End of Award Report: Evaluating significant environmental effects - Fuzzy sets and decision making in EIA

Executive Summary

The concept of the *significance* of effects has been recognised as the most critical component of Environmental Impact Assessment (EIA), yet it remains one of the most complex, contentious, and least-understood aspects of EIA systems across the globe. This research has examined the concept of ‘significant environmental effects’ during EIA screening (deciding whether or not a development proposal should be subject to EIA), scoping (determining the focus of the EIA), and impact prediction leading up to the submission of an Environmental Impact Statement (EIS).

The research comprised two distinct phases. The first *extensive* stage explored the characteristics of significance evaluation in current EIA practice. A questionnaire survey of all local planning authorities (LPAs) in England and Wales was undertaken to establish the nature of significance decision-making during screening and scoping. The scoping questionnaire was also sent to 510 environmental consultancies with EIA experience, and 171 representatives of the statutory consultees. The response rate was 26% for LPAs, 30% for environmental consultancies and 23% for statutory consultees and provided a broadly representative sample. The treatment of significance in impact prediction was examined through a review of a representative sample of 20 EISs.

For LPAs, project size/scale and proximity to sensitive environmental receptors are critical in project screening, whilst professional judgement and consultation with colleagues are also important. In scoping, the statutory consultees were found to strongly influence LPA scoping, with LPAs subsequently exerting the most influence on consultancy scoping decisions. Public consultation during scoping is limited and does not appear to affect the scoping outcome. Consultants spend the most time on scoping activity and consider more complex issues (e.g. uncertainty or impact interrelationships), whereas LPAs focus principally on impact identification.

Expert judgement dominates the assessment of significance in EISs, although clear ‘methods statements’ were found in only 50% of cases. The impact dimensions most commonly considered are magnitude, temporal nature, and spatial extent. Explicit significance criteria are defined most frequently for landscape and visual impacts, ecology, noise, and transport.

The second *intensive* stage of the research focussed on the application of fuzzy set analysis to explore significance decision-making. An empirical approach was used to determine fuzzy set membership functions relating to linguistic variables that describe impact significance (e.g. “high” or “acceptable” impact). In screening decision-making a scenario approach was employed, whilst for scoping and impact prediction the research focussed on a limited number of impact themes linked to three live EIA case studies: a windfarm and an urban development proposal (for which a range of stakeholders perspectives were captured), and a waste-to-energy incinerator (focussing on significance assessment by different individual experts).

The fuzzy screening analysis revealed considerable diversity in responses, although two case types were identified: (i) ‘gradualists’, whereby respondents demonstrate a gradual and incremental appraisal of significance; and (ii) ‘step change’ responses, punctuated by sharp changes in relation to the size/scale of the proposal. The LPA group fuzzy set revealed no direct relationship with government guidance thresholds.
The fuzzy scoping analysis was restricted to exploring the ‘Limits to Acceptable Change’. By using simulations of a potential range of environmental change, stakeholders were able to formulate their assessments of ‘acceptability’ without the need for technical knowledge of assessment techniques or terminology. The fuzzy sets derived revealed the heightened sensitivity of local residents and facilitated cross-stakeholder comparisons. In particular, using fuzzy set analysis it was possible to identify ‘zones’ of disagreement between stakeholders.

In a similar manner, fuzzy sets were determined for a sequence of natural language terms (e.g. “slight”, “moderate” etc) to be used in the actual EIAs to evaluate the significance of impact predictions. In all cases, the boundaries between levels or degrees of impact expressed using such language terms were not clear cut, and fuzzy set analysis provided a methodology that captured the ‘shades of grey’ that present a more realistic characterisation, whilst again facilitating inter-stakeholder comparisons. In the air quality example, fuzziness was also clearly evident in terms of the interpretation and understanding of degrees of impacts between different experts.

In evaluating the potential of the fuzzy method, we observe that fuzzy sets can provide an effective vehicle for capturing ‘interpretive knowledge’ and articulating the perceptions that underpin technical-subjective judgements in a way that remains sensitive to the particular environmental and social context. In particular, the approach serves to capture the gradients that exist in the degree to which a significance language term fits a given situation, whilst preserving and expressing in an explicit way the imprecision inherent to definition, thus potentially enhancing transparency. Fuzzy set analysis can also be applied to impacts that are quantitative or qualitative, although we consider it is most effective where there is a strong link with an underlying quantitative continuous variable.

However, in considering the wider potential of the method we make the following observations:

1. Deriving meaningful fuzzy set membership functions for the full array of EIA impacts is likely to be challenging e.g. where an impact is not immediately experiential, where it lacks any resonance with a stakeholder, or where values relate to fundamentally different ethical positions.
2. The approach appears less suited to areas that are dominated by highly qualitative expert assessment approaches (e.g. archaeology), or where quantitative dimensions do not necessarily capture the complete essence of the impact e.g. with socio-economic effects.
3. Important practical constraints exist, including the time and resources required to elicit fuzzy set membership functions; the difficulty of encouraging stakeholder participation due to the adversarial nature of EIA; and the conceptually abstract nature of the approach, which could potentially alienate participants.

We propose that future research could focus upon further development of the methodology and the study of the implications and effectiveness of its usage by means of a detailed case study involving an EIA working group (comprising an array of stakeholders, including members of the public) to establish fuzzy significance criteria as part of an intensive deliberative process.
Evaluating Significant Environmental Effects: 
Fuzzy Sets and Decision Making in EIA

Award R000239676

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1. **Background**

1.1 **Context**

Environmental Impact Assessment (EIA) is a process intended to provide an analysis of the potential significant environmental effects associated with major development proposals and to communicate this information to decision-makers and the public. Following implementation of the amended European Directive 97/11/EC (CEC, 1997) the importance of EIA as a public policy tool for environmental decision-making has increased, with EIA activity rising by over 50% in the UK, resulting in the annual production of around 700 Environmental Impact Statements (EISs).

The concept of the *significance* of effects has been recognised as the most critical component of EIA (Duinker and Beanlands, 1986; Sadler, 1996; Sippe, 1999) with legislation, guidelines and EISs making liberal - if nebulous - use of the term. Despite the central importance of significance evaluation, it remains one of the most complex, contentious, and least-understood aspects of EIA systems across the globe.

In this research we have examined the concept of ‘significant environmental effects’ during EIA screening (deciding whether or not a development proposal should be subject to EIA), scoping (determining the focus of the EIA), and impact prediction leading up to the submission of EISs for project authorisation decision-making. The research focuses principally upon decision-making under the Town and Country Planning (Environmental Impact Assessment) (England & Wales) Regulations 1999, which account for approximately 70% of all EIAs conducted in England and Wales.

1.2. **Impact Significance in EIA**

The complexity of impact significance in EIA can be linked to four interrelated dimensions of the concept – namely that it may be characterised as dynamic, contextual, political and uncertain. Firstly, significance evaluation is inherently *dynamic* in the sense that as the EIA process progresses, the nature and availability of environmental information changes and the characteristics and conceptualisation of significance evolves in decision-making processes (Hilden, 1995; Sadler, 1996) (see Table 1).
## Table 1. Significance Evaluation in Screening, Scoping and Impact Prediction

<table>
<thead>
<tr>
<th>Purpose of significance evaluation</th>
<th>Formal Screening</th>
<th>Scoping</th>
<th>Impact Prediction in EISs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Identification of development proposals requiring formal EIA</td>
<td>Identification of impacts and issues requiring assessment</td>
<td>Identification, evaluation and communication of key impacts for the competent authority and the public</td>
<td></td>
</tr>
<tr>
<td>Time-span for decision making</td>
<td>Less than 3 weeks</td>
<td>Less than 5 weeks where a scoping opinion is requested</td>
<td>Typically between 6 months to two years</td>
</tr>
<tr>
<td>Conceptualisation of significance</td>
<td>Aggregate or ‘global’</td>
<td>Impact identification. Generalized.</td>
<td>Disaggregated, impact specific, and detailed</td>
</tr>
<tr>
<td>Availability / detail of information for significance evaluation</td>
<td>Limited</td>
<td>Low - Moderate</td>
<td>Moderate - High</td>
</tr>
<tr>
<td>Influence / control over significance evaluation and communication</td>
<td>Competent Authority</td>
<td>Competent Authority where a scoping opinion is formally requested. Otherwise the developer and associated consultants</td>
<td>Developer and associated consultants</td>
</tr>
<tr>
<td>Stakeholder involvement</td>
<td>Consultation between professionals</td>
<td>Generally restricted to consultation between professionals. Limited public involvement</td>
<td>Evaluation and communication of impact significance is largely a closed process</td>
</tr>
<tr>
<td>Potential for communicative distortion in presentation of outputs</td>
<td>Limited – EIA either required or not</td>
<td>Moderate. Stakeholders concerns may be ‘reframed’ or ignored</td>
<td>High - EIS author controls significance communication; potential for creation of advocacy documents</td>
</tr>
<tr>
<td>Decision style</td>
<td>Intuitive judgement, bounded rationality</td>
<td>Intuitive judgement, technical / instrumental framing</td>
<td>Detailed instrumental analysis and technical-subjective decision-making</td>
</tr>
</tbody>
</table>
Secondly, significance considerations operate within a context (Lawrence, 2003) comprised of multiple dimensions such as spatial scale, temporal change, social and ethical values, ecological sensitivity, economic considerations, and institutional arrangements. Thirdly, the adversarial nature of EIA in the UK, involving the entrainment of power and influence, conflicting interests, and values, indicates that decision-making in the context of evaluating impact significance cannot be considered as a purely technical or ‘scientific’ process but is characterised by a strong political imperative. As such, decision-making is dominated by discretionary judgements, subjectivity, and an inherent pluralism of environmental perceptions amongst stakeholders. The intricacies of significance evaluation are further aggravated by uncertainty surrounding the information available for decision-making e.g. uncertainty surrounding the exact detail of the project proposed (during screening), knowledge of the existing environment (during scoping) and uncertainty surrounding the accuracy of predictive techniques.

1.3. Fuzzy Set Theory

To address the complexities of this decision-making environment, the research has employed fuzzy set theory as a methodological approach to structure and delineate evaluations of significance made by a range of stakeholders. Fuzzy set theory was introduced by Zadeh (1965) to provide a model capable of dealing with inexact concepts, imprecision and subjective judgements in a clearly definable way. A fuzzy set is one in which classes do not have sharply defined boundaries, and the transition from membership to non-membership of the set is gradual. Zadeh proposed the use of natural language or ‘linguistic variables’ defined as fuzzy sets (see Figure 1) as a means of characterising phenomena that are either too complex or too ill-defined (or both) to permit description in conventional quantitative expressions (Zadeh, 1975).

![Figure 1](image-url)
The key objectives of the research were to:

1. Identify the characteristics and nature of the way in which ‘significant environmental effects’ are currently determined and articulated under the Town and Country Planning (Environmental Impact Assessment) Regulations, 1999;

2. Explore the use of fuzzy set theory to understand the way in which significance is evaluated by a range of stakeholders at different EIA decision stages leading up to the submission of an Environmental Impact Statement (EIS) for final project authorisation decision-making;

3. Theorise the evaluation of the significance of environmental effects and develop heuristic models of EIA information appraisal and decision-making in the stages leading up to the submission of EISs; and

4. Evaluate the extent to which fuzzy sets may be employed to develop improvements in procedures used to evaluate significant environmental effects in screening, scoping and impact prediction in EIA.

At this time, all of the research objectives have been met to a greater or lesser extent, and Table 2 identifies sections within this report that provide evidence of this.

<table>
<thead>
<tr>
<th>Objective</th>
<th>Evidence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Objective 1</td>
<td>Table 1; Section 3.1; Section 4.1</td>
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<tr>
<td>Objective 2</td>
<td>Section 3.2; Section 4.2</td>
</tr>
<tr>
<td>Objective 3</td>
<td>Section 1.2; Table 1; Sections 4.2.1 – 4.2.3</td>
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<tr>
<td>Objective 4</td>
<td>Section 4.3</td>
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</table>

Due to the detail, depth, and quality of the data collected, further analysis and dissemination will make additional contributions to meeting the objectives over the next 12-18 months.

3. Methods
The research has largely followed the approach outlined in the original proposal, comprising an *extensive* stage (to ascertain the characteristics of significance evaluation in current practice) and an *intensive* stage (focussing on fuzzy set analysis).

### 3.1. Extensive Stage

To identify the nature and characteristics of significance evaluation during formal screening, a questionnaire survey of all local planning authorities (LPAs) in England and Wales was undertaken. In addition to questions on screening practice in general (e.g. the level of screening activity, key constraints etc), more detailed information was requested with regards to the *most recent project* screened by the LPA, focussing on the specific approaches employed and the overall decision-process. After follow-up, the response rate to this survey was 26% (a typical figure for postal questionnaires) and provided a representative sample. Results were collated, coded and analysed across the three levels of LPA (County, District and Unitary Authorities) and on the basis of (i) a rudimentary north / south regional partition; and (ii) a simple urban / rural division. Responses were also analysed according to the proportion of screening decisions within LPAs that lead to EIA being required.

The LPA survey also incorporated questions relating to scoping practice and again more detailed information on scoping approaches (including assessment of significance, consultation and its influence on decisions etc) were sought with regards to the most recent project respondents were involved in. A scoping questionnaire was also sent to 510 environmental consultancies with EIA experience, and 171 representatives of the statutory consultees. The response rate for environmental consultancies was 30% and 23% for statutory consultees and provided a broadly representative sample. Data analysis focussed upon identifying the general pattern of responses across the three different types of organisation, particularly the similarities and differences in their scoping approaches.

The treatment of significance in impact prediction and evaluation was explored via a systematic review of a representative sample of 20 EISs. A comprehensive review framework was employed to identify both general ‘method statements’ and the more detailed approaches applied to specific impacts. The review also identified related impact significance issues e.g. links to scoping, mitigation, and uncertainty.

### 3.2. Intensive Stage
Fuzzy sets are defined by means of a function that assigns the degree of membership of each element over the interval range 0 to 1 (0 = non-membership, 1 = full membership) in order to express the degree of compatibility with the concept or linguistic variable being represented. The research employed an “empirical semantic” approach (Turksen, 1991) to the determination of set membership functions relating to linguistic variables that describe impact significance. In overview, three main methods were used: (i) direct estimation; (ii) polling; and (iii) interval estimation.

The direct estimation approach was principally used where stakeholder inputs to the research were represented by one individual (Chameau and Santamarina, 1987; Bilgic and Turksen, 2000). Using a sliding scale, a subject gives a response to indicate the position that they consider is compatible with the fuzzy concept under investigation. Through repeated experiments, the subject is randomly presented with the same situation a number of times in order to avoid memorisation.

The polling approach was used for unravelling a representative membership function for a group (Leung, 1988). In this method, fuzzy set membership values are extracted by repeatedly (and randomly) presenting individuals with a direct question requiring either a ‘yes’ or ‘no’ response, e.g. “do you agree that the impact is substantial?” Using n trials, the membership grade of the impact being substantial i.e. $\mu_{A[\text{substantial}]}$ can then be determined as:

$$\mu_{A[\text{substantial}]} = \frac{\text{number of positive responses to “X is A”}}{n}$$

In the interval estimation approach respondents are asked to give an interval or range that they consider describes the concept under consideration. Response frequencies are then calculated and the membership function is expressed as a histogram.

Having extracted a series of set membership values, polynomial regression was then used to model the shape of the membership functions. This technique has the advantage of being able to generate a continuous function from the raw data, providing a visual representation of the membership function and the equation to describe its shape. Basic characteristics of the membership functions were analysed (e.g. shape, slope, crossover point etc) and these were compared across different
stakeholder groups. Where appropriate, standard set theory operations were used to identify the union and intersection of fuzzy sets across the different stakeholders.

The fuzzy set analysis of formal screening decision-making employed a scenario approach relating to two cases: (i) a windfarm and (ii) an urban development proposal. Direct estimation and polling approaches were applied in a series of 53 interviews with LPA officers to derive both individual and group membership functions respectively.

For the scoping and impact prediction fuzzy analysis the research focussed on a limited number of impact themes linked to three live EIA case studies, namely:

(i) a windfarm - the Morris Fen Windcluster, in rural fenland near Peterborough (noise and visual / landscape impacts);
(ii) an urban development proposal - the Phoenix Project, High Wycombe (visual / townscape impacts); and
(iii) a waste-to-energy incinerator on the urban / rural fringe - the North Quay Energy Recovery Facility, Newhaven (air quality, namely NO₂).

For the windfarm and urban development case studies, a range of stakeholders perspectives were captured, including the actual developers and environmental consultants, representatives from NGOs and regulatory agencies, and the local general public (76 individuals in the windfarm case study, 44 for the urban development). The incinerator case study focussed on an investigation of fuzziness in significance assessment by 39 different experts. This is in contrast to the other case studies where the emphasis was upon the individual experts actually involved in the EIA and upon comparing fuzzy assessments with other stakeholder groups.

4. Results

4.1 Extensive Stage
4.1.1 Screening Decision-Making

In screening projects, LPAs considered the most important factors to be the size and scale of a project, with nearly 87% indicating that these are “important” or “very important”, followed by proximity to sensitive environmental receptors (76%). These factors, particularly project size/scale, can be closely linked to the indicative screening thresholds provided in government guidance (DETR, 1999). Indeed, thresholds were identified as the main consideration in screening decision-making by 44% of LPAs, being particularly popular in northern regions (54%) and rural areas (53%), and amongst LPAs with more limited screening experience (i.e. screened < 5 proposals). However, clearly the thresholds are not used in isolation, with some 93% of LPAs acknowledging the importance of professional judgement, and nearly 70% undertaking informal consultation within their organisation. Screening checklists were used by 27% of respondents. Evidence was found that ‘precautionary’ LPAs (those where more than 50% of their screening decisions have led to EIA) are more inclined to adopt a ‘deeper’, more complex consideration of screening issues (e.g. cumulative impacts and uncertainty), although in terms of legitimising their final decision, the thresholds remain highly valued.

4.1.2 Scoping Decision-Making

Over 75% of LPAs, consultants and statutory consultees indicated that professional judgement was the primary factor in determining potential impact significance. Consultation between experts is also important, although 10% of LPAs failed to liaise with statutory consultees as required by the Regulations. Statutory consultees were found to exert the greatest influence on LPA scoping opinions, leading to appreciable changes in 38% of cases. In turn, LPAs have a similar degree of influence on consultancy scoping decisions. Public consultation is limited (reported by only 4% of statutory consultees, 15% of LPAs and 33% of consultancies) and where it has occurred, no notable changes to the scoping outcome were identified.

All three groups showed a strong interest in site characteristics, geographical issues, and impact magnitude. Consultants make greater use of pre-determined standards / guidelines (51%) and scoping ‘tools’ (e.g. impact matrices, overlay maps, modelling), although with the exception of checklists, such tools are used by only 15-20%. Checklists are generally more popular and are used by around one third of all three groups. Consultants were more likely to consider complex scoping issues (e.g.
temporal impacts, uncertainty, impact interrelationships), whereas LPAs focus principally on impact identification. This is reflected in the time spent on scoping activity; over one third of LPAs spent < 5 hours whilst approximately 75% of consultancies spent > 20 hours preparing a scoping report.

4.1.3. Impact Prediction in EIS
Expert judgement dominates the assessment of significance in EISs, although there is considerable diversity in the extent to which the foundations of such judgements are made transparent. A methods statement to outline the general approach to significance evaluation was found in 50% of the EISs reviewed, although only 15% subsequently apply the approach consistently across all impacts. Impact themes for which clear, explicit significance criteria are most frequently defined include landscape and visual impacts (26%), ecology (28%), noise (25%), and transport (25%). Reference to environmental standards and absolute thresholds to aid significance evaluation are used most frequently in the case of noise (55%), air quality (53%), contaminated land (33%) and traffic assessment (13%). The three impact dimensions most commonly considered are magnitude of impact (60%), their temporal nature (36% - particularly with traffic and noise impacts), and spatial distribution (28% - especially ecology and landscape / visual assessment). There is very limited explicit evidence that consultation has directly influenced and informed significance appraisal, and the significance of residual impacts were examined in detail in only one case.

4.2 Intensive Stage
The highly case-specific nature of the intensive stage findings precludes meaningful generalization and due to limitations of space, in this report we restrict our discussion to a range of illustrative examples drawn from the research.

4.2.1 Screening Fuzzy Set Analysis
During screening, the restricted regulatory time-frame for decision-making (< 3 weeks) coupled with the limited existence of any detailed analysis on potential impacts and baseline conditions, mean that LPA officers must exercise judgement in a characteristically ‘information poor’ environment. In such circumstances, LPAs adopt a decision-making approach commensurate with the notion of ‘bounded rationality’ (Simon, 1976), in essence reducing the number and complexity of the factors considered and seeking a pragmatic solution based on intuitive professional
judgement. Thus, whilst possessing a broad awareness of a range of potential project related impacts, LPAs revealed an ‘aggregate’ or ‘global’ conceptualisation of significant environmental effects, employing heuristics or ‘short-cuts’ to enable them to identify the need for EIA (Table 1). Accordingly the size and scale of a proposal and proximity to sensitive environmental receptors are key factors used by LPA officers as proxies for the potential occurrence of significant environmental effects.

For illustrative purposes we present findings which relate to the application of fuzzy sets for screening windfarm developments on the basis of development size. This example is of particular interest as a close link can be made with government guidance in that the relevant screening thresholds are expressed in terms of the number of wind turbines\(^3\).

Whilst there is considerable diversity in the precise characteristics of the individual fuzzy sets derived, two case types or exemplars can be identified: (i) ‘gradualists’, whereby respondents demonstrate a smooth, gradual and incremental appraisal of significance; and (ii) ‘step change’ type responses that are punctuated by sudden, sharp rises (see Figure 2).

![Graphs showing 'Gradualist' and 'Step Type' responses](image)

(a) ‘Gradualist’ (Respondent N° 10)  
(b) ‘Step Type’ (Respondent N° 22)

*Figure 2. ‘Significant Effects’: Examples of ‘Gradualist’ and ‘Step Type’ Responses*

‘Step change’ type respondents appear to have clear personal thresholds that reflect their conceptualisation of significance based upon the numbers of turbines, although interestingly only in three cases did these precisely match the guidance thresholds. The group set reveals no direct relationship with the guidance thresholds (Figure 3),
with proposals for greater than 10 turbines being considered to fully match the group conceptualisation of significant effects.

![Graph showing degree of membership vs number of turbines](image)

**Figure 3.** Group Fuzzy Set: ‘Significant’ Environmental Effects

Fuzzy sets were found to be effective in clearly delineating screening decision heuristics and provide a model that captures the subsequent ‘framing’ of significance. However the degree to which these heuristics shape the final decision of individuals appears to vary: ‘step change’ type respondents generally use their heuristics as a central pillar of their decision-making, whilst ‘gradualists’ perceived them to be of value, but only as a starting point - considerable importance is placed on consultation with colleagues along with a detailed consideration of site specific issues.

4.2.2 Scoping Fuzzy Set Analysis

As outlined in the original proposal, the intensive stage scoping analysis was restricted to exploring the ‘Limits to Acceptable Change’ defined by fuzzy sets. For illustrative purposes, here we consider the acceptability of noise effects amongst stakeholders associated with the Morris Fen windfarm case study.

Using a simulation approach, sound recordings of noise from comparable operational wind turbines were played to research participants under controlled conditions. In this way, stakeholders experienced the nature and range of potential noise effects on equal terms, and could formulate their assessments of impact significance and acceptability without the need for technical knowledge of assessment techniques or noise terminology.
The fuzzy sets derived (see Figure 4a-e) demonstrate the heightened sensitivity of the Thorney residents (the village closet to the proposed site, at 2.4Km), and the contrast with residents of Crowland (a village 5Km distant) is particularly striking.

(a) Developer  
(b) Noise Consultant  
(c) Thorney Citizens  
(d) Crowland Citizens  
(e) CPRE Participant  
(f) Stakeholder Union and Intersection

**Figure 4.** Stakeholder Noise ‘Acceptability’ Fuzzy Set Membership Functions

This is further exemplified in Table 3 which shows the ‘cross-over’ value i.e. the noise level with set membership 0.5, below which noise levels become more ‘acceptable’ than ‘not acceptable’, and the degree of set membership for the worst case predicted impact (drawn from the final EIS).

**Table 3.** Cross-over Noise Value and ‘Acceptability’ of the EIS Worst Case Noise Impact Prediction

<table>
<thead>
<tr>
<th>Noise Level at Crossover i.e. 0.5 Set Membership (dB (A) Leq)</th>
<th>‘Acceptability’ of Worst Case Prediction (36.7 dB(A)Leq) (Degree of Set Membership)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Developer 47.5</td>
<td>1.00</td>
</tr>
</tbody>
</table>
With the exception of the Thorney residents the worst-case impact prediction has a high degree of membership in the set ‘acceptable’ and broadly comparable cross-over values. The sensitivity of the Thorney residents in this context is exemplified given that the 10 dB increment in the cross-over value between the developer and the Thorney citizens (Table 3) equates to a doubling of the noise level experienced.

The notion of acceptability was further examined across the different stakeholders using fuzzy set union (i.e. the maximum degree of set membership for each and every noise level across the stakeholders), and intersection (i.e. the smallest degree of set membership representing the most precautionary interpretation of ‘acceptability’)(see Figure 4f). Comparing perceptions in this way enables the identification of zones of potential disagreement e.g. with noise levels below 35 dB the difference between the maximum and minimum set membership is relatively narrow, as it is again for noise levels beyond 50 dB, indicative of less disagreement regarding notions of ‘acceptability’. This contrasts to the region between approximately 37-45 dB (noise levels that are close to the baseline conditions in the area) where the width of the graph is greater, indicative of more diversity in perceptions of what is considered ‘acceptable’.

4.2.3 Impact Prediction

By the impact prediction stage of EIA the detail and availability of environmental information increases dramatically and the evaluation of significance become an impact specific, disaggregated, technical / instrumental activity, based around the assessment of impact dimensions such as magnitude and duration. EIA is essentially an adversarial system within which the responsibility for supplying ‘appropriate’ environmental information rests with the project proponent, who consequently exerts considerable power and control over the analysis supplied in the EIS (Table 1). This raises the potential for communicative distortion and lexical uncertainty in the language terms and criteria used to communicate and evaluate significance.
For illustrative purposes we present results relating to: (i) a predominately qualitative impact, namely landscape and visual assessment, involving the actual project stakeholders at the Morris Fen case study; and (ii) a predominately quantitative impact involving an expert group assessment of air quality impact significance for NO$_2$ impacts at the Newhaven incinerator case study.

In the case of Morris Fen, a series of animated digital photomontages were used as a basis for determining fuzzy sets for a sequence of natural language terms to be used in the EIA namely: ‘negligible’, ‘slight’, ‘moderate’, ‘substantial’ and ‘very substantial’ effect. Results derived from the landscape consultant and the Thorney citizens are shown in Figures 5 and 6, enabling a comparison of expert and lay perceptions of impact significance. In both cases, a gradual fuzzy transition is revealed when moving from a ‘very substantial’ impact at one extreme in the sequence through to a ‘negligible’ impact at the other. For the consultant, a higher degree of set membership is generally evident for each linguistic term than is the case for the residents (reflected in the darker shading), and it is possible to identify ‘zones’ most closely associated with each term. These zones are also evident for the Thorney residents although they are less clearly defined, with lower set membership values.

The set ‘very substantial’ is the only one for which membership values are higher for Thorney citizens than for the consultant. This is most evident at close range to the development, where the number of turbines contained in a view clearly raises the perceived significance of the visual effect. For impacts that the consultant considered ‘slight’ and ‘negligible’, it is interesting to note that the degree of set membership changes very little with any increase in the number of turbines seen in the views, reflected in the almost vertical nature of the bands in the graphs. In contrast, for Thorney citizens, the pattern is such that the shaded bands more characteristically lie at right angles, suggesting that the design of a proposal (in terms of the number of turbines incorporated) does influence perceptions of impact significance.
Thorney Citizens

Very Substantial

\[ y = 0.514 - 0.104x - 0.020y + 0.008x^2 - 0.003y^2 \]
RMSE = 0.067

Substantial

\[ y = 0.382 - 0.091x + 0.028y + 0.007x^2 - 0.003y^2 \]
RMSE = 0.046

Moderate

\[ y = 0.176 + 0.059x - 0.031y - 0.006x^2 + 0.003xy + 0.003y^2 \]
RMSE = 0.045

Slight

\[ y = -0.040 + 0.069x + 0.023y - 0.003x^2 - 0.002y^2 \]
RMSE = 0.051

Negligible

\[ y = -0.027 + 0.064x - 0.001y - 0.006x^2 - 0.001y^2 \]
RMSE = 0.031

Figure 5. Fuzzy Classifications of Visual Impact Significance: Thorney Citizens
Figure 6. Fuzzy Classifications of Visual Impact Significance: Landscape Consultant

Landscape Consultant

Very Substantial

Substantial

Moderate

Slight

Negligible

Key: Fuzzy Set Membership

0.000 - 0.1
0.101 - 0.2
0.201 - 0.3
0.301 - 0.4
0.401 - 0.5
0.501 - 0.6
0.601 - 0.7
0.701 - 0.8
0.801 - 0.9
0.901 - 1

RMSE = 0.067
RMSE = 0.200
RMSE = 0.199
RMSE = 0.144
RMSE = 0.077
Clearly the boundaries between levels or degrees of impact expressed using such language terms are not clear cut, and fuzzy set analysis provides a methodology well placed to capture the ‘shades of grey’ that present a more realistic characterisation. Fuzziness can also occur in terms of the interpretation and understanding of degrees of impacts between different experts, and this was explored for air quality (NO$_2$) impacts for the Newhaven incinerator.

Figure 7 presents the model produced to describe the significance of air quality impacts and again illustrates the ‘shades of grey’ between linguistic terms. For instance, for an impact of 0.4 ugm$^{-3}$, the impact is a member of the set ‘low’ to degree 0.1, and the set ‘negligible’ to degree 0.9 - in other words, the impact might be considered “almost entirely negligible and very slightly low”. The evaluation appears to be most fuzzy in the range, 0.5 – 5 ugm$^{-3}$, for instance an impact of 2.5 ugm$^{-3}$ has a set membership of 0.06 negligible, 0.56 low, 0.29 moderate and 0.09 high.

Figure 7. Expert Group Assessment of Annual NO$_2$ Impact Significance

4.3 Critical Reflections on Fuzzy Sets and the Assessment of Significance in EIA

Fuzzy sets provide a theoretical framework which recognises that subjective judgment influences the use and meaning of language employed in the evaluation of significant effects. In this overall context, fuzzy sets were found to provide an effective means of capturing ‘interpretive knowledge’ (Innes, 1998) and articulating the perceptions that
underpin technical-subjective judgements in a way that remains sensitive to the particular environmental and social context. The approach is particularly successful in capturing the gradients that exist in relation to the degree to which a natural language term (e.g. ‘high’, ‘moderate’, ‘low’ etc) fits a given situation, whilst preserving and expressing in an explicit way the imprecision inherent to definition, thus enhancing the transparency of EIA decision-making.

In screening, the process of defining individual fuzzy thresholds linked to heuristics such as the size/scale of development can encourage practitioner reflection (Tewder-Jones, 1996) and provide an a priori assessment of a decision-makers ‘significance boundaries’. Fuzzy thresholds defined by an expert group provide a more detailed and realistic decision support aid than ‘crisp’ guidance thresholds, although they potentially undermine the certainty that such thresholds currently provide.

In terms of scoping and the fuzzy concept of impact ‘acceptability’, the approach can help scoping as a project design process and in terms of mitigation, and also with regards to gauging stakeholder sensitivity to an issue (and hence assisting the allocation of assessment resources). However, it does not necessarily serve to reduce the range of impacts to be addressed in the EIA.

Arguably fuzzy sets hold most promise in the evaluation and communication of impact significance in EISs, particularly when a range of stakeholder perspectives are captured. However, a key challenge relates to the construction of membership functions. To make impacts meaningful to a wide array of stakeholders we have employed a simulation approach that enabled participants to actually experience the nature of the potential effects. Despite the success of the approach in the context of noise and visual / landscape impacts (both in rural and urban settings), gauging the extent to which meaningful membership functions can be derived for a broader array of impacts requires caution – for instance where an impact is not immediately experiential, where it lacks any resonance with a stakeholder, or where values relate to fundamentally different ethical positions e.g. ecological impacts where values are underpinned by contrasting utilitarian, welfare, or moral positions (Adger et al, 2004).
The methodology has been shown to be flexible in the sense that fuzzy set analysis can be applied to impacts that are quantitative or qualitative, although we consider it is most effective where there is a strong link between the significance of environmental effects and an underlying quantitative continuous variable (especially related to magnitude), or when other factors e.g. receptor sensitivity can be held constant and systematically explored. The approach is less suited to areas that are dominated by highly qualitative assessment approaches (e.g. archaeology) or where quantitative dimensions do not capture the complete essence of the impact e.g. socio-economic effects. An index of impact significance can be created (e.g. Borjorquez-Tapia et al (2002) develop indices to represent impact intensity and ecological vulnerability) although the approach then becomes highly mathematical, more abstract, and effectively servers the powerful link with the underlying language terms.

Ultimately, important practical constraints may limit the application of fuzzy sets for evaluating and communicating impact significance in EIA. Firstly the time and resources required to elicit set membership functions is considerable. Secondly, due to the adversarial nature of EIA, encouraging the participation of the public and other stakeholders (including the developer) is likely to be problematic. Finally, the overall approach is conceptually abstract and would need careful explanation if it is not to be dismissed as overly technocratic and confusing amongst participants.

Where there is potential disagreement amongst technical specialists, expert-based fuzzy sets (as in the Newhaven air quality case study) hold promise, although it may serve to reinforce the dominance of orthodox, technically focussed approaches to the assessment. Another approach could involve establishing an EIA working group comprising an array of stakeholders (including members of the lay public), for establishing significance criteria involving fuzzy set analysis as part of an intensive deliberative process. This opens up the possibility of facilitating the transfer of information from the public and other stakeholders back to the experts, such that EIA moves towards a more transactive planning tool, involving an exchange of the processed knowledge of experts with the local knowledge of affected citizens in a more communicative orientated model.

5. Activities
(i) A major one day conference “Evaluating Impact Significance in EIA”, co-sponsored by the Institute of Environmental Management and Assessment (IEMA) was held at Oxford Brookes at the end of the award in September 2004. The conference included two papers from the research team, along with presentations from leading practitioners (see Annex 1). The conference was attended by over 85 people from academia, LPAs, consultancy, government, NGOs and regulatory agencies.

(ii) Findings from the extensive stage of the research were presented by Julia Becker at Planning 2003, Oxford, April 2003.

(iii) Findings relating to the intensive stage were presented by Graham Wood at the International Association of Impact Assessment annual conference in Vancouver, Canada, April 2004.

(iv) Graham Wood was interviewed by the ENDS Report, which subsequently published an article that draws extensively upon the research findings (“EIA in practice: New challenges in screening and scoping” ENDS Report 340, May 2003, pp 25-29).

(v) Graham Wood was invited to review the Environment Agency scoping guidance for Impact Assessment and Project Appraisal, the journal of the International Association of Impact Assessment.

(vi) EIA good practice examples were supplied to Phil Weatherby of the Office of the Deputy Prime Minister (ODPM) for use in a European meeting of government EIA agencies in June 2003.

(vii) Joe Weston has led three short courses “Screening Scoping and ES Review” designed to promote best practice amongst practitioners.

6. Outputs
To date a wide range of outputs have been produced (see Annex 2) including 3 journal articles, 4 conference papers, 2 reports to the ODPM (access to electronic copies of these was also made available to all survey respondents), 2 articles in the professional press, and four seminar presentations including to academics, practitioners, and the public. A project web-site has also been created to promote the research further and extend access to the study findings.

7. Impacts
Use of findings relating to the extensive stage of the research has far exceeded expectations, including dissemination by the ENDS Report and through more direct contact with practitioners via our short course “Screening, Scoping and ES Review”.

At a policy level, our scoping findings have fed directly into an ongoing research contract “Review of Scoping in Environmental Impact Assessment” for the ODPM (held by the University of Manchester and Land Use Consultants), and Graham Wood has been invited by the ODPM to sit on the Advisory Group Panel for this contract. As previously noted, best practice examples were supplied to the ODPM for use in a European meeting of government EIA agencies.

In the windfarm and urban case studies, the simulation approach employed was found to stimulate social learning (Webler et al., 1995) amongst members of the public involved in the workshops, with the researchers making time to facilitate open debate between participants in an informal forum. The simulation approach and data from the study have also been of considerable interest to a windfarm developer.

8. Future Research Priorities

Three priorities leading on from the research are identified:

1. The fuzzy sets and simulation approach was particularly suited to windfarm appraisal. Further development of the methodology and the study of the implications and effectiveness of its use as the central pillar of significance evaluation and communication in an ongoing EIA would be worthwhile. (By design the current research has been observational i.e. it has not sought to change the nature and communication of impact significance in the production of EISs).

2. Research which seeks to combine fuzzy set methodologies with participatory mapping techniques (Cinderby, 1999; Yearley et al., 2003) is worthy of investigation e.g. in noise mapping and management under Directive 2002/49/EC

3. Research which explores the treatment of impact significance in higher level strategic environmental assessment (SEA) is urgently needed.

Footnotes
1. As with conventional sets, specifically defined logic operations (including union and intersection) have been defined that allow the combination of fuzzy sets. Following Zadeh (1965), the union of fuzzy sets $A$ and $B$ is denoted by $A \cup B$ and corresponds to the logical connective ‘OR’, defined as the maximum degree of membership found in set $A$ or $B$. The intersection of fuzzy sets $A$ and $B$ is denoted by $A \cap B$ and corresponds to the logical connective ‘AND’, defined as the smallest degree of membership of the sets $A$ and $B$.

2. Selection of an urban case study broadened the type of projects considered beyond purely renewable energy schemes. This was partially in response to feedback on the original proposal received from the ESRC review panel, but it also served to enable comparison of the approach to visual impact appraisal across both rural and urban settings.

3. Paragraph A15 of Circular 02/99 (DETR, 1999) states “The likelihood of significant effects will generally depend upon the scale of the development, and its visual impact, as well as potential noise impacts. EIA is more likely to be required for commercial developments of five or more turbines, or more than 5MW of new generating capacity”.

4. This example has particular policy relevance, as Annex 13 of Planning Policy Guidance Note PPG22: Renewable Energy requires windfarms to be located so that noise levels are kept to acceptable levels, but provides no indication of what “acceptable levels” are.
Annex 1. “Evaluating Impact Significance in EIA”: Conference Details

These can be accessed electronically at:

http://www.brookes.ac.uk/schools/be/planning/shortcourses/media/EI_significance_EIA.pdf!
Annex 2. Research Outputs

Journal Articles

Wood, G.J., and Becker, J., (submitted). Screening development proposals for environmental impact assessment: discretion and diversity in local planning authority decision-making. *Journal of Environmental Planning and Management*


Conference Papers


Reports


Professional Press


**Research Seminars and Presentations**

May 2003: Graham Wood presented “Screening development proposals for Environmental Impact Assessment” to the Planning Practice Liaison Committee, Oxford Brookes University, Oxford

July 2003: Julia Becker presented “Ecological effects and the treatment of impact significance in EIA” to the Crowland Wildlife Trust, Crowland, Lincolnshire

April 2004: Graham Wood presented “Fuzzy sets and simulated environmental change: evaluating and communicating impact significance in EIA” at the Department of Planning and Landscape Research Seminar, University of Manchester

June 2004: Graham Wood presented “Evaluating the significance of environmental impacts using fuzzy sets” to the Thames Valley Environmental Protection Advisory Group, High Wycombe.

**Other**

A project website providing details of the research and outputs has been developed and is available at:

http://www.brookes.ac.uk/schools/planning/iau/ESRC.html
References


