer a possible means of investing the origin of secondary impacts and quantifying them.

Walters (1975) has applied modeling techniques and procedures for rapid preliminary EIA of a specific large-scale regional project. Essentially the study revealed that the impacts (positive and negative) were often exactly opposite from the intuitive judgments of the participants. The impacts predicted by the model were very useful to decide on a research and monitoring program after the project completion.

3.2 Criteria and Evaluation

The review criteria 2-1 through 2-5 in Table 2 correspond to the methods in this section. A general evaluation of the different methods for measuring and predicting impacts is not attempted, since the methods used in the different systems do not yield themselves for distinct classification. But the evaluation of the systems reviewed in this paper is discussed later.

4. METHODS FOR ASSESSING THE SIGNIFICANCE OF IMPACTS

In general, these methods consider the magnitude of the impacts and adopt some kind of value judgment to determine the significance of impact. Qualitative information can also be handled by these methods under certain conditions (Lee, 1982).

4.1 Display Individual Values for Impact Indicators

These methods avoid the problem of synthesizing the data and display in a list or array with the magnitude of all the impact indicators. They can be applied so long as: the information on magnitudes of individual impacts is meaningful to the decision maker; the number of variables and volume of data are not too great to handle.

4.2 Rank Alternatives on Selected Impact Types

These methods rank project alternatives within groups of impact indicators and no formal attempt is made to assign weights to the impact indicators. They avoid value judgments to a certain extent, but the total impact of alternatives cannot be compared directly.

For example, the Leopold et al.(1971) approach displays about 17600 pieces of information and uses a scale of 1-10 to score the significance and importance of the environmental attributes. Although the alternatives can be compared visually, the voluminous information may be very confusing to the decision makers.

4.3 Weighting Systems for Evaluation of Impacts

These methods use various approaches that fall into mainly two categories, to convert the magnitudes of the impacts into either monetary equivalents or ordinal values according to a common scale within each impact category. In the first approach, the monetary equivalents can be added together to obtain a single measure for the total environmental impact (which can be a cost or benefit) for each alternative. However, there a number of limitations to the practical application of this approach because: 1) simplifying assumptions are required to calculate the monetary equivalent; 2) some types of impact cannot be evaluated monetarily.

The second approach is often criticized, because of the fundamental difficulty in handling the value judgments behind the scaling and weighting. Also, the idea of aggregating scaled values into a single is a controversial issue (Sorenson, 1971).

The Sondheim (1978) method involves weight and aggregation of impact involves the participation of special panels. Each expert rates each activity according to special criteria developed individually. The scores are normalized and inserted into a matrix (say A) in which rows consist of alternatives and columns, the components of environment. The relative importance of the different environmental aspects, according to an independent scale, are inserted into a matrix (say B) in which the rows and columns consist of the environmental components and the members of the panel respectively. The numerical preference of the alternatives can be obtained from the vertical matrix obtained by the lateral summation of the product of matrices A and B.

4.4 Treatment of Uncertainty

EIA contains at least four kinds of uncertainty due to

1) the natural variability of the environment;
2) inadequate understanding of the behavior of environment;
3) inadequate data for the region being assessed;
4) socio-economic uncertainties.

The representation and evaluation of uncertainty can be achieved through many classical statistical methods. A number of recent studies have given increasing importance to uncertainty in EIA (Holling, 1978; Munn, 1979). There are three possible ways:

1) Risk Analysis, in which a range of estimates each with an objectively determined likelihood of occurrence is accepted in the absence of a single value estimate of impact. The expected value derived from these is used in the assessment.
2) Sensitivity Analysis to test the changes in the choice between alternatives for feasible changes in magnitude of impact where uncertainty exist. It is very convenient to simulate this on a computer. When the ranking of alternatives is not changed, the uncertainty becomes irrelevant; and when the uncertainty in some elements are significant a trade-off analysis can be extended.
3) Risk Aversion, by which only the alternatives which would be environmentally preferred under adverse circumstances are selected. This approach may not yield the optimal alternative at different situations.

One of the important aspects of uncertainty is that it increases as a prediction is made for times further and further into the future. Holling (1978) recommends EIA as an essential component of environmental management strategy, with a long term perspective, even after the proposed action has been complemented. Risk analysis seems to be a part of this approach. Munn (1979) recommends the sensitivity analysis approach here, although no specific application has been demonstrated in the text.

4.5 Criteria and Evaluation

The review criteria 3-1 through 3-4 in Table 2 correspond to the methods in this section. A general evaluation of the sub-classification of methods is given Table 4.

Table 4 Evaluation of Methods for Assessing the Significance of Impacts

METHODS	CRITERIA 3333 1234
DISPLAY INDIVIDUAL VALUES FOR IMPACT INDICATORS	!!p!p!p!p!!
RANK ALTERNATIVES ON SELECTED IMPACT TYPES	!!n!n!n!n!!
WEIGHTING SYSTEMS FOR EVALUATION OF IMPACTS	!!s!s!s!n!!
TREATMENT OF UNCERTAINTY	!!s!s!s!s!!

5. METHODS FOR COMMUNICATION WITH RELATED PARTIES AND REPORTING

Communication plays a vital role in the EIA. The link between the assessor, decision-maker and the interested & affected parties of the proposal is very crucial for the environmental decision-making. There are two contrasting views to the consultation and participation, particularly of the general public in the EIA.

5.1. Participation after the completion of the EIA

The participants are introduced

into the system after the draft Environmental Impact Statement (EIS) (completion of the EIA study) stage. Usually, the participants assume the role of objectors and the methods are devised to facilitate mediation between conflicting interest groups.

5.2 Participation during the EIA

The general public participate right from the pre-study in identifying alternatives and key environmental issues, until finally assessing the significance of impacts.

Bishop (1973, cited in Munn, 1979) has listed a host of techniques for communication with their relative performances for the various stages in the EIA at which they are employed.

Table 5 Evaluation of methods for Communication

METHODS	CRITERIA 4 4 / 1 2
PARTICIPATION AFTER THE COMPLETION OF EIA	p s
PARTICIPATION DURING THE EIA	s s

5.3 Criteria and Evaluation

The review criteria 4-1 and 4-2 in Table 2 correspond to the methods in this section. A general evaluation of the sub-classification of methods is given Table 5.

6. COMPREHENSIVE EVALUATION OF THE EXISTING EIA SYSTEMS

This review has considered 30 systems developed for some of the representative applications in various fields, available in the literature, for the following evaluation, although only 13 of them have been included in this paper, due to lack of space.

The existing systems can be first exploded into the elemental methodologies in them, which can be classified for better understanding, into the different types discussed in the previous sections. The chronological listing of these systems, the keywords describing their field application and the elemental methodologies in them are presented in Table 6.

The application of the different systems for EIA of transportation projects can be rated using the former 16 criteria and other 6 criteria related to resource and application requirements as given in Table 2.

Table 6 Evaluation of the Existing EIA Systems

SYSTEM (AUTHOR & YEAR)	APPLICATION IN EIA OF	METHODS INCLUDED* 2 2 2 2 3 4 4 4 4 5 5 / 1 2 3 4 1 2 3 4 1 2	CRITERIA FOR EVALUATION** 1 1 1 1 1 2 2 2 2 2 3 3 3 3 4 4 5 5 5 5 5 5 / 1 2 3 4 5 1 2 3 4 5 1 2 3 4 1 2 1 2 3 4 5 6
McHARG, 1968	Highway Route Selection	* * * * *	p p n n s p p n n n s p p n s s p p p p s s
LEOPOLD et al., 1971	Construction Project	* * * * *	s s s s n p p s n n s s s n p p p p p p p
SORENSON, 1971	Residential Development	* * * *	s p p p p p p n s n p p p p p s s s s s n p
DEE et al., 1973	Water Resources Management	* * *	s s p n n p n s n n s s s n s p p p p p p p
PETERSON et al., 1974	Large Scale Projects	* * * *	s s s s s s s s n n s s s p n n s p p p s s
DELAWARE RIVER BASIN COM. (cited by Chase, 1976)	Water Resources Management	* * *	s s s p n p n s n n p p n n n n p p p p n n
GULDBERG et AL, 1977	Urbanization Projects	* *	p p s p s s s s s s n n n n p p n n n n s n
SONDHEIM, 1978	Dam construction Project	* * * * * * *	s p s s s s s p s s s s s s s s s n n n n p s
MANNING & MONCRIEF, 1979	Land Use Analysis	* * *	s p s p n p n p n n n n n n n n p p p p p s
CLARK et AL, 1980	Highway Route Selection	* * *	p p n n s s p s n n s s s n s s s s s s s
COUILLARD, 1984	Construction Project	* * * *	s p p p p p p n s n p p p p p s s s s s n p
CONOVER et al., 1985	Offshore drilling project	* * * * *	s s s s p p p s n n s s s p p p s s s s n s
WRIGHT & GREENE, 1987	Mining Project	* * * * *	p p s s s s s s p n p p p p n n n n n s n

Note: * Methods refer to those discussed in Sections 2.1 through 5.2 respectively.
** Criteria refer to those discussed in Sections 6.1 through 7.1 respectively.

The criteria are numbered in such a way that the entire set of criteria can be used in the evaluation of the systems for EIA. Any particular method (for example, a method for identifying the impacts by identifying the chains of causality), incorporated into a typical EIA system is specific to that particular application. This also varies with the actual type of application. So the evaluation of a system as a whole, against a criterion, can differ from the general evaluation of the methods presented earlier.

7. A COMPUTER-AIDED SYSTEM FOR EIA

The summary of the evaluation as presented in Table 6 can be used to choose the best-suited set of methodologies to build a system for conducting the EIA of a particular public transportation project.

Further, the rapid growth of computer graphics and the application of Geographical Information Systems (GIS) in EIA applications is very well explained by the variety of inherent advantages they offer in assimilating and presenting information, and decision making.

Environmental data can be collected through satellite and other airborne sensors, and easily assimilated in the GIS data base. GIS enhances update and retrieval of environmental data that are very drudgerous in manual planning. GIS based systems facilitate the sensitivity analysis through simulations, thus improving the applicability of the EIA system.

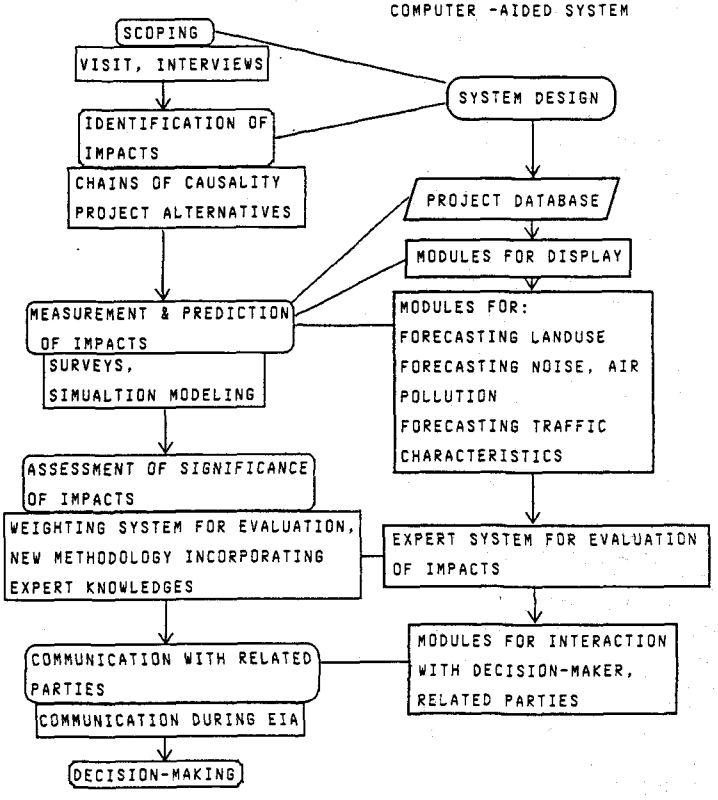
In this section, we present the general framework of the computer-aided system for EIA designed by the authors. The different methods chosen for the modules of the system are illustrated in Figure 1.

8. CONCLUDING REMARKS

This review has indicated that the present classification and evaluation of the existing many methods and techniques available for use in EIA are very beneficial to usefully combine them and develop new systems.

A computer-aided system based on the above mentioned review and new developed methodologies is now being developed with the Light Rail Transit (LRT) in Manila as a case study. New view points are expected to be included in this review, during the new system development.

FIGURE 1 A PROPOSED STRUCTURE FOR THE COMPUTER-AIDED SYSTEM FOR EIA



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