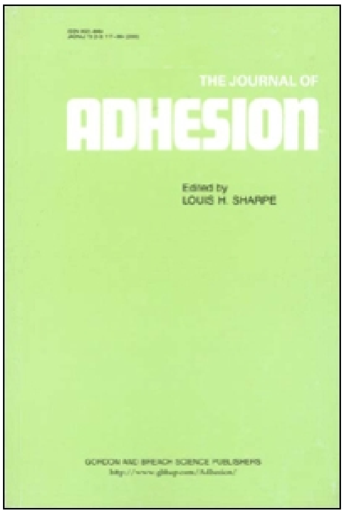

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Adhesive Selection by the PAL† Expert System*

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"Shell" systems have been extensively developed to cope with material selection. However, none of those available during the development of PAL have been able to meet either the industry's requirements or to match PAL's expanding capacity. This paper deals therefore with the development of the latter's unique rejection-residue process and a form of "fuzzy" logic, both of which function without the use of an inference program. PAL's present status is reviewed together with a description of its functional mechanisms and how these could be developed in the future. Particular emphasis is placed on the ability of the program to offer unsolicited important advice and information which only a real expert might normally be aware of.

KEY WORDS Expert system; adhesive selection; engineering adhesives; fuzzy logic; data base; unsolicited information.

INTRODUCTION

Material selection has always been a problem and one which is becoming more complex with the introduction of ever more sophisticated and novel products. New plastics, new alloys and new design concepts present the engineer with a myriad of possibilities. The problem of choice becomes even more difficult when adhesives are involved, for they must not only function effectively in a working environment but they must also be compatible with the other materials and the process of production itself.

"Adhesive selection" is a subject which has received considerable attention at Permabond, a Division of National Starch & Chemical, for a number of years. Primarily driven by the need to supplement staff training, the Company has produced a number of selection procedures of increasing sophistication and capability. The first informal selection procedure was proposed in the mid-Seventies[1] and formalised with the publication of Fulmer Materials Optimiser in 1981[2]. The first computerised version of this – CAAS (Computer Aided Adhesive Selection) was made available in 1982[3,4] and this was followed by EASel (Engineering Adhesive Selector) in 1984[5].

* One of a Collection of papers honoring James P. Wightman, who received the 13th Adhesive and Sealant Council Award at the ASC's 1993 Fall Convention in St. Louis, Missouri, USA, in October 1993.

† PAL is available from both the Permabond Division and Permabond International-480, South Dean Street, Englewood, NJ, 07631, USA.

Subsequent to the development of EASel, it is known that several attempts were made to write general selection programs. Although programs were completed, the majority were, in the author's opinion, not really expert systems for they related more to conventional databases than "true" expert systems. Unfortunately, only one paper which has some immediacy has been published. This is by Moseley and Cartwright[6] and it deals exclusively with the selection of individual types of industrial tape. The paper does not describe the process of selection which is attributed to the language "Leonardo". This latter offers an inference engine and is also said to possess a number of useful features. One such is a frame structure which allows the knowledge base of rules to be set in a maintainable modular structure. Interestingly, the authors point out that they had some success in deriving rules by induction, using an implementation of the ID3 algorithm. However, they did run into a fundamental problem which hindered substantive progress by this route. This was the number of "training sets" required and they quoted Bratko[7] in supporting their view that this approach was not likely to be successful until thousands of training sets were available. Going on the inference of their specific interest, this requirement will be for only one generic type!

Algorithms were actually used by Silberman, Pritykin, Vakula and Silberman[8] to create what they described as an expert system. The object of their work was the computation of the strength of adhesive joints using an algorithm based on hierarchical polymer structure. However, while it is claimed that their system will allow the "proper choice of adhesive" to obtain a desired result, it is specifically pointed out that the approach developed "gives an opportunity to solve the reverse problem", namely, the molecular design of the adhesive required. How this might be achieved in practice is not discussed. This being so, the system which they are developing cannot be compared in any way with EASel or its derivative – PAL.

EASel's success prompted the development of PAL (Permabond Adhesive Locator) through version I to the vastly expanded PAL II which still uses the same form of "fuzzy" logic originally developed for EASel. PAL was not based on any of the commerical "shell" systems available at the times of its conception, because investigation indicated that they were unlikely to be able to cope with the scale of the problems involved. One particularly difficult task was the need to be able to change the users' requirements directly and to be able to re-address the selection process rapidly and continuously. By contrast with such "shells", PAL will completely re-appraise most problems in 1 to 2 seconds. This is despite the fact that it is operating on an interactive base of some 30,000 "Rules" covering approximately 300 materials used in an endless variety of combinations under many imposed conditions of design, production and use.

An assessment of the "Rules" which had been gathered showed that they were found to cover the following major areas:

* The chemical and physical nature of the adhesives themselves.
* The surfaces, and their condition, upon which the adhesives are used.
* The manner in which the adhesives are applied and hardened.
* Various design criteria.
* The conditions under which the bonded assembly is actually used.

The "Rules" have been used to create the question, answer and rejection routine that lies at the heart of PAL. In interpreting the answers to this routine, PAL utilises scientific fact, precise calculation and also, it should be noted, subjective personal experience. In carrying out this assessment, the program evaluates all the possible answers to the requirements presented by the user in order to isolate and identify a material, or materials, whose characteristics appear to be most suitable for the intended purpose.

PURPOSE

The PAL program will assist in the selection of engineering adhesives and sealants for both structural and mechanical assemblies. While capable of addressing less-well-defined subjects, it specifically covers such individual issues as-

* Lap joints
* Butt joints
* Bushings
* Bearings
* Splines
* Cracks
* Sandwich panels
* Honeycomb assemblies
* Gears
* Shafts
* Holes
* Porosities
* All manner and type of threaded fitting and pipe
* Numerous gasket and related applications.

In doing so, PAL uses its rules (covering the inter-relationship of the common engineering materials, generic adhesive types and the Company's own products) to assess the relationship between:

* Materials
* Design
* Production
* Use

PAL first tries to find a Permabond product which meets the user's requirements. If it cannot, then it will study the Company's immediate technology to determine whether this can be of assistance. If both its searches are unsuccessful, it determines whether or not some other generic type, not manufactured by the Company, might suit. Whichever of the three occurs, the program *always lists every generic type* that could be considered useful- even if there is also a Corporate candidate. Thus, in this sense, the technical operation of the program is commercially unbiased – as it must be if user confidence in its veracity is to be both generated and maintained.

BASIC CONCEPTS

The Fulmer Materials Optimiser[2] already referred to reveals, in detail, the extremely simple mechanism used to implement the selection process without the use of a conventional inference engine. The relevant sequence of events is given in Figure 1 for both the program's creation and use. The form of matrix used in the "Optimiser", and referred to in Figure 1, is given in Figure 2. It can be seen that it is indeed very simple and its creation, though on a vastly greater scale, is the program's fundamental task. The manual creation of even a small matrix is very tedious and time consuming and offers neither the speed nor flexibility of a program – hence the need for an expert system.

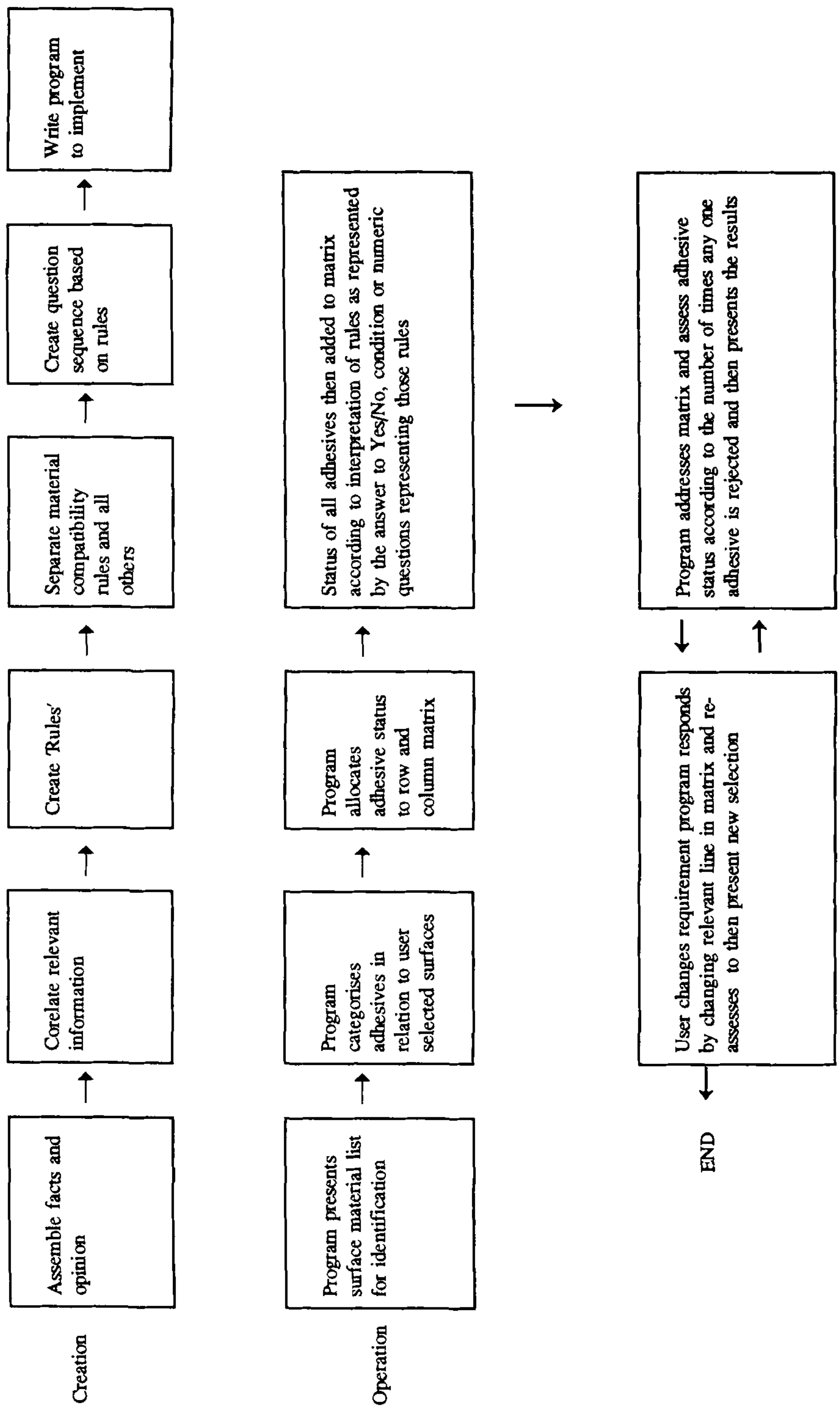

FIGURE 1 Sequence of events relating to the creation and use of PAL.

Assessment table

	a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p	q	r	s	t	u	v	w	x	y	z	Special note ref
Adherend 1																											
Adherend 2																											
Question 1																											
2																											
3																											
4																											
5																											
6																											
.																											
.																											
.																											
.																											
.																											
.																											
22																											
23																											
24																											
Total																											

Application questionnaire

Question Number	Questions	Yes/No	Reject	Go To
1	Do you intend to operate at temperatures above 220°C?	Yes	– See Special Note 24	
		No	–	2
2	Is the joint gap greater than 0.125 mm (0.005 in.)?	Yes	e	3
		No	–	4
3	Is the joint gap greater than 0.50 mm (0.020 in.)?	Yes	b c d e m n s t u v	4
		No	–	4
4	Is the joint co-axial ie composed of round, turned, threaded or fitted parts (Note: not axial butt joined parts)?	Yes	h o r	6
		No	c d	5
5	Is the width of the bond greater than 50 mm (2 in.)?	Yes	e	7
		No	–	7
6	Is the joint intended to be permanent – ie no possibility of dismantling for maintenance is acceptable?	Yes	r	8
		No	reject all but c d and k	Finish
.				
.				
.				
.				
.				
.				
22	Is warming or heat curing possible even if not desirable?	Yes	–	23
		No	b g h j m n o x z	23
23	Are you prepared to use a two-part, mixed system?	Yes	–	24
		No	a b i j l m n p y z	24
24	Is the joint continuously exposed to water?	Yes	a b e l p s t See Special Note 31.	Finish
		No		Finish

FIGURE 2 Matrix created in the table (upper section) by answering the relevant questions in the application Questionnaire and making appropriate entries (Source: Fulmer Materials Optimiser[2]).

A full and proper understanding of the entire process depends upon the definition of a "rule" as used here and upon the relationship between such rules and the questions presented to the user by PAL.

Consider the "rules" relating to the capability of an adhesive to fill a gap. Also consider how such rules apply to anaerobic (acrylic based) and epoxy adhesives.

In generic terms, an epoxy adhesive can be formulated to be a liquid, viscous paste or solid. Hence, there can be no upper limit on gap filling capability. The rule is that generic epoxies can fill any gap. However, although one could fill a container with generic anaerobic adhesive and therefore conceptually fill any gap, the adhesive will not function properly (because it is anaerobic!) and thus, even for viscous pastes, the effective upper limit is 0.5 mm. The rule is then that generic anaerobics cannot fill gaps greater than 0.5 mm.

As for specific individual formulations, the manufacturer sets upper and lower limits which reflect the viscosity, thixotropy and particle size characteristics of the grades concerned. Thus, for Product A there could be two rules-

* it is unsuitable for gaps greater than X and-
* unsuitable for gaps less than Ymm's.

All such rules relating to individual adhesives of a generic type, coupled with all those of all the generic types themselves, are gathered together and implemented in the form of a single question- "What gap do you need to fill?" A figure is given by the user and the reject status of both individual grades and the generic types themselves are posted by the program to its version of the matrix shown in Figure 2 for assessment at the end of the sequence.

The fundamental concept behind the construction and entire operating practice of PAL is that the would-be users know very little, if anything, of the subject technology. What is assumed is that the users have a reasonably clear picture of what they wish to achieve, the materials they have to use and the sorts of products they must make, and the circumstances under which these will be employed. There is no presumption that users will have any clear concept of the physics or chemistry involved or their linking mechanism- material science. PAL has been created with a view to presenting a user with the series of rule-based questions referred to above. These require a choice to be made. That choice may not be easy to make but the decision does not require specialised knowledge. The decisions users make are not binding for, at the completion of the program's enquiry, a user can change any decisions very easily. The program will accept the changes and reassess the new situation almost instantly. Thus, when coupled with a printer, the program can give a number of assessments of any given situation where a particular sub-set of possibilities needs to be explored.

As has been inferred, one of the basic premises of PAL is that it is easier to say that a material is not suitable and reject it rather than to say it is suitable. The statement that a material is suitable is normally supported by some proof of suitability, but obtaining this proof may involve many detailed experiments or measurements. Unsuitability is much easier to gauge. Suitability is much more complex and probably depends on other factors. Unsuitability is more likely to be absolute and independent of other factors.

The program, therefore, rejects materials as unsuitable according to the answers to a set of questions which describes an application for an adhesive. A likely reason for an adhesive being rejected is some form of incompatibility between it and the adherend's surface. If an adhesive is almost invariably suitable for a surface then that adhesive is said, by the program, to be a "Primary" for that surface. If an adhesive is suitable for a surface in most circumstances but can give rise to problems in some applications then it is classified, by the program, as "Secondary". If two different surfaces are to be bonded then the possible Primary/Secondary combinations are examined. If both are Primary then the adhesive's classification remains Primary. If either surface is Secondary the adhesive is said to be Secondary. Similarly, if an adhesive is unsuitable for one surface then the adhesive is rejected. This rejection is absolute, and the adhesive will not be shown as suitable in the PAL Report nor in the lists of Primary and Secondary adhesives.

Each of the questions can reject adhesives, depending on the answer given. When the program creates its recommendation list the number of rejections given for an adhesive gives an indication of its suitability. Adhesives having no rejections at all are deemed to be appropriate candidates for an application.

The reject data sets used in conjunction with a number of questions may themselves be changed. One data set is replaced by another if required as part of the program's response to a user's requirements. Such changes may be initiated by material factors, geometric issues or factors relating to production and use. Whatever the cause, the concept of data set interchange is a very important feature of PAL. When a data set is actually changed there is not, as might be presumed, a total change in all the data used at a particular question. What actually happens is that any one of a number of "graded" data sets may be inserted. Figuratively, the process may be envisaged as the sort of gentle shift in shape and texture often seen in a moiré pattern.

SELECTION

The number of criteria governing the process of selection clearly reveals the complexity of the process. However, by breaking it into two separate activities – the selection of generic types, and the selection of individual formulations – the problem may be eased. First, the basic compatibility of the various adhesive types, with the 50 or so adherend surfaces usually used by engineers, needs to be assessed. Such an assessment reduces the number of candidate adhesive types considerably. Then, as a separate operation, further refinement based on the special characteristics of individual adhesive formulations can be employed to reduce the number still further. Good discriminatory questions are required to do this and these, using the principle of a simple go/no-go gate, will readily eliminate unsuitable materials.

A good example is a question concerning the acceptability of two-part materials that must be mixed prior to use. It will be immediately apparent that only a few questions can be asked that are so precise. Consequently, no selection procedure can produce precise answers.

However, because so many questions need to be asked, a remarkably fine filter can be created. According to the severity of the conditions imposed by a question and answer sequence, the filter will allow a variety of possibilities.

If, for example, production times are unimportant and the working loads are nominal, then many candidate families will get through and will be offered. On the other hand, if production times must be short and the working loads are high, then only two or three types will be listed as viable candidates. In such situations, it is worth considering types which, while not classified as meeting all the criteria, are listed by the program as failing to meet the requirements of only one or two questions. This is because either some formulations will perform in a manner which is atypical of the family as a whole, or because it might prove, on further consideration, that the issues raised by the question involved are not as important as was first thought. Reflections such as these could well lead to a re-examination of apparently restrictive production and design considerations.

Several problems are incurred by this process which could well be avoided if the principle of "probability" were truly invoked by PAL's system. For example, there is the difficulty of identifying questions which are relevant to both production and use and which will positively discriminate against certain generic types of adhesive. A second point is that the questions in the program are based on "general truths" about types. There are always exceptions within the characterization of families and this leads to a certain degree of overlap. Fortunately, where this is not too great, the subjective process of editorial discrimination does not lead to the inaccuracies that might be anticipated. This is because those individual formulations within a family which could have served, but which had been eliminated along with the rest of the group, will most likely be randomly redistributed throughout the family group when some other characteristic is assessed. It has been found in practice that the chance of a suitable, but a typical, formulation being arbitrarily eliminated more than once is not high provided the questions are appropriate.

The process may be illustrated as follows. The population distribution of three types of adhesive is shown in the upper section of Figure 3 where their differing viscosity characteristics are illustrated. Adhesive type A is always limited to low-viscosity liquids. Type C must always take the form of a thick paste or semi-solid, while type B falls between the two. Types A and B have a small but common viscosity range that is represented by a few formulations of each – the common range being demonstrated by the shaded area. Questions relating to viscosity can be used to separate the three materials. However, while there is no problem with the separation of C from both A and B, the separation of A and B demands some form of compromise. The solution is seen in the expanded (lower) section portion of Figure 3. Here, the overlap zone of families A and B is shown in detail. As the distribution of B falls away rapidly to the left, it is most convenient to create a viscosity-based question, the answer to which will allow separation at the vertical line. This favours all members of family B but discriminates against those formulations of family A (represented by stars) which actually lie to the right of the vertical line. These adhesives based on type A could serve but are eliminated because all of the A type are eliminated by the decision related to that question. If some other adhesive characteristic is used, instead of viscosity, the individual formulations which were rejected by the viscosity decision are unlikely to be rejected again because of their new position in the family distribution pattern. Thus, the starred A formulations (previously rejected) will be randomly re-distributed throughout the group's population in a new distribution pattern. This is seen in Figure 4 (the triangular and other forms being used for identification) where only a couple of "stars" are captured in the overlap between family types B and C. It can be seen that discrimination could now, on this new basis, be used to separate B and C while only prejudicing two formulations.

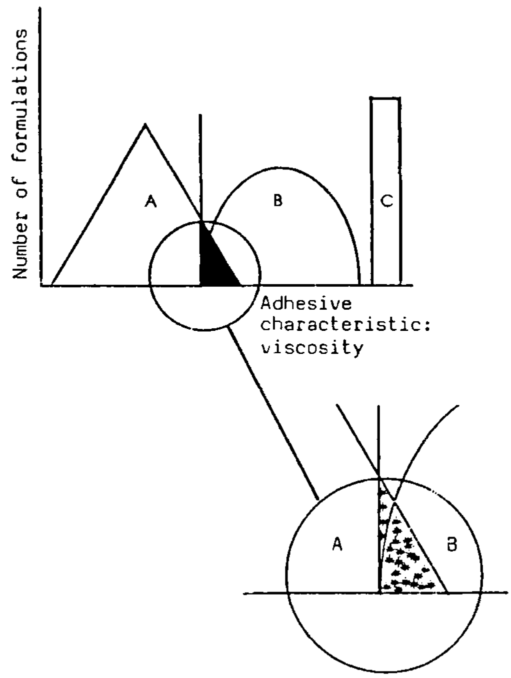

FIGURE 3 The population distribution of three types of adhesive based on viscosity characteristics is given. These range from low viscosity liquids (A) to pastes and semisolids (C). Lower circled section is an expansion of overlap area.

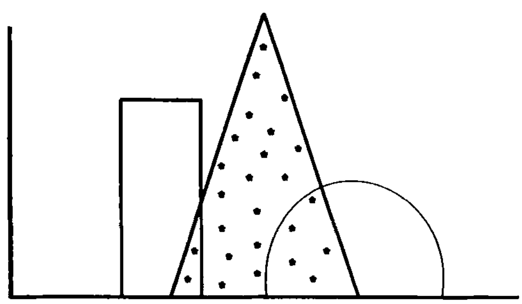

FIGURE 4 Differing distribution patterns shown by the three adhesive types (Fig. 3) when a different characteristic (not specified) is considered.

However, the new criterium cannot be used to separate A and B because, in this particular case, there is too much of an overlap.

While practical experience appears to have justified the technique, it is the author's view that the processes involved should be amenable to a proper mathematical proof. One such may already be available but has not been found by the author who would welcome an appropriate reference.

The second step, the process of separation and identification of individual adhesive formulations within a family type, is effected by a similar process to that used to identify and select generic groups. Occasionally, because user demands are few, many materials will be located that could be considered to be prime candidates for the proposed application. When this occurs, the program will refine the selection further by reference to known market preferences. If necessary, the final selection of a couple of materials from a small group of three or four possibilities can be based on comparative data from an itemized data bank.

Obviously, computerized selection needs to be followed by careful practical evaluation. It should never be forgotten that programs such as PAL are as fallible as their "expert" authors and employ subjective information supplied by both author and user!

QUESTION MECHANISM

The user sees the selection questions (which, according to circumstances, can be presented in a variety of orders) and the program's conclusions when the sequence is complete. The mechanism underlying the process is given below.

A question within PAL comprises several parts. These are shown in Figure 5. The "question" is what the user sees, together with a list of answers to select from. Associated with each answer is a pointer to the next question to ask. Also associated with each answer is a set of rejection data. Each question also has a type, numbered 1 through 4. Type 1 is a conventional question, using the arrow keys to highlight and

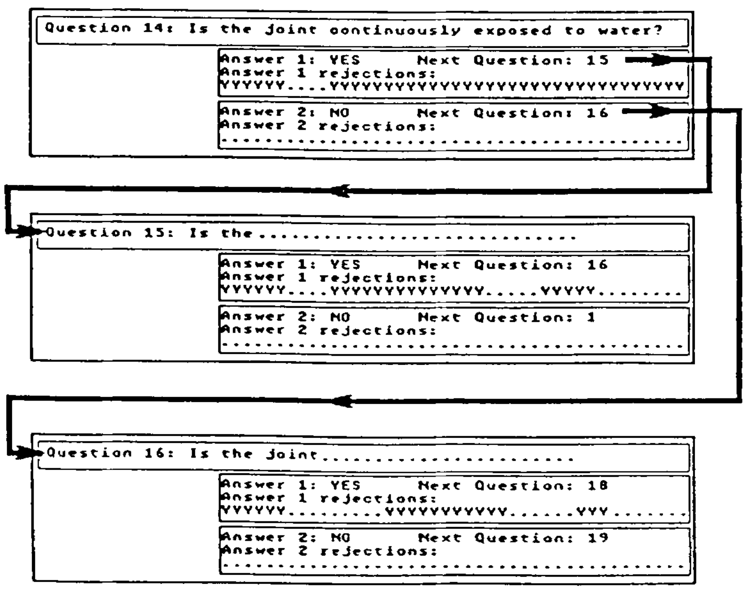

FIGURE 5 Typical question sequence, routes and reject data.

"Return" to select an answer. Type 2 questions require a numerical answer. This answer is evaluated and allocated to one of the answer bands. These answer bands are like answers, having a next question pointer and rejection data associated with them. Types 3 and 4 are the same as types 1 and 2 but can be linked to pictures.

The rejection data can be considered as "Y", reject a material and "." do not reject. There is a string of "Y"s and "."s, for each material in each set of rejection data. In many cases no materials are rejected, usually associated with a "No" or "Not Concerned" answer. In this case, a special pointer is used indicating that no data are to be loaded into the program's array.

As in the "Optimiser"[2], Figure 2, the program maintains a two-dimensional array of integer data, one dimension equalling the number of materials and the other dimension equalling the number of questions. The rejection data are loaded for a particular answer for a particular question and if a material is to be rejected, *i.e.* has a "Y" in that material's position in the rejection data, then a "1" is entered for that material against the question. This procedure is followed until all the appropriate questions have been answered. An end pointer instead of a question pointer can also be used. When such a pointer is invoked, then the program will terminate the question and answer routine before all possible questions have been asked. However, it will have asked all that are needed for a balanced assessment. A small, simplified but typical array is given in Figure 6.

In this array the rejection totals are shown in the right hand column. Only one material, E02, has zero rejections and this material will be the one recommended by the program. Notice that two materials, ESP102 and ESP103, each have one rejection, though at different questions. If there are no materials with zero rejections the program presents a list of questions whose answers, if changed, might reduce the number of rejections for some material to zero. The user can select any one of the re-posed questions. The question is then asked again when the answer may be changed. If the answer is changed, then the whole selection is recalculated when there will then be an increased probability that at least one material will have zero rejects.

An interesting side issue to the selection mechanism is that the process appears to be relatively impervious to some input data error. Again, a mathematical proof would be nice to have but the evidence is readily acquired. For example, during the construction of the program it was necessary, from time to time, to remove entire data sets for a

Question	1	2	3	4	5	6	Total Rejections
Mat′							
EO1	1	1	1				3
EO2							0
EO3		1		1		1	3
ESP101		1	1				2
ESP102	1						1
ESP103		1					1

FIGURE 6 Typical small simulated array.

variety of purposes. To the author's astonishment, it was found that despite the fact that substantial quantities of data were actually missing the program could still produce answers with a very high level of accuracy. The primary defect was no more than the widening of the selection offered to include materials of only slightly dubious qualification. Absolute errors were generated from time to time, but so infrequently that considerable reassurance was provided with regard to the ever-present possibility of actually inputting, by error, incorrect data. PAL would appear to be addressing so much information in coming to its conclusions that the effect can be likened to that of a hologram. Clearly recognisable and useful information is provided whose detail and clarity becomes progressively debased as the data base is increasingly either obliterated or corrupted.

With the mechanism used in PAL the sequence of questions is determined by the program itself, rather than by a separate, but associated, inference program. The routing can be thought of as branches of a tree. The creation of the paths has proved a complex operation. There are two main types of questions within the tree. Some are data-gathering questions concerning, for example, size, contamination and operating temperatures. Others are route-determining, while a few questions combine both functions. The route-determining questions concern the general type of joint being constructed, *e.g.* coaxial or flat, screw threads or bearings. All the questions use the mechanism in the same way.

In the most general case all the questions would be unique, each approached by a different route. The rejection data used for a particular answer could depend on the answer given and all other answers given to reach the question. If separate questions are used for every different path through the tree the data for each of the questions could be different, even though the question appears to the user to be identical. The rejection data and even the forward routing would depend on the answer to the question and the answers to earlier questions. This would, of course, mean a large increase in the amount of data to be stored and maintained.

Within PAL, in order to save data, and the problems associated with creating and maintaining the data, the question routes join and split as required. This is possible because the questions are mostly independent of the answers to previous questions. For example, a requirement for a two-part material is independent of the operating temperature. Thus, there can be one "single/two-part" question and it may be approached from any other question.

Within PAL it has been found that the number of times that the earlier routing has an effect on the data is very small and so, in general, the need for duplicate questions has been ignored. The modifications necessary for any particular question have been implemented using route-dependent logic to change the nature of a question or its data. It is perhaps worth pointing out that in effect this means that the program is actually addressing a very large three-dimensional data structure through which it can find a large number of routes. However, in outward appearance the matrices that appear on the programmer's screen are always only two-dimensional because of the interchange mechanism.

When the answers to other questions are important, PAL uses logic statements (IF THEN ELSE Rules) to modify a question. For example, within PAL both operational temperature and assembly technique determine material rejection at the temperature question. There are several sets of rejection data, and the set used depends on the answer to the earlier assembly technique question. The answer to the temperature question then determines which element of the set is actually used for calculating the rejection total.

AUTOMATIC ROUTE DETERMINATION

Bearing in mind the lessons learned from the use of CAAS, where presentational techniques could induce user bias, PAL intentionally asks all the questions required to obtain a "balanced" assessment of the situation being presented, rather than the minimum necessary to select a single material. This could be done if the matrix were totalled as each question was asked and the results used to determine the next question to use. The question selected could be the one most likely to reject the remaining materials. PAL could also use rule-modified routing to determine what questions are asked. *i.e.*, if a rule needs the answer to a question not yet asked then PAL would ask the question before determining the route and rejection data. Most automatic routing systems use a "goal" to determine the questions. Normally the goal is "What is the best material" but with PAL it is suggested that the goal is "What is the best material, knowing all the circumstances". Thus, it is possible to get an explanation from the system of what it has done and why.

As a consequence of the foregoing, the levels of subtlety that can be traversed within the program are considerable and perhaps best seen in the mechanical assembly sector. Here, for example, in the apparently simple case of the assembly of a nut and bolt, the program will make changes to its suggestions on the basis of possible changes in any one of the following parameters:

* Diameter, length of engagement, gap between threads, type of thread, whether the fasteners are to be permanently locked or dismountable, or even whether they are to be adjustable.

Also taken into account are such issues as whether or not the adhesive is to be applied before or after assembly or whether or not the parts are metal or plastic and, having determined which, the program will make decisions concerning the alloy or plastic type actually used.

An outline of the entire procedure, discussed above, is given in Figure 7 which also illustrates the addressing of the Special Notes discussed below.

SPECIAL NOTES

PAL contains a small but comprehensive "library" of "special notes". It could be made very much bigger. The notes are very brief summaries of important – perhaps even crucial – industrial experiences which the program presents automatically. The trigger mechanism for their presentation is constructed from any one of a set of complex interactions between the surfaces to be bonded, the geometry, the user's answers to the question sequence and the interaction of that sequence with itself to produce its final

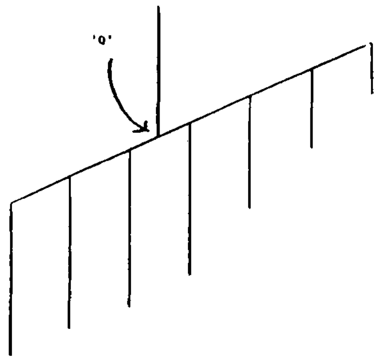

FIGURE 7a As the program moves through its decision tree a question (Q) is posed. The user's answer will result in any one of a number of routes being selected and followed.

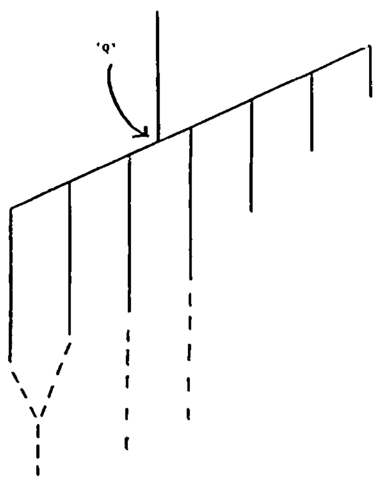

FIGURE 7b The routes may or may not rejoin.

recommendation – together with the special notes. The entire exercise is a substantial extension of the concept originally devised for the Optimiser and developed for the CAAS program referred to previously. To be really useful, an expert program must be able to tell its user of hard-won experience so that he may avoid the traps that so readily catch the inexperienced[9]. In this manner, the user may benefit from the knowledge of a previous generation. Automatic information presentation can ensure that crucial knowledge does not become buried in conventional libraries and Corporate archives. Recent tragedies in the field of civil engineering have been said to be attributable, at least in part, to this cause. It is considered that PAL could be developed into a major anecdotal archive which could not only bring forward its special notes but also link in

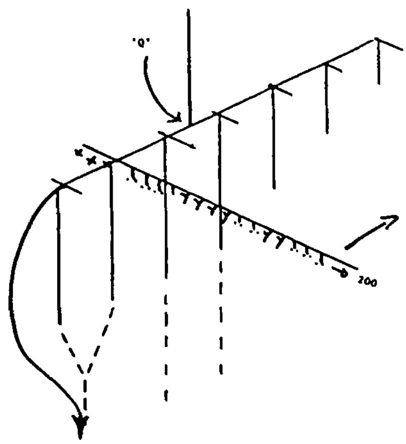

FIGURE 7c Various rejection data sets are allocated to each question, the maximum at the present time being 24. The data set actually used in the array (Fig. 6) is dictated by both the user's answer to the question and possibly also by the user's answer to a previous question. The forward influence of one question upon another is symbolically illustrated by the heavy arrow at the left of the diagram. Associated with each data set are the latches (X) which may, or may not, release critical information according to their interaction elsewhere in the program. In the case of the single question given here, the program has the potential to address some 5,000 pieces of information. It is envisaged that this could be readily increased to some 50,000.

to conventional data bases, as these notes in turn could present actual references and keywords which could be used in keyword and other acquisition systems.

MAINTENANCE

At present the maintenance of PAL is very simple. Software tools have been created which will allow the reject status of any material to be altered at will and in a matter of moments. Data sets for both new materials and new questions are readily inserted, as are also further "special notes".

In the future, problems may be caused by major shifts in the fundamental properties of generic types. For example, if polyurethane adhesives were to become as tolerant of hot, humid conditions, as are some classes of the toughened acrylic adhesives, then there would be need for a major revision of the currently-fixed links between the questions. However, this sort of thing is not likely to happen very often, as theoretically-perceived limits of performance have already been built in (this is expert opinion) to the described characteristics of the generic types – even if individual adhesives do not, as yet, have such capabilities. Thus, what might be done in the near/medium future has been anticipated.

Because the program's structure is a reflection of the capability and fundamental chemistry of the generic types, useful additional questions can usually be inserted within loops or on the program's speciality legs without system distortion. Addition to the main stem of the question sequence presents no difficulties at all.

What does cause a problem is the assembly and verification of the information to be inserted. However, these tasks need to be faced no matter what the nature of the program and they are tasks which are very demanding and time-consuming.

REVIEW, RECENT ACHIEVEMENTS AND FUTURE POSSIBILITIES

Approximately 18 years have now elapsed since the first attempts were made to devise a logical technique which could be used to select adhesives. Many lessons have been learned along the way and have been incorporated into PAL when appropriate. However, the most important requirement appears to be an extremely close working relationship between the expert team and the programmers. Without a thorough professional and personal understanding of each other's work, programs such as PAL would, it is believed, be impossible to create. A second point is that the "shell" systems which have been developed to date still do not appear to have the speed and flexibility required to cope adequately with the situations faced by PAL. As evidence of this, it is perhaps worth pointing out that the "Adhesys" program produced by the Harwell Laboratory of the UK Atomic Energy Authority uses a simplified version of PAL to run the selection portion of that program. Similarly, the Centre for Adhesive Technology in the UK is using PAL-based techniques as the core of a program which, while currently under development, will be able to select adhesives from the data contributions of the British adhesives industry.

The program's contribution to industry has been much appreciated. Version 1.0 was given a certificate of merit by the British Computer Society in conjunction with the government's Department of Trade and Industry. In the summer of '94 PAL II was awarded the Sir Charles Lillycrap gold medal by TWI (the UK Welding Institute) for the "best contribution..... to construction".

Recent developments have been the creation of the processes which allow PAL to present information about any particular material in the system in a manner which allows comparison with any other that has been selected. This means that common properties can be determined and individual differences highlighted. This information, coupled with formulation knowledge, can be used to speed development because it allows both interpolation and extrapolation of composition data.

For example, very fast setting, toughened acrylic adhesives of the Permabond F series, can be made by utilising very pure initiating compounds based on amine-aldehyde condensates. An "expert" would know that such materials could speed the cure of other acrylic adhesives and could be used in a variety of ways. However, the expert may not be available and the question that then arises is – "Is there anything in the 'system' which could enable us to speed the cure of an acrylic adhesive (of some type or other)?" The running of PAL's corresponding comparator program will rapidly relate generic types and give access to closely allied formulations. Their differences and their correspondingly-different performance characteristics can be highlighted and the different initiator systems presented from the formulation file. In this manner, the previous solution to the question of "speed" can be identified and a wheel will not have to be re-invented.

Other recent refinements include the further provision of "starter" points for the growth of new speciality trees within the program – two of the earlier ones being the fitting of bearings and the filling of holes.

Such an ability lends itself admirably to the development of, say, an "electronic" branch dealing with the potting and encapsulating of micro and macro electrical devices.

Similarly, the bonding of generic materials could be drawn out as a speciality spur which could be split into a variety of material specific, but object variable, lines. The bonding of cellulose is a case which could benefit from this capability.

Paper, card and tissue may all be bonded with the same generic adhesives. However, the generic objects formed from them need very different individual adhesive formulations to cope with their manufacture and use. This is immediately obvious when one considers the different nature of cellulose based products – books, boxes and diapers. PAL's functional concepts can deal with such situations in speciality spurs. Further, the comparator sub-program would also allow formulation manipulation.

There is no reason to believe than PAL cannot be extended to cover as many as 2000 or so adhesives without deviating too far from its present form.

While far from perfect, PAL functions well and so far has proved to be very accurate. Unfortunately, because of its long history, it does not incorporate any of the presentational techniques which have become available over the last few years. Consequently, at the next major revision it is intended that this deficiency will be addressed. The somewhat old-fashioned pseudo "Windows" technique it uses can be upgraded and the context-sensitive "Help" feature extended.

OBSERVATION

Finally, it is perhaps worth emphasising that if expert systems are really to help the inexperienced they must function on the basis that users can not be expected to provide much more than the concept of their intent, a concept that must be refined by the program as a result of the dialogue between it and the user. It must not be forgotten that users need the help of an "expert" because they do not know what is involved. Consequently, users cannot be expected to provide data in order that the machine can search for an appropriate material. What is required is a framework of carefully-phrased questions which are used to gain the answers necessary to enable the program to address its memory, select an adhesive and compile a report which will include not only the required data but also unanticipated critical information. The data could include the reasons why no materials are considered to be suitable, should this be the case. However, the end effect is that the user's needs are carefully identified and addressed even though these, as a result of inexperience, may initially have only been vaguely formulated.

It has been found that if there is a likely candidate for a specific project PAL is almost certain to find it. However, it should never be forgotten that despite its obvious capabilities the PAL program is no more than a machine driven system of restricted logic. It can never outperform real "experts" – experienced and trained technicians – provided that their individual thought processes have not themselves started to run on habitual lines. The one thing that PAL does not do is to overlook any of the possibilities it has access to – it never forgets; because of this it often outperforms its creator!

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