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RECOT: an expert system for the reduction of environmental cost in the textile industry

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Abstract *Environmental legislation and its enforcement has undoubtedly forced the textile industry to be rather cautious in selecting the appropriate processes and equipment. The most efficient, economic and minimal environmental pollution processing methods will be increasingly demanded throughout the 1990s. However, the majority of the textile industry consists of small and medium enterprises, where the lack of expertise on the use of best available techniques leads to levels of operation far away from the optimal. An expert system for a priori economic evaluation of potential interventions in the textile manufacturing processes and equipment is necessary to support decision making in the management level. This paper presents such an expert system, designed and implemented in four stages: formal description of the key factors that affect the dyeing process in the textile industry, development of models for the representation of relevant information, development of models for the representation of knowledge and integration of the above-mentioned models in a unified information system that supports the decision-making process in the management of textile enterprises.*

1. Introduction

The textile industry is one of the most productive and active sectors of European industry, with a high level of exports and high added value. In the framework of improvement of the production processes and the quality of products, the capability for rational use of resources and selection of optimized production processes plays a significant role. Moreover, the capability to select and apply environmentally optimized processes, which minimize the pollution of the environment according to the European standards (ECOaudit, ECOlabel), is a key factor of efficiency.

Despite the fact that the potential environmental pollution level is a highly critical parameter for most of the textile industries, there is no capability for them to analyze it before dyeing. Moreover, because of the lack of appropriate systems for environmental pollution control, most of the textile industries in Europe make a rough estimation of the economic and environmental cost. Hence, they usually operate at levels which are far from the environmental pollution standards. So, the wet processing of textiles, and especially dyeing, is highly polluting, while a total lack of rationalization of the use of natural resources (energy and water) is observed.

Some efforts have been made in the past in order to deal with this problem, although they were solitary and characterised by a low degree of integration. The environmental parameter has not been taken into account in the rationalization of the use of resources in the textile industry, even when it has been approached by using scientific methods. This problem cannot be seen regardless of other parameters, because in this case we are led to a development without props and perspectives. In addition, the majority of

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the textile industry in Europe consists of small and medium sized enterprises (SMEs), where the lack of expertise in the utilization of best available techniques (BATs) leads to levels of operation far from the optimal ones. These enterprises could be supported by an expert tool, in order to review, evaluate and select the most suitable BATs. To respond to this need, the expert tool should incorporate knowledge and experience in the domain of textile production "clean" techniques and provide a two-step evaluation of available BATs which are as follows:

(1) Environmental evaluation to select a set of technically appropriate processes and equipment to respect environmental standards.

(2) A priori economic evaluation to select, from the previously identified set, the processes and equipment with the highest cost-benefit ratio.

In this framework, this paper comes to propose a knowledge-based expert system approach as a tool for effective *R*eduction of the *E*nvironmental *CO*st in the *T*extile industry (called RECOT). The author's main goal is to advocate the concept of solving such problems by using an expert system (ES) approach and to show how a system of this kind can be developed.

2. The dyeing process

Textile wet processing is executed in a multitude of stages, including dyeing, sizing, desizing, weaving, scouring, bleaching, mercerization, carbonising, fulling, milling, printing, washing and finishing. Dyeing is one of the most complex and diverse processes, characterised by a multitude of factors that affect the results of the process, including the pollution cost.

The complexity of the dyeing process can be demonstrated even by considering only one of the factors that characterise the whole process, which is the type of fibre. There are several types of fibres, and different basic guidelines which apply to each one of them. There exist natural fibres (animal fibres and vegetable fibres) and man-made fibres (polyfibres and cellulosic fibres). Polyfibres include polyamides, polyesters, acrylics and modaclylics, vinyls and vinylidines, spandex, polyolefins and fluorocarbons. Nylon is the most important representative of polyamides. Dyeable acrylics are generally copolymers with modifying constituents. Dyeability of wool, acrylic, modacrylic and nylon is good, while polyesters are difficult to dye. For the dyeing of vinyls and vinylidines, colour is added by introducing pigment into the mass. Polyolefins are difficult to dye. The generic term of cellulosic fibres comprises the group of regenerated cellulose and of cellulose esters.

A classification of dyes is given as follows.

- Acid dyes are used for dyeing protein fibres such as wool, silk and nylon, leather and paper as well. The application of acid dyestuffs is mainly a process of chemical combination.
- Azoic dyes are brilliant and long-lasting and are used primarily for printing on cottons.
- Basic dyes can be used to dye wool or cotton with a mordant, but are usually used for duplicator inks, carbon paper and typewriter ribbons. In solvents other than water, they form writing and printing inks.
- Direct dyes are used to dye cotton directly, that is, without the addition of a mordant. They are also used to dye union goods (mixed cotton and wool or silk).

- Disperse dyes are applied as very finely divided materials which are absorbed onto the fibres with which they form a solid solution. They are used for modern synthetics (cellulose acetate, plastics, polyesters) which are difficult to dye. The application methods for disperse dyes are discontinuous and continuous methods. Continuous dyeing of polyester fabrics is carried out by the pad-thermosol procedure.
- Fibre-reactive dyes are used for dyeing of cotton, rayon and some nylons.
- Fluorescent brightening agents absorb ultraviolet light and emit bright blues, which gives greatly improved whiteness. Greater brilliance can be obtained with soap, textiles, plastics, paper and detergents by the addition of these "optical brighteners".
- Mordant dyes are usually used as pigments. If a cloth made of cotton, wool or other protein fibre is impregnated with an aluminium, chronium or iron salt and then contacted with a lake-forming dye, then the metallic precipitate forms in the fibre.
- Solvent dyes are mainly used to dye synthetics, polyesters, polyacrylates and triacetates. Such technology would greatly solve the problem of removing unabsorbed dye from outfall waters, which can be very troublesome to dyers. They are used to colour oils, waxes, varnishes, shoe polishes, lipsticks and gasolines.
- Sulphur dyes are a large, low-cost group of dyes which produce dull shades on cotton.
- Vat dyes are used to impregnate cotton fibres, which are then treated with an oxidant or exposed to air to develop colours. Vat dyes are expensive, but are used for fabrics in severe service with frequent washing, such as men's shirts. Some vats are supplied as pastes for printing. The best known dye of this class is called indigo. When used for dyeing wool, it makes dark (navy) shades with excellent fastness properties.

The above-mentioned types of dyes apply to most of the types of fabrics in general. However, different levels of results and environmental pollution are achieved, depending on the type of dye to be applied, the special physical characteristics of the fabric and the technical characteristics of the machine to be used. This is where the complexity of the control of the whole process lies and where BATs can be applied. These are techniques that impose minimal environmental pollution for achieving prescribed results. However, an intelligent choice between BATs is extremely difficult, since many interdependent parameters are involved. Each potential solution to the problem has constraints and side-effects on production quality and cost.

3. The proposed expert system RECOT

3.1 The architecture

ESs are one of the most commercially successful branches of artificial intelligence (AI). Welbank (1983) defines an ES as follows:

> An expert system is a program which has a wide base of knowledge in a restricted domain, and uses complex inferential reasoning to perform tasks, which a human expert could do.

In other words, an ES is a computer system containing a well-organised body of knowledge, which emulates expert problem-solving skills in a bounded domain of expertise. The system is able to achieve expert levels of problem-solving performance, which would normally be achieved by a skilled human when confronted with significant problems in the domain (BCS, Expert Systems Specialist Group). As shown in Figure 1, an ES consists of three main components, which include the knowledge base, the inference engine and the user interface.

The knowledge base is the heart of the system and contains the knowledge needed for solving a specific problem. Knowledge may be in the form of facts, heuristics (e.g. experiences, opinions, judgments, predictions, algorithms) and relationships usually gleaned from the mind of experts in the relevant domain. Knowledge can be represented using a variety of representation techniques (e.g. semantic nets, frames, predicate logic) (Ignizio, 1991; Mital and Anand, 1994), but the most commonly used technique is "IF-THEN" rules, also known as production rules.

The inference engine is employed during a consultation session, examines the status of the knowledge base, handles the content of the knowledge base and determines the order in which inferences are made. It may use various inference methods. The user interface part enables interaction of the system with the user. It mainly includes screen displays, a consultation/advice dialogue and an explanation component. In addition, expert systems provide interfaces for communication with external programs including data bases and spreadsheets.

The proposed expert system RECOT for the rational application of BATs in the textile industry follows this general architecture.

3.2 The development approach

A successful ES development needs a well-planned course of activities, as shown in Figure 2. It is important that a systematic approach is adopted from the identification of the problem domain, through the construction of the knowledge base and eventually to the implementation and validation of the system.

Concerning the implementation of ES, there are mainly two groups of development tools (Baker, 1988, Huntington, 1985):

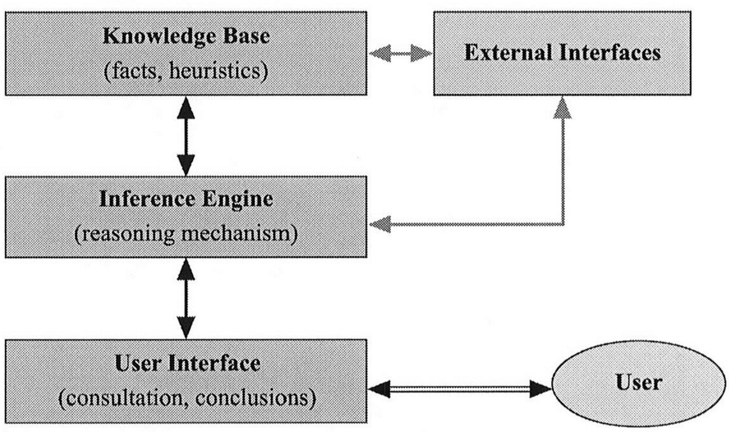

Figure 1. Expert system's architecture

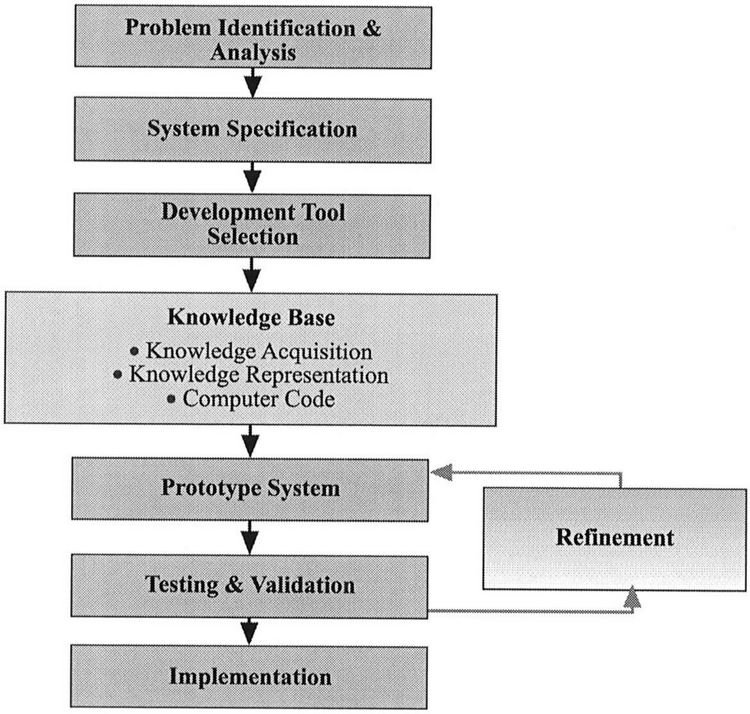

Figure 2.
Expert system development approach

(1) Computer Programming Languages, either conventional (e.g. C++, Pascal, etc.) or AI languages (e.g. PROLOG, LISP, etc.). Using these languages, the system designer has a great deal of freedom in his choice of knowledge representation techniques and control strategies. However, use of these languages requires a high degree of expertise and skill.

(2) Expert system shells. They attempt to combine the flexibility of AI languages with cost-effectiveness and provide more general development facilities. There are a number of commercial shells available in the market with varying features (Nexpert Object, XpertRule, KnowledgePro, CLIPS, ReSolver, EXSYS, VP-Expert, ACQUIRE, etc.). Most of them are relatively low priced and provide a rule-based knowledge representation mechanism.

It is common knowledge that the knowledge acquisition stage is the major bottleneck in the development of expert systems, regardless of the domain. In a few words, the success of an ES depends on how much knowledge it has and how qualitative that knowledge is.

3.3 The knowledge acquisition model

A formal description of the factors that affect the dyeing process of textiles is performed in the beginning. This phase includes knowledge acquisition from the domain experts and deals with:

- the natural properties of fibres (the length of fibres, the denier, the crimp, the tenacity, the elongation at break, the elasticity) – examples of the knowledge acquisition model are given in Tables I and II;
- the textile processing operations (wool scouring, wool finishing, dry processing, knit fabric finishing, woven fabric finishing, carpet manufacture, stock and yarn dyeing) and their interdependencies concerning environmental pollution and rational use of resources (Vigo and Turbak, 1991);
- the natural limitations which concern the use of resources (e.g. synthetic fibres demand oil supplies for their production, cellulosic fibres demand wood pulp, natural fibres demand land and animals to be produced, while water is necessary for the production of both natural and man-made fibres);
- the technical characteristics of various types of machines concerning the capability of "ecological" processing;
- the aspects of air emission sources (e.g. oil and acid mists, dust, solvent vapours, odours) and water pollution sources (wastewater);
- the limits of pollution (BOD, COD levels) – example of the knowledge acquisition model is given in the Table III; and
- the environmental priorities as general strategy to be followed, concerning rational wastewater treatment (optimizing process cycles, recycling effluent, effective housekeeping), biological treatment, ultrafiltration and optimization of chemical usage.

Fibre	Typical_length (in.)	Typical_diameter (in.)	Length : diameter
Cotton	1	0·0007	1,400
Wool	2	0·001	3,000
Flax (ultimate)	1	0·0008	1,200

Table I. Knowledge acquisition model: natural properties of fibres (1)

Fibre	Wool	Acrylic	Modacrylic	Polyesters	Nylon
Elongation, (per cent)	25-35	16-21	16	18-22	25-28
Elastic recovery	0.99 at 2 per cent	0.97 at 2 per cent	0.80 at 2 per cent	90-110 at 4 per cent	100 at 8 per cent
Strength (mPa)	137-200	405-508	302-453	536-797	467-556
Effect of age	Little	Little	Little	Little	Slight
Effect of sun	Weakened	Resistant	Slight	Little	Weakened
Effect of acid	Resistant	Resistant	Resistant	Resistant	Weakened

Table II. Knowledge acquisition model: natural properties of fibres (2)

Category	BOD (mg/l)	COD (mg/l)	TSS (mg/l)	Cr (mg/l)	Sulfide (mg/l)
Wool scouring	6,000	30,000	8,000	0.05	0.2
Wool finishing	300	1,040	130	4.00	0.1
Dry processes	350	1,000	200	0.014	8.0

Table III. Knowledge acquisition model: limits of pollution

3.4 Data and knowledge representation models

All the information acquired from the experts is used in the next phase of development of the expert system, which is the development of data representation models. This phase corresponds to the static dimension of the overall architecture which was described in the previous sections. An object-oriented-based architecture was used for the representation, which is based on the following:

- the classes and sub-classes, which are objects that have several properties in common; any object that belongs to a class inherits its properties from the class;
- the objects, which are instances of the classes and sub-classes;
- sub-objects, which are objects that inherit properties from other objects; and
- properties, which are the elements that characterise an object and to which data values are attributed.

For instance, the class *Dry_Processing* includes objects with the same properties. The objects *fabric_coating*, *fabric_luminating*, *tire_cord*, *fabric_dipping*, *unfinished_fabric_manufacturing*, *yarn_texturing* inherit the property type. This model is represented in Figure 3, where all these objects are located in the area of the class *Dry_Processing*. We must note that many properties are common in most of the classes. The objects of a specific class have common properties which indicate that these objects are members of this class.

The second level of the system architecture is developed in the next phase of the development, the knowledge representation modelling. Knowledge representation is achieved with the use of rules that have the format "IF…THEN…". The list of rules is the knowledge base. The rules are used during the extraction of the solution and are connected with each other, creating a rule network. Practically, this is a graph consisting of rules, data and hypotheses. Knowledge navigates through this network in either direction or in both backward and forward directions, considering the strategy that the inference engine dictates. However, the complexity of the evaluation is quite high, pointing out demands for sturdy platform of the operation of the system.

For instance, during the knowledge acquisition process, interviewed experts pointed out that the cotton finishing effluents have a high colour content. This piece of

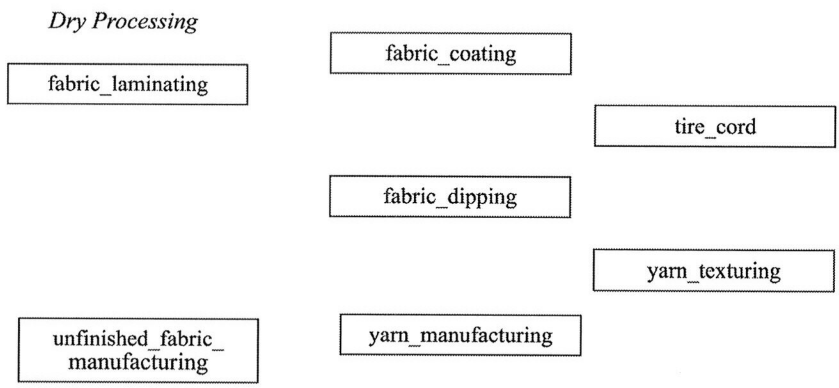

Figure 3.
Example of data representation model

information has been registered in the knowledge representation model in the form of an IF...THEN rule, shown in Figure 4.

3.5 The reasoning strategy

Control and inheritance mechanisms change dynamically at runtime, producing conclusions and suggestions on the rationalization of the utilization of BATs. Considering a given state of the problem, there is a set of potential interventions and BATs to be applied. According to the reasoning strategy, the relevant rules are evaluated taking into account the economic aspect, and new values are attributed to the hypotheses. Knowledge navigates through the rule network and the evaluation terminates only when all relevant rules have been addressed. The suggested solution is the optimal one from the economic and environmental point of view.

4. The development of RECOT

After the completion of the previous stages, the integration of both data and knowledge representation models in a unified expert system (called RECOT) follows. A PC-based expert system shell (NEXPERT OBJECT™ by Neuron Data®) was chosen as the development tool. In this shell, the knowledge is represented by rules in "IF-THEN" format. The NEXPERT architecture is event-driven. It can integrate messages from the outside world or external programs, which themselves might have been triggered by NEXPERT rules or objects. It is able to use *backward* (deductive) or *forward* (evocative) *reasoning*. These inference mechanisms are completely interdependent. How a given rule is processed at a given time depends upon the events as well as upon the current focus of attention. The direction to be processed depends on the design and the actual problem to be solved. In the same application and problem-solving session, the same rule can often be used in both modes. This symmetry is fundamental not only in terms of economy in the number of rules and compactness, but also because it allows one to approach a problem-solving session in different ways. More complex problems can also be handled using data-driven and hypothesis-driven approaches to problem solving, mimicking human knowledge processing.

By utilizing the principles of inheritance and symmetric design of rules, the current version of the system:

- contains 50 classes and sub-classes, 120 objects and 430 rules;
- has a friendly environment of operation; and
- has the capability of full and detailed justification of the conclusions it suggests, keeping the trace of the evaluation of the rules.

Rule 087:

If

Effluent.type is "cotton finishing effluent"

Then

high_colour_content is confirmed.

Figure 4. Example of knowledge representation model

Knowledge, which was inserted to the system, was acquired from various sources. Such sources included textile textbooks, papers, specific literature, and in some cases direct interviews with subject experts associated with this problem. Some knowledge refinement was necessary as differences in knowledge prevailed from different sources of knowledge.

The advantages of this system are fundamental:

- The optimal solution is pointed out to the user on the basis of the rationalization of the resources and the minimum environmental pollution.
- An organised, well-structured and effective action plan is recommended. This plan considers the physical and technical constraints of the textile industy, as well as the requirements for optimal operation.

5. Performance evaluation

In order to validate and test RECOT towards the quality and reliability of the produced outputs, we used a real data set, which concerned the small-medium Greek textile company "CORFIL S.A." It is stressed that the company wanted as an output from the system specific recommendations related to the dyeing process in order to reduce the environmental cost.

For this specific data set, the author, in co-operation with the production manager of the company, made a comparison between the results produced by the real application of the system's proposals/recommendations and the results produced by the potential application of the production manager's decision.

The detailed study of this comparison resulted in the following quantitative and qualitative conclusions:

- reduction of the BOD by 6 per cent;
- reduction of the COD by 11 per cent;
- high quality of the products; and
- facility for the production manager's dynamic intervention in the system's recommendations in order to make potential modifications.

6. Conclusions

The expert system, RECOT, has been proposed for the "solution" of the reduction of the environmental cost in the textile industry. The system described in this paper is an ongoing prototype and further expansion of the system is being undertaken by the author. The author has started working in the way of interconnecting the developed software to an Integrated Management Information System of Enterprise Resources, which consists of a number of sub-systems regarding financial and sales management, monitoring of production cost accounting, resources scheduling, warehouse management, allocation management and equipment sustenance.

It is the author's belief that the usefulness of ESs in the field of environment and pollution will gain more recognition, if they are properly integrated with operations research techniques – especially simulation – or if they are embedded in ERP systems. We should keep in mind that since most operations management problems – in general – are not isolated problems by their nature, isolated ESs cannot exactly solve the problem of the manufacturing manager.

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