Journal of Industrial Microbiology, 12 (1993) 263–267

Published by The Macmillan Press Ltd

The concept and application of expert systems in the field of microbiological safety

Carol Adair and Philip A. Briggs

Unilever Research, Colworth House, Sharnbrook, Bedford, UK

(Received 18 December 1992)

Key words: Expert systems; Microbiological safety; Chilled meals; Predictive modeling

SUMMARY

Recent developments in microbiology have led to the construction of mathematical models that can be used reliably to predict the growth and death responses of microorganisms under a wide range of situations relevant to food safety and spoilage. During the same period developments in available software and hardware platforms for information technology (IT) have meant that the construction of expert systems in disciplines like microbiology have become a reality. The concept and stages of development of an expert system are described using an example of a prototype system that assesses the microbiological safety of chilled ready-to-eat meals.

INTRODUCTION

Recent developments in microbiology have meant that a more systematic approach is taken to problem solving and that the knowledge is becoming more structured and organized. This can be seen in the application of the Hazard Analysis Critical Control Point (HACCP) concept to microbiology, the gathering of quantitative data for predictive modeling and the move from Quality Control to Quality Assurance for food manufacturing where the processes are more stringently controlled.

Developments in information technology (IT) can be seen as the application of computers to an increasingly wide range of tasks. Each technical advance has made computer power available to new groups of users with different types of problems to solve. A few years ago the idea of developing 'true' expert systems in the microcomputer environment would have been the subject of derision amongst serious artificial intelligence researchers [8]. Microcomputers are now equipped with multi-megabyte memory, increased processor speed and large mass storage capacity which all allow expert system technologies to be applied successfully without the need for large remote processors.

Developments in both disciplines mean that the construction of real expert systems in microbiology is now a possibility.

Correspondence to: Carol Adair, Microbiology Section, Unilever Research, Colworth House, Sharnbrook, Bedford, MK44 1LQ, UK.

THE CONCEPT OF EXPERT SYSTEMS

Expert systems originated from a field of academic research, artificial intelligence, which set out to embody computers with some degree of what is generally considered to be intelligent behavior. Expert systems, then, are computer programs that attempt to emulate the performance of human experts [5].

The structure most commonly used to represent expert knowledge in software is described as a knowledge base and this provides a more varied and flexible way of representing information than conventional software. The knowledge base normally stores expertise in the form of rules and/or objects.

Rules, or conditional 'if...then' statements are common in scientific fields, and expert systems have found success in applications such as medical diagnosis, oil prospecting, and chemical analysis because the knowledge in these areas is well established and well organised.

Similar successes have been achieved in the use of expert systems with invented, rather than natural, rules. For example, there are expert systems which can advise on the complexities of tax regimes, pension schemes and computer configuration. The structure of the knowledge in these areas is well defined.

Rules

The concept of storing knowledge in rules is as straightforward and logical as the name might imply. Examples of expert system rules might be:

Rule 1: If A is true
and B is true
then
C is true

Rule 2: If C is true
or D is true
then
E is false

Rule 3: If E is true
then
F is true

Expert system software uses what is known as an inference engine to search through the knowledge base in response to external signals, which might be user queries, or direct input from other electronic sources or software.

For instance, using the above rules, a user might type into the system the fact that A is true. The inference engine will look for rules which will make use of that fact. Rule 1 can use the fact, but only if B is known. A value for B might be elicited from the user or might, for example, be found in a database. If B is found to be true, then the expert system will infer that C is true (rule 1), and seek to make use of that new fact. It can be used in rule 2 to prove that E is false. No inferences can logically be drawn about F, as the fact that E is false is not sufficient a condition to conclude that F is false.

Objects

A second widely used means of representation is to store knowledge in the form of objects or frames. Each object is an independent entity which has a series of associated attributes or properties and procedures which are available for processing. Objects can inherit attributes from other objects and a complex network of interrelated objects may be formed. In expert system applications objects and rules are usually combined to give a powerful representation and programming style.

In a microbiological example an object might be *Staphylococcus aureus*, which would belong to the class *Staphylococcus*, and would have attributes such as infective dose, thermal resistance, salt tolerance etc. Each attribute would have a value specific for *S. aureus* or an associated procedure such as an equation for determining the value. The attributes themselves, and in some cases the values of those attributes or the associated procedures, could be inherited from the class of objects *Staphylococcus*. Figure 1 shows an example of objects and classes, properties and values.

DEVELOPMENT OF AN EXPERT SYSTEM

Expert systems are no different from any other form of software in that it is vitally important to have a requirements specification at the start of development. Confining the scope of the knowledge to manageable proportions is particularly important as it is easy to be over-ambitious with the size of project. The requirements specification should cover the following items.

Problem statement

Why is the expert system needed in the first place? What problem is it aiming to solve? Is there an expert available to provide the expertise?

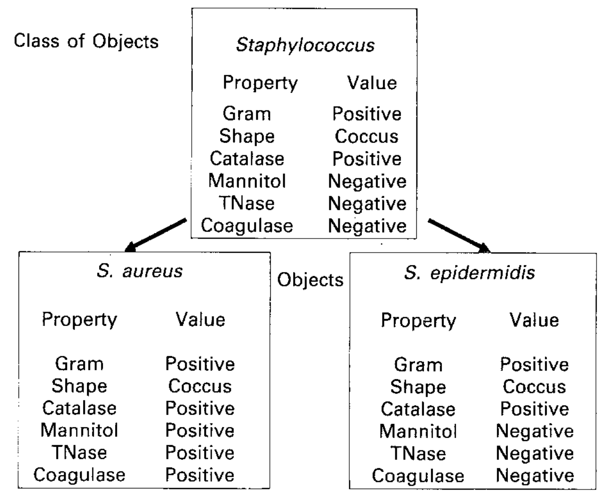

Fig. 1. Expert systems: objects and properties.

Operational concept and definition of the whole system

The intended scope of the system must be defined as well as the end users. Will it be used by experts to aid their decision making or is it to be used by non-experts?

Objectives and benefits of the whole system

The system will capture expertise in a defined area. The benefits will always include consistency of decision making.

Definition of the prototype

Prototyping is a technique for developing computer systems and is characterized by iterative development of a simplified system or part of the system. Exploratory prototyping models all or part of the functions and user interface of the full system [1]. Expert systems are normally built on a prototyping basis with the prototyping exercize itself functioning as a technical feasibility study. The boundaries of knowledge to be included in the prototype should be defined.

Figure 2 shows a flow chart defining the process for the development of a prototype expert system.

KNOWLEDGE ACQUISITION

Many human experts rely on rules of thumb, gut feelings or intuition to make correct decisions or judgments. These 'heuristics' are often necessary for computer systems faced with so many possible linked causes and effects that it would be impossible to investigate them all (good examples are the chess playing programs which use heuristics to eliminate silly moves from all the vast range of possibilities).

In building expert systems, the skills of the expert need to be formalized and subsequently transferred into computer code. The person who performs this task is usually called a 'knowledge engineer'. The job of engineering the knowledge can be an extremely demanding and time-consuming task for both the expert and the knowledge engineer and is the most important step in the construction of any expert system and should not be underestimated.

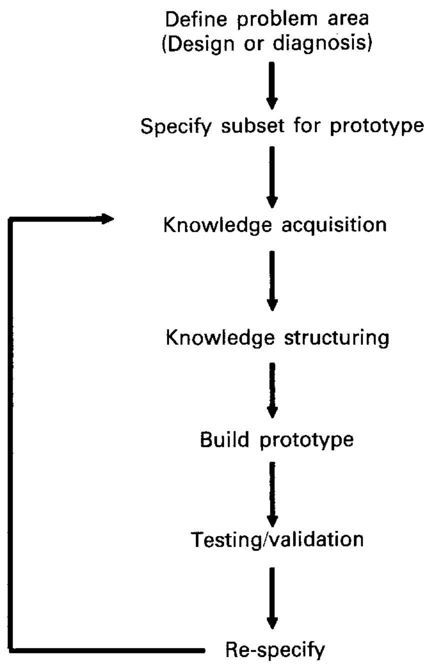

Fig. 2. Expert systems: development of a prototype.

The knowledge engineer usually engages in intense interview with the expert and then encodes the knowledge into a language of choice, encoding the facts into objects and rules [7].

HARDWARE AND SOFTWARE

Selection of hardware and software for an expert system application should follow the same procedure as for any other software development. Ideally software should be selected first to match the application required. A whole range of approaches is possible, ranging from the use of high level expert system shells through to coding in a low level language. Hardware appropriate to the software can then be chosen although, in practice, there may well be financial or organizational constraints.

Expert systems are by their nature often highly interactive and particular attention should be paid to the user interface. It may be worth considering separate interface software linked to the expert system software.

EVALUATION AND TESTING OF EXPERT SYSTEMS

Once an expert system has been built it is important, of course, to ascertain the accuracy of the embedded knowledge and the accuracy of any advice or conclusions that the system provides. This will be done by the expert. Evaluations by users will determine the utility of the system, namely whether it produces useful results, the extent of its capabilities, its ease of interaction and its reliability [4].

THE APPLICATION OF EXPERT SYSTEMS

Examples of expert systems can now be seen in many areas of microbiology, for example, in diagnosing bacterial infections and interpreting microbiological data [2,6].

In our laboratory we have built a prototype expert system to determine the feasibility of a full system which would enable us to assess the microbiological safety of many food products. The system, at present, contains knowledge for chilled ready-to-eat meals. In defining the requirements of the prototype it was decided to concentrate on the design aspects of chilled ready-to-eat meals and not the diagnosis of faults in products. This was important to the way the information was structured during development of the prototype, especially the rules.
The system is divided into four sections:

- a database of information on the manufacture of chilled ready-to-eat meals
- a database of information on microorganisms
- a meal design knowledge base
- a predictive modeling spreadsheet system

The system links together three different types of software packages:

- a hypertext system which provides the interactive interface with the user
- an expert system shell which provides the structure for the rule and object base, and the inference engine which carries out the reasoning process
- a graphical spreadsheet which provides a means of interrogating the predictive bacterial growth models.

Manufacture of chilled ready-to-eat meals

The knowledge contained in this section deals with microbiological aspects of producing unpreserved foods which rely mainly on temperature to maintain their microbiological safey and quality. Chilled ready-to-eat meals are intended to give every apearance of being freshly prepared in the kitchen.

The knowledge is subdivided into sections on distribution, packaging, processing, products, shelf life and microbiology.

Microorganisms

The database of information on food pathogens and spoilage organisms is chosen from the contents map or index for the system. For each organism chosen, a new window opens up displaying a fact sheet about that organism.

For each pathogen the following facts are displayed:

- description of microorganism
- severity of hazard
- reservoirs of infection
- temperature range for growth
- pH range for growth
- water activity range for growth/salt tolerance

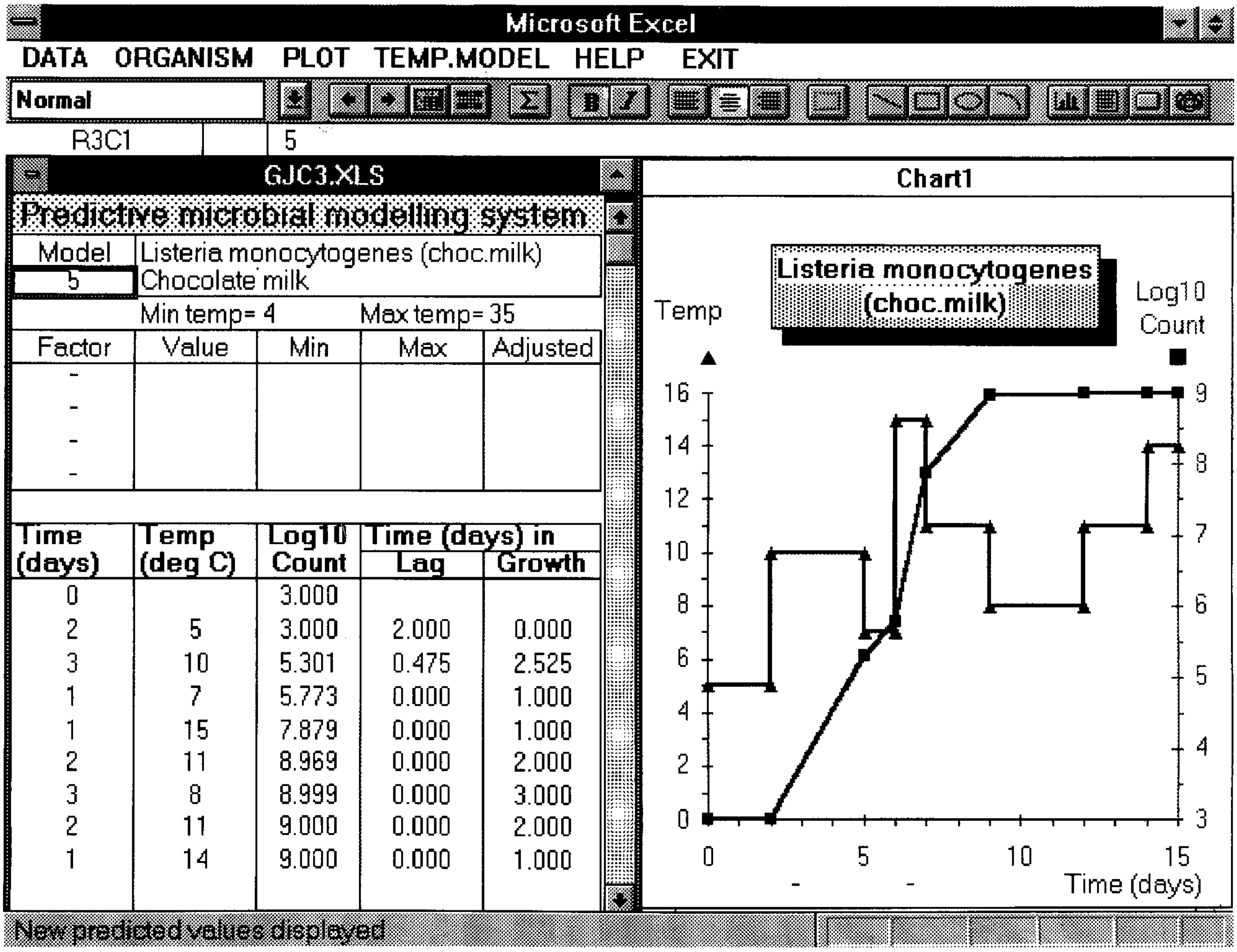

Fig. 3. Expert systems: screen from prototype expert system demonstrating the effect of fluctuating temperature on the growth of *Listeria monocytogenes*.

- survival (freezing/drying)
- thermal resistance
- ionizing radiation
- infective dose
- main symptoms in man
- mode of transmission
- incubation period
- susceptibility and resistance
- treatment
- microbiological analysis
- raw food materials
- processed foods

A similar scheme exists for spoilage organisms with a more limited range of categories.

Meal design knowledge base

This section is the true expert system in as much as it is here that the rule base is applied in response to users inputs to give processing recommendations. The system requires inputs on the ingredients to be used in the meal, the shelf life of the meal and how the meal is to be assembled in production.

Once the system has these inputs, it displays a recommendation of the processing requirements for a microbiologically safe ready-to-eat meal. These recommendations cover assembly and packing conditions, minimum thermal process and maximum shelf life at a given temperature. The inputs can be amended and the system re-run to provide a 'what-if' capability.

Predictive growth modeling section

On entering this section the users are confronted with a list of growth models available to them. These cover a wide range of both pathogens and spoilage organisms.

The models can be interrogated to investigate how changes in environmental conditons, such as temperature, pH and water activity, affect the growth of microorganisms. The system incorporates the ability to model changing temperature with time. Figure 3 shows an example of a screen from the system.

Multiple windows can be opened up during a session and when environmental conditions are altered the graphical display instantly recalculates the predictions.

This spreadsheet system is still being developed but it shows great potential.

BENEFITS OF EXPERT SYSTEMS

There are many potential benefits for expert systems. The main benefits expected to be gained from the application under discussion are noted below.

- Multiplying available skills by allowing organizations to offer a more widespread expert service without increasing costs.
- Saving valuable time of busy experts.
- Ensuring consistency of decision making.
- The process of knowledge engineering itself is of great value in formalizing knowledge and identifying inconsistencies and gaps, irrespective of the final system.

THE FUTURE OF EXPERT SYSTEMS

Many expert systems are understood as 'intelligent advisors' since their most useful function is to speed up the tedious preliminaries necessary to any informed decision in a complicated area of human activity. They can assist human beings and make them more productive. Where there is a shortage of skilled workers or experts, expert systems may help to fill the gap by providing answers to the less complex types of problem.

In microbiology, expert systems will be used to provide intelligent interfaces for national and international databases for predictive microbial models [3]. In the UK, the Ministry of Agriculture, Fisheries and Food is funding a program which has produced a computerized predictive microbiology database for food safety. Work is under way at present to create the expert system to allow non-experts to access the relevant models. There is much interest in developing expert systems to aid HACCP studies, and microbial identification and methodology.

ACKNOWLEDGEMENTS

The authors would like to thank Dr Martin Cole for his helpful comments during preparation of this manuscript.

REFERENCES

1 Born, G. 1988. Guidelines for quality assurance of expert systems in Computing Services Association Working Group on QA and Expert Systems, Working Paper, Issue 1.1.

2 Buchanan, B.G. and E.H. Shortliffe. 1984. Rule-Based Expert Systems: The MYCIN Experiments of the Stanford Heuristic Programming Project. Addison-Wesley, Reading, MA.

3 Cole, M.B. 1991. Databases in modern food microbiology. Trends Food Sci. Technol. 2: 293–297.

4. Gaschnig, J., P. Klahr, H. Pople, E. Shortliffe and A. Terry. 1983. Evaluation of expert systems: issues and case studies. In: Building Expert Systems (F. Hayes-Roth, D.A. Waterman and D.B. Lenat, eds), pp. 241–280, Addison-Wesley, Reading, MA.

5 Harmon, P. 1990. Creating Expert Systems for Business and Industry. John Wiley & Sons, Inc., New York.

6 Lusth, J.C., A.K. Bhatt and G.V. Meehan. 1989. An Embedded Knowledge-based System for Interpreting Microbiology Data in Proceedings of the Second Annual IEEE Symposium on Computer-Based Medical Systems, pp. 76–80, IEEE Computer Society Press.

7 Reitman Olson, J. and H.H. Rueter. 1987. Extracting expertise from experts: methods for knowledge acquisition. Expert Systems 4: 152–168.

8 Shafer, D.G. 1985. Microcomputer-based expert systems: where we are, where we are headed. Expert systems 2: 188–195.