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# THE DEVELOPMENT OF AN EXPERT SYSTEM FOR THE ACOUSTICAL DESIGN OF URBAN SITES

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## 1. INTRODUCTION

Expert systems are one outcome of many decades of research into Artificial Intelligence. They represent the realisation that the ultimate goal of a machine, which is truly intelligent, remains a distant dream but that considerable benefits can be gained from the application of computer software, which at least mimics some aspects of intelligent behaviour [1]. Expert systems can be described as a program, which includes expertise or knowledge that enables an individual or group lacking that expertise to perform an intellectual task. In developing an expert system one would normally assume that the potential user has little or no knowledge of the subject area. The expertise can be encoded within a program as declarative knowledge, which represents truth as a state, or as algorithms and can therefore be flow-charted.

Whilst expert systems have been developed for many applications there appear to be few concerned with acoustics [2]. This paper is concerned with the development of ENA (Environmental Noise Advisor) which is aimed at providing a designer with expert advice at all stages of the development of a site in the vicinity of potential noise sources.

## 2. ELEMENTS OF AN EXPERT SYSTEM

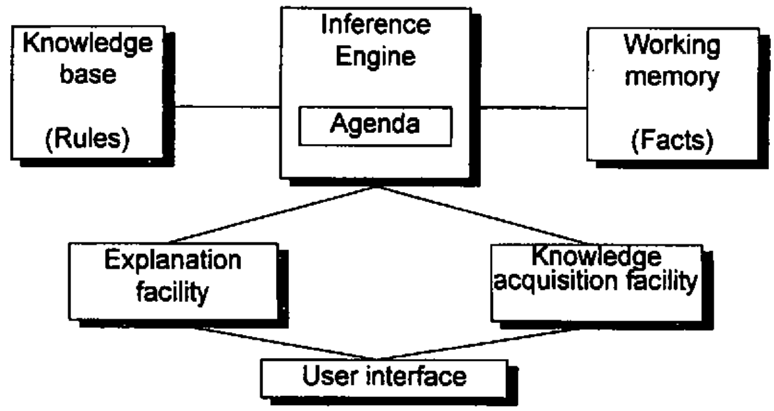


**Figure 1. Elements of a Typical Expert System.**

The elements of a typical expert system are shown in Fig (1). The *knowledge base* contains the domain knowledge needed to solve problems frequently coded in the form of rules. The other elements of an expert system include: the *user interface* which is the mechanism by which the user and the expert system communicate; the *explanation facility* which explains the reasoning of the system to a user; the *working memory* which is a global database of facts used by the rules; the *inference engine* which decides which rules are satisfied by facts and prioritises the satisfied rules; and *the knowledge acquisition* facility which is an automatic way for the user to enter knowledge in the system rather than by having a knowledge engineer explicitly code it.

Knowledge acquisition is the process of eliciting, analysing and modelling the knowledge that an expert system will use to solve a specific problem [1]. A starting point in developing a specification is to analyse the contribution that such an expert might make. Buchanan et al [3] have proposed the model of knowledge acquisition shown in Fig. (2).

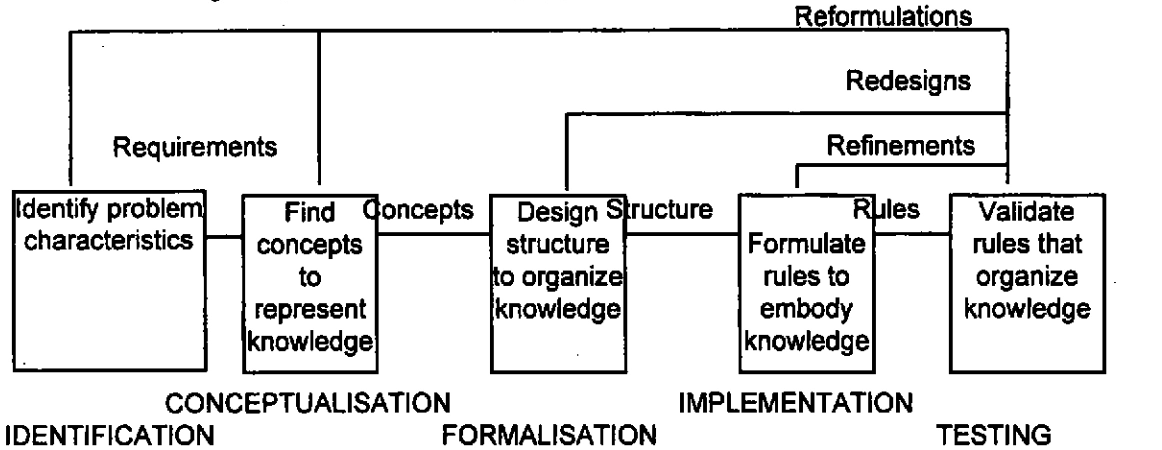


**Figure 2. Stages of Knowledge Acquisition.**

This paper is concerned with the identification and representation of the knowledge.

# 4. IDENTIFICATION OF PROBLEM CHARACTERISTICS

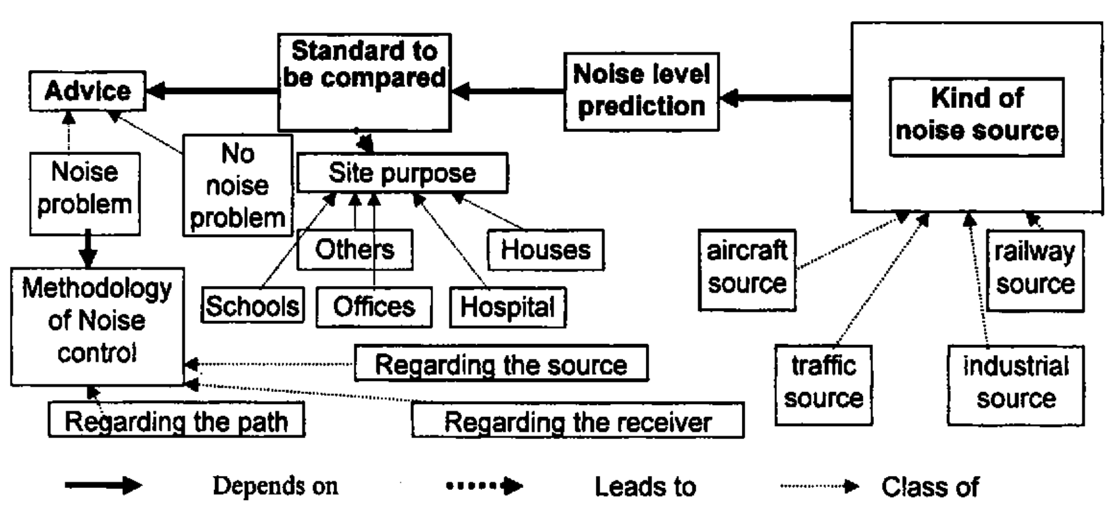


**Figure 3. Procedure Followed by Noise Control Experts**

Extensive discussions with a single expert resulted in the specification of outline requirements. These were used to draw up a questionnaire, which was used to initiate discussions with eight other experts. Following this it was concluded that the expert system has to replicate the procedures followed by experts as shown in Fig.(3). The system is required to do the following:

- Predict the noise level arising from one or more noise sources over the site using the methods employed by experts.
- Reach conclusions regarding the planning of the site according to the predicted level. This conclusion will relate to how the noise on this site compares to relevant noise standards.
- Give advice depending on what is acceptable to the user such as the cost of noise control measures and design concepts.
- Provide the user with a step by step explanation of the reasoning which has led to the recommendations.
- Have an interface which is user friendly.

## 4. KNOWLEDGE REPRESENTATION

The objective of ENA is to provide advice to the designer seeking to develop a site in close proximity to potential noise sources. ENA requires the input of information relating to two parameters before such advice can be offered. These are the maximum acceptable level of intrusive noise and the external noise level at a position on the site. In the case of the former this will be determined by the proposed function of the building. In the case of the latter this might be measured data or, more likely, the results of applying a standard predictive technique. In order to provide advice ENA has to relate these parameters to a third parameter which quantifies the performance of various noise control strategies so that it can make appropriate recommendations.
Discussions with the panel of experts resulted in the identification of published information containing the relevant knowledge regarding internal standards, noise prediction methods and the acoustical performance of noise control strategies. These sources were located and employed in the next stage.

## 5. STRUCTURE OF KNOWLEDGE

In the case of noise standards and acoustic performance, the information was typically in tabular form. For example, locations and corresponding maximum permissible background noise levels and wall construction and corresponding average insulation. Information in this form is very easily built into a knowledge base. External noise levels, on the other hand, tend to be a value at a specific location. However, there was remarkable agreement amongst all experts about the usefulness of using the concept of noise exposure categories such as those employed in PPG24[4].This suggested an approach to the structure of the knowledge base in terms of Internal Standard Categories ($IS_C$), Noise Exposure Categories ($NE_C$) and Noise Reduction Categories ($NR_C$). Design advice could then be offered in terms of strategies capable of achieving a Noise Reduction Category calculated from the following simple relationship:

$$NR_C = NE_C - IS_C$$

In using these various categories means that all aspects of the calculation are expressed in terms of discrete "quanta". The magnitudes of the ranges of each category have a considerable importance for the performance of the system. The choice of wide range, say 10 dB, will result in a very blunt design tool with the danger of over specification or under specification of design solutions. On the other hand, the choice of a very narrow interval, say 1 dB, would result in a large unwieldy system. The intervals employed for noise exposure categories in PPG24 are 8 or 9dB.

In deciding upon the class intervals for ENA the first decision was that they should be the same for all three categories. Data relating to internal noise standards and noise reduction performance were then examined. The former were found to lie neatly within 5 dB steps and the latter could also be conveniently classified in 5dB intervals. As a consequence it was decided to express the noise exposure categories in terms of 5dB class intervals. Figure 4. shows how this approach can be applied to achieve a particular value of $IS_C$.

| Noise performance class($NR_c$) / Exposure category($NE_c$) | Class (1) | Class (2) | Class (3) | Class (4) | Class (5) |
|---|---|---|---|---|---|
| Category (A) | Optimum noise performance for Category A | | | | |
| Category (B) | | Optimum noise performance for Category B | | | |
| Category (C) | | | Optimum noise performance for Category C | | |
| Category (D) | | | | Optimum noise performance for Category D | |
| Category (E) | | | | | Optimum noise performance for Category E |

**Figure 4. Relationship between Noise Exposure Category and Noise Performance Class**

## 6. FORMULATION OF KNOWLEDGE

In turning of knowledge formalisation, knowledge has to formulate into an executable program, one is primarily concerned with the specification of control and the details of information flow. Rules will have to be expressed in some executable form under a chosen control regime, while decisions must be made about data structures and the degree of independence between different modules of the program [5]. The options available to the designer of an expert system range from the use of any general purpose programming language, through the use of programming languages developed for specifically Artificial Intelligence to so-called expert system shells. The latter are "ready made" expert systems which require developers to incorporate a subject specific knowledge base and rule base. Expert system shells provide the most rapid means of developing an expert system but may impose some restrictions on what can be done.

The procedures followed by noise control experts can be represented in the form of flow charts. As an expert seeks to solve a problem he or she will branch to different options such as those relating to the kind of noise source. The facts associated with the procedures followed by the expert can be represented as production rules (IF...THEN rules). The Leonardo expert system development tool was selected for ENA because its ease of use, knowledge representation and default consultation environment were judged most suitable for this work. The shell was originally developed by Creative Logic, but is now being enhanced and supported by Bezant Ltd. It is consists of an empty knowledge base and an inference engine which includes both backward and forward search mechanisms. Furthermore, it has most of the knowledge representation forms that is, production rules, frames, classes, procedures, screens and the capability of interfacing with other programs. In Leonardo, the prototyping a knowledge based system in coding of facts and rules, the inference engine provides the medium process, the end - user interface provides the methods of consulting the system and the explanation facility provides the responses to user queries during consultation.

The knowledge base formalised in the previous section was implemented as a set of knowledge that represents rules, heuristics and calculation procedures. The implemented knowledge can produce conclusions regarding traffic, rail and industrial sources separately or together at the same run time. Figures (5) and (6) give examples of typical rules and a frame of the ENA knowledge base.

```
if stage2 is done
and sourcekind excludes 'Railway source.'
and sourcekind excludes 'Industrial source.'
and predict_traffic is done
then final_pred_lev=final_level;
source_prediction_stage is done

if establishing_site_perf is done
and sourcekind excludes 'Traffic source.'
and sourcekind excludes 'Industrial source.'
and sourcekind excludes 'Aircraft source.'
and catagories_to_establish_rail_or_air is done
then consultation is done.
```

**Figure 5. Typical rules in ENA knowledge base.**

Name: Percentage of heavy vehicles
Type:TEXT
LongName:
Value:
ertainty: {0.0}
DefaultValue:
AllowedValue:High,Medium,Low,Not permitted
ComputeValue:
OnError:
QueryPrompt: The percentage of heavy vehicle in the traffic road is:
QueryPreface: Please, give me a description of the heavy vehicles situation In your traffic road.
Introduction:
Conclusion:
AVExpansion:
-
High percentage means the range of 40 % of the road traffic volume.
-
Medium percentage means the range of 25 % of the road traffic volume.
-
Low percentage means the range of 10 % of the road traffic volume.
-
The heavy vehicles not permitted through the road.

**Figure 6. Typical frame in the ENA knowledge**

The ability of knowledge base systems to provide an explanation when the end-user asks during the consultation is a key characteristic that distinguishes them from conventional programs. Rules and questions have explanations attached which are used whenever the user asks why a question is being asked or how a conclusion was reached [6]. When the explanation facility is called the system is currently trying to prove a certain clause within a particular rule [7]. ENA's knowledge has been represented in form of rule based deduction systems. This approach enables the system to explain how and why it performs certain actions. In ENA, three explanation reporting facilities have been used. One is in terms of a "WHY" facility which gives an explanation as to the reason for particular questions or actions. At any time during the consultation, the user can press the "F3" key to activate the "WHY" facility. For example if ENA is asking the following question:

*What is the kind of the traffic road?*

The user can press the "F3" key to see why ENA is asking him/her this question. The system responds will be as seen in figure (8).

The second is the "HOW" facility used in describing the process taken by the system in performing some actions or concluding some results. This facility is available at the end of the consultation session and allows the user to trace backward in the reasoning chain. This facility is activated by pressing the "F4" key. For example, ENA concluded that the site was category (A) and introduced the required conclusion regarding this category. When the user pressed "F4" key to activate the "HOW" facility, the system response is as shown in Figure (9).

*In predict_traffic, I am using the rule:*
*If stage3 is done*
*and traffic_road is 'Rural road.'*
*and accurate_rural is 'Normal 7.3m single carriageway.'*
*then Q = 13000 vehicle/hour;*
*v = 50 mile/hour*
*predict_traffic_Q_v is done*
*to establish the value of predict_traffic_Q_v and the value of traffic_road is not known and can not be inferred.*

**Figure 8. ENA responds when the user activates the "WHY" facility.**

*To find if conclusion was done, I used MAINRULESET, Rule:*
*if establishing_site_perf is done*
*and Categories_to_establish is done*
*then Conclusion is done.*

**Figure 9. ENA response when the user activates the "HOW" facility.**

The third available facility in ENA is the HELP explanation. This facility is automatically generated each time the system questions the user. This facility contains information and examples to help the user to answer questions. The HELP facility is activated by pressing "F1" key at any time during the run time.

The main rule set supplies the fundamental control for the knowledge base. The concept or the plan of the control strategy in the main rule set orients ENA's search techniques to the planned procedures. Figure (10) presents the plan of the main rule set in ENA.

The default search technique in Leonardo is backward chaining. I in effect, after ENA is activated, the goal is the first state the inference engine will look for. The ENA goal state is written in the main rule set in the form of" *SEEK CONSULTATION*". The search will go back using backward chaining looking for the necessary rules, which will qualify this goal. To be captured, "RULE FIVE" needs the standard to be established. The search will go back looking for the necessary rule for establishing the standard. Then "RULE FOUR" has to be captured and so on till arriving at "RULE ONE". This is was a first stage "backward chaining". The second stage comes using "forward chaining", this is by firing "RULE ONE, TWO, THREE, ...etc." until arriving to the goal.

At the beginning of execution, all objects with a "Fixed Value Slot" are set to the value in the slot. All "ask", "run" and "use" assertive rules are executed in the order in which they appear in the "main rule set".

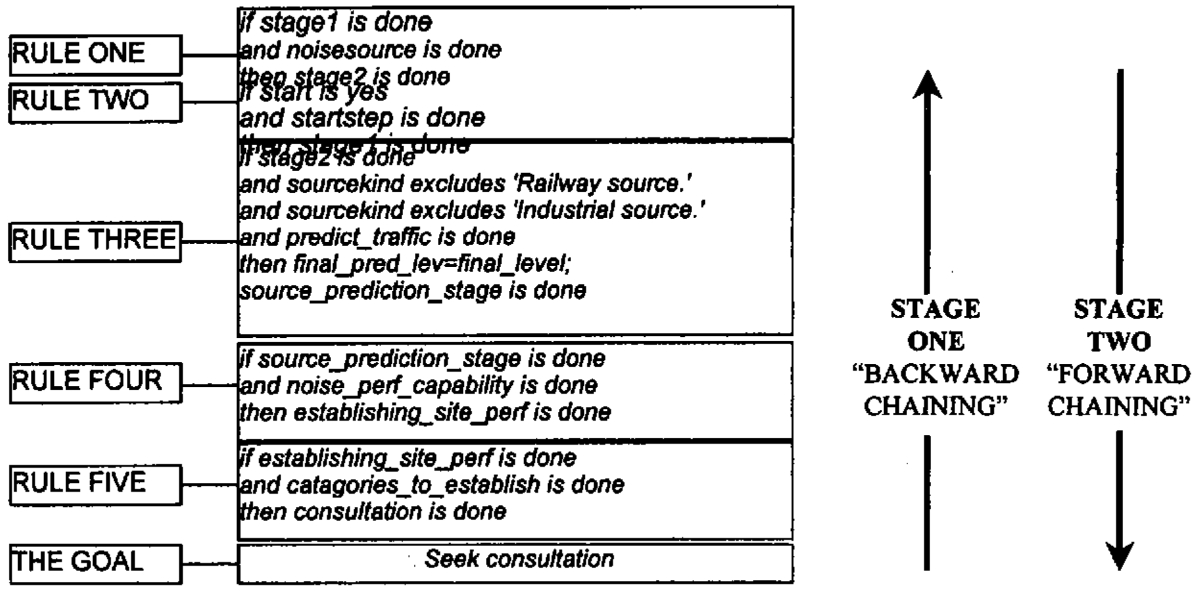


Figure 10. The concept of the control techniques in ENA main rule set.

## 7. VALIDATION

At the time of writing the validation process has yet to be undertaken. It is proposed that it will take two forms. The first will involve the technical content with design solutions proposed by ENA for a variety of site configurations being evaluated against detailed design methodologies. The objective will be to establish whether the design solutions proposed by ENA result in satisfactory conditions without being over cautious. The second will involve the use of ENA by a mixture of experts and novices with a view to establishing its limitations.

## 8. CONCLUSION

The paper has introduced ENA, an expert system for the identification and evaluation of environmental noise problems and the provision of advice to the designer regarding the development of a site. Interviews with a number of experts have yielded a specification for the system. Sources of knowledge have been identified and examined and a structure for the knowledge base established. The knowledge base has been implemented in the Leonardo expert system shell in the form of production rules.

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