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Quantifying Environmental Impact Assessments Using Fuzzy Logic (2005) R.B. Shepard

Richard B. Shepard

Quantifying Environmental Impact Assessments Using Fuzzy Logic

With 42 Illustrations

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Preface

Formal requirements for the assessment of environmental impacts of development activities may have begun in the United States with the passage of the National Environmental Policy Act (NEPA) in 1969, but they now are found in more than 200 countries worldwide. The details vary, but the underlying goals of minimizing environmental degradation and improving environmental conditions are the same. In many countries, these national requirements are supplemented by additional requirements by states, provinces, counties, cities and other political divisions that are collectively called sub-national statutes and regulations.

I am most familiar with the requirements at the national level in the United States as well as at the state and county levels in the western half of the country. However, books, other published reports, and communications with peers amply document that problems caused by the subjective nature of environmental impact assessments are international in scope. This subjectivity can be quantified and treated with mathematical rigor by the application of advanced computational intelligence techniques. This approach will work equally well regardless of geographic location or political jurisdiction because it is responsive to variations in societal values, legal frameworks, and regulatory agency practices. Trans-national organizations such as the European Union, World Bank, and United Nations Environmental Program also set project environmental standards that must be met in addition to the standards set by local governments.

It is important to make this disclaimer emphatically: in no way is this book to be taken as criticism of environmental impact assessment (EIA) laws, regulations, practitioners, or theorists. Such criticism would be neither warranted nor justified. Identifying subjective aspects is not criticism. Such identification forms the basis for understanding this book and benefitting from its content.

This book has three objectives:

1. The first objective is to document how environmental impact assessments have been conducted and to explain when and why contention develops. The book stresses that environmental assessments (whether of impacts or of existing conditions) are subjective expressions of societal, group, and individual values and opinions. As such, they are not objective or measurable. Science, particularly ecology and environmental science, has difficulties dealing with feelings, beliefs, and values, which are "nonscientific" concepts.

   The specifics of the EIA process vary with the controlling jurisdiction; there is no attempt to describe all the variations and subtle differences, because this is not a book to teach the theory and detailed practice of environmental impact assessments as implemented worldwide. However, specific points will be based on my experiences as well as what others have experienced and described in published literature.

   The first objective establishes two important points: EIAs are subjective and existing assessment methods do not effectively handle subjectivity. We speak and write using terms that cannot be measured. Concepts such as *significan*t, *distant*, *acceptable* and others are understood by everyone – but we each may have a different definition of these terms. Almost all environmental regulatory processes depend on such imprecise, vague, inherently uncertain terms. Commercial development may be prohibited on *steep* slopes, but how is *steep* defined? It is almost always an arbitrary, crisp value; for example, 20 percent. This does not mean that a slope of 19.5 percent is not *steep*, but it means that there is no sharp threshold that separates *steep* from *not steep*. Fortunately, fuzzy sets, fuzzy logic, and approximate reasoning (among other computational intelligence methods) handle subjectivity effectively by

quantifying it and manipulating it with mathematical rigor.

2. The second objective is to justify the use of fuzzy sets, fuzzy logic and approximate reasoning to provide decision-makers with the ability to make well-informed decisions: ones that are technically sound and legally defensible. I do this by describing core issues of an environmental impact assessment in terms of fuzzy modeling and other computational intelligence techniques.

   The concept of fuzzy sets was developed explicitly to address the inherent imprecision of everyday language which we all use to express ideas that cannot be measured. Fuzzy logic is the mathematics that permits rigorous operations on fuzzy sets to arrive at a outcome that is meaningful and can be explained. Approximate reasoning is the computer modeling of how humans make decisions (IF this THEN do that) when all the input data are subjective and not directly measurable. Other advanced techniques of artificial intelligence (AI) (including expert systems, decision support systems, and data mining using neural networks and evolutionary algorithms) also can be effectively and productively applied to addressing the underlying purposes of environmental impact assessments.

3. The third objective is to illustrate the use of computational intelligence techniques presented in objective 2 for environmental impact assessment. This example creates an approximate reasoning model applied to a project completed the traditional way under Washington state laws and regulations. While the example is based on a real industrial development proposal, the original environmental impact assessment was not developed with computational intelligence techniques. Therefore, the example has been adapted to demonstrate the application of these tools by adding missing information and deleting some components to make the example a reasonable size.

Mathematical symbols used in fuzzy logic (from [9]).

Symbol	Meaning
$\neg$	set NOT (also complement or inversion)
$\cap$	set AND (also intersection operator)
$\cup$	set OR (also union operator)
$\aleph$	higher-dimensional fuzzy space
[x,x,x]	fuzzy membership value
$\in$	member of a set; within
poss(x)	the possibility of event x
prob(x)	the probability of event x
{x}	crisp, or Boolean, membership function
$\bullet$	dyadic operator
$\xi(x)$	expected value of a fuzzy region
μ	fuzzy membership function
$\propto$	proportionality
$\mu(x)$	membership, or truth, function in fuzzy set
$\Re$	element from domain of fuzzy set
$\otimes$	Cartesian product or space
$\oslash$	empty, or null, set
$\supset$	implication
$\wedge$	logical AND
$\vee$	logical OR
Σ	summation

Acknowledgments

Among all the people whose efforts have brought me to the level of understanding and experience that allows me to write knowledgeably about environmental impact assessments and fuzzy system models a handful stand out of the crowd. Earl Cox introduced me to fuzzy sets and fuzzy logic with the first edition of his *The Fuzzy System Handbook* a decade ago. Since then his comments and suggestions have been helpful to my understanding of this subject and the subtleties of writing software that function to compute fuzzy system models with parallel rule-firing and the ability to solve otherwise intractable problems. Dr. William Siler created a parallel-firing fuzzy inference engine that

is at the core of the solutions presented here. Three other friends and professional colleagues deserve public thanks for the highly productive conversations we have had over the years on environmental issues and running natural resource industries. These friends, Jonathan Brown, Paul Scheidig, and Ivan Urnovitz, manfully read drafts of the book and let me know at what sections their eyes started to glaze over. Paul Scheidig bravely read the first two parts and gave me his usual invaluable feedback. The suggestions from all the above for elucidation and clarity make this book a much better work. My fiancee, Pamela Sue Alexander, cheerfully accepted my long hours at the computer with patience and understanding; this made the process both easier and more pleasant. My editor at Springer, Janet Slobodien, has been a great guide into the world of book publishing, a world much different from that of peer-reviewed scientific or trade journal publishing. Despite the best efforts of all these outstanding people, any errors or mistakes that remain are mine alone.

Richard B. Shepard
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Troutdale, Oregon

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