An expert system for predictive quality control in industrial production

Focusing on the knowledge acquisition process with several experts

Alain MILLE[1] Daniel PIALOT[2] André MICHEL[1]

and

Jean Marie BECKER(1), Luc DELCROIX[3], Olivier LECOINTRE(2), Marc POURPRIX(3), Thierry SIMONI(1),

Claude STELLMANN(2)

[1]LISA-Informatique Industrielle, CPE Lyon, 31 Place Bellecour, 69288, Lyon Cedex02

[2]Société Rhône-Mérieux, Service des Biomathématiques,254 Rue Marcel Mérieux, 69007 Lyon

[3]Société DIPOLE, Rue Claude Terrasse, 69210 L'Arbresle

Sommaire

Figures

Monitoring the quality of an industrial product such as veterinary vaccines is a difficult challenge, especially when it has to be implemented in « real time » on the production line. This is firstly because vaccines are made in batches which go through a sequence of operations, each taking place in strictly separate areas of the factory, due to biological constraints, and secondly because each operation involves a high degree of specialist expertise.

The system CCMV (Carte de Contrôle Multivariée) described below was developed in order to improve quality management in the triple context of batch processing, monitoring by a large number of parameters and assessment by several different experts.

CCMV consists in collecting data on the different reactors while they are working, in order to fire an early warning on any detected quality drift and display to the operators what remedial action they should take.

To achieve this early detection, the system had to integrate some of the sophisticated statistical tools used in multivariate analysis, some simulation models of the biochemical reactions involved along the production line and a rule-based expert system encapsulating the multi-faceted knowledge of the Company's engineers.

Multivariate discriminant analysis yields a quality control map on which all batches can be positioned.

The control map provides a graphical support displaying clusters of batches of similar quality. The allocation of a new batch to a quality group can therefore be estimated not only by calculation but also at a glance by the operator.

The project was an industrial one. The design of the resulting CCMV stressed the importance of complying strictly with specifications of robustness, data safety, «rules of good manufacturing » and user friendliness.

The project lasted two years and CCMV is now in test on the production site.

The article presents briefly the features of the CCMV as it is run now. We then focus on the complexity of the knowledge acquisition process. We discuss our experience with regard to recent research work on knowledge acquisition. We conclude the article by a proposal for further study in the framework of Case Based Reasoning and traceability Agent Architecture.

1. The three tasks assigned to the system are : to detect quality drift, to give explanations and to plan remedial action

1.1 The vaccine production process is completed in several stages which take place in strictly separate areas

The system works in the context of batch processing of veterinary vaccines. The production runs in different phases each taking place in a separate area. Each area is reserved for a specific activity, either a production activity, or a control activity. The passage from one area to another is strictly controlled and a control sheet follows the batch throughout the process. At the end of each production phase, the product is carried inside containers or by pipes for temporary storage in a specific area. The sterility of the product must be guaranteed, so particular attention is paid to intermediate storage conditions. Each area is under the responsibility of a different team and precise protocols have been written to ensure sterility throughout the process. When a product is collected by an area team, it is assumed that all the upstream activities have been carried out correctly. Interested readers could consult [Cam83and [Fon86]for more information about production of veterinary vaccines.

In our case, the main operation areas are: the primary material production area, the purification area and the pharmaceutical packaging area. While each area has a different function, their internal organization is on the same plan. A production stage can be represented according to the following figure:

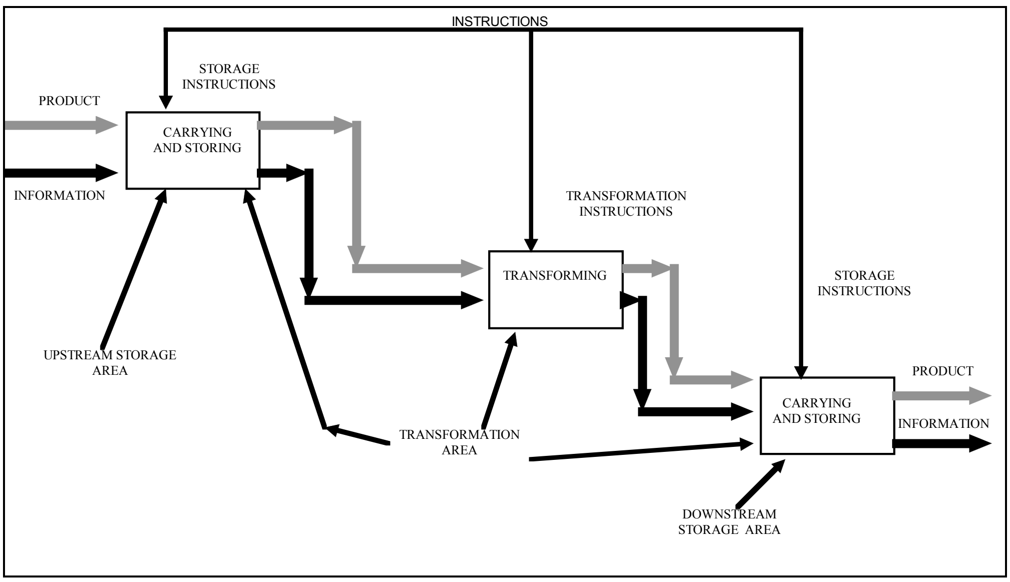
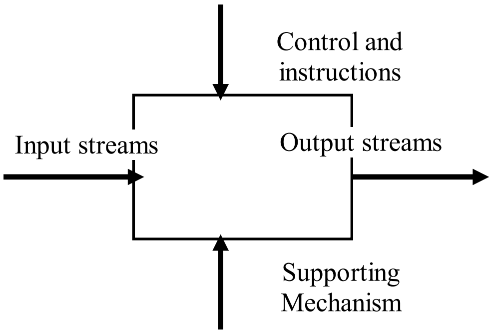


Figure 1-1 Description of a production stage

<table>
<tr>
<td>Figure 1-1 uses the SADT (Structured Analysis Design Technique) model to express activities, controls, mechanisms and the information-production stream. The following figure recalls the essentials of the model:


</td>
<td>The product, together with its description sheet, is taken out of storage according to specific instructions. This operation is initiated by the transformation area team according to a schedule (Schedule assisted by a central computer).

Information and product are carried into the transformation area to be processed according to the transformation instructions.

When the process is finished, the product is carried out and stored in the downstream storage area with its updated description sheet. The storage is under the double responsibility of the upstream and downstream transformation areas.</td>
</tr>
</table>

Figure 1-2 SADT model

Such a model is useful for describing the compartmentalization of the production line. When the product is correct for a downstream area, there is a signed acceptance that the upstream production is correct. The goal of such compartmentalization is to be able to trace any sterility problem and the point at which it occurs. It is this aspect of the organization which demands a multi expert knowledge acquisition process.

1.2 The main goals of the system are: to detect quality drifts and to modify production parameters in order to remedy the problem.

Because vaccine batches need close attention to safety and quality rules, the Company must follow each batch throughout its production cycle according to many parameters. The analysis of the historical data of many batches of the same vaccine show that some parameters more than others have an impact on the final quality. The batch quality is established at the end of the production by effectiveness and sterility tests and can later be confirmed or denied by customer feedback, for example in the case of poor appearance. When there is quality drift, the Company needs the system to give explanations about the phenomenon to the operators and to propose corrective action to steer the quality back to the acceptable standard.

We are assuming that all the necessary expertise can be found in-house. Our task is to formalize this expertise and to encapsulate the resulting knowledge in an expert system to provide effective help in the case of quality drift. The detection of a quality drift is based on statistical similarity between the current batch and the batches available in the historical data base. The quality rank of the closest cluster on the control map is assigned to the current batch.

2. Investigation of past production and elicitation of expertise are the two facets of the modeling work

This section presents the preliminary work carried out to acquire information about statistics from previous production and how experts currently cope with quality drift.

2.1 Statistical analysis of past production allows the creation of multivariate control maps

We divided the data from past production into segments and analyzed each phase of the production separately: first, the historical data about the production of the primary material , then data on purification and finally that on pharmaceutical packaging. We used this data to create local control maps for each production area. For each stage of the production , historical data is available about the production itself and about the quality obtained. Usually, several quality parameters are available. Correlation between parameters are analyzed and compared to the whole set of historical data. This can be done either by using Principal Components Analysis (when all parameters are quantitative) or by using Multiple Correspondences Analysis (if some parameters are qualitative).[**LMN77**]. The corresponding quality groups chosen as future references are based on the multivariate analysis results (4 groups in the prototype - « very good », « good », « acceptable» and « unacceptable»). A quality rank is assigned to each batch in the historical database. The data relating to the production is then examined. We try to find correspondences between observations on the production and the quality rank assigned to the batch.. We use discriminant factorial analysis on qualitative variables [**Sap90**] because of the constant presence of qualitative parameters within the production data. Factorial planes of discriminant analysis provide the support for the graphical representation of a multivariate control map. This approach comes from [**Cos84**] and from [Pia90]. A convex envelope of each cluster is drawn on the control map. Depending on the characteristics of the real or simulated process, each batch is projected onto the control map. It is then easy to see immediately in which quality group the batch falls and to predict what will be its quality rank if nothing changes. If a batch leaves its quality group (in terms of distance on the control map) we must decide whether there has been a change in the production or whether data about this batch is unreliable. In the first case the database has to be revised. In the second case, the batch data has to be ignored in the calculations.

From production characteristics (real or simulated), we compute a distance between the batch and the center of each quality group. The batch gets the quality rank of the nearest group. If the batch is too far from all the groups (according to an agreed threshold) it does not receive a quality rank.

If the production gets a bad quality rank, or is on the borderline of an « unacceptable » group, we compute the relative contribution of each production parameter to that result, and we retain those parameters which are most heavily implicated (in our prototype: two parameters).

2.2 Elicitation of expertise is a long and difficult process; knowledge representation is easier

The compartmentalization of the production process and the number of different areas concerned demand that we collect knowledge from several experts. They are in executive positions and possess both theoretical and practical knowledge of the process. Experts are chosen among those responsible for different production areas. They are involved in the production process at different stages and so have quite different points of view on the product and its characteristics. Some of them have long experience of several areas and, when necessary, they are brought together to explain possible quality problems. Such a meeting is of course quite rare. It is an exceptional procedure and not very well documented; it seems to consist of a collective reconstitution of the « history » of the batch concerned. Of course, information about these investigations is highly confidential. However, we are very interested in this procedure because it corresponds largely to the tasks we have to model in our expert system - interpreting drift and planning remedial action -.

Work organization

Elicitation of expertise has three main objectives:

- eliciting the quality criteria used by each expert.
- eliciting the parameters that the expert feels are most important for explaining quality drift.

- gathering knowledge from each stage of production and from each area to identify cause-effect relationships in the production process (as seen from a quality point of view).

The working group is composed of:

- A Project Manager - who represents the company in the group and must coordinate the project.
- An industrial leader and a scientific leader to provide guidance on the interviews
- Four « Knowledge Engineers ».
- Eight experts nominated by the Project Manager, one for each production area:
    - Primary product preparation
    - Primary material production
    - Purification
    - Pharmaceutical packaging
    - Physical and chemical controls
    - Biological controls.

A generalist is added and, in one of the areas, two experts are brought in for the interviews.

A classical method is used:

- exploiting to the maximum the written material available,
- using sound-recorded, reported[4] and validated[5] interviews.
- asking the expert to « reason out loud » about production cases.
- generalizing information drawn from individual cases.

The knowledge elicitation process is complex because of the number of experts and because several « knowledge engineers » are necessary to complete the work in time[6]. The work lasted around six months, and we detail it in the next paragraphs. Key-moments and interesting points are emphasized while the elicitation process is presented in a chronological way.

---

[4]The interviews are not reported verbatim but only in summary. This decision was made in order to save time. But lost information can be important and biases can occur easily. We now think that it is preferable to make a verbatim report of an interview.

[5]The report of the interview is submitted to the expert who can modify it. One bias often observed occurs when the expert modifies the report in order to transform it into a kind of « course manual » on the subject.

[6]Compartmentalization of the factory makes for the compartmentalization of knowledge, so that it is difficult to gather and make connections between the different knowledge bases.

2.2.1 The three phases of the knowledge elicitation process are : preparation stages, interviews and synthesis.

The following table presents a summary of the different stages followed in the elicitation process. After the synthesis, key-points and lessons from experience are emphasized in the following paragraphs.

Stage code	**Time table and short description of the event**	**Stage category**	**Comments about goals and results of each stage**
PM1	Working Group 3 meetings on 2 months 91/09,91/10	**Preparation** Meetings	The working group prepares its strategy, its methods and the calendar. Interviewers agree about goals and tools of the knowledge elicitation process.
PM2	Working Group and Experts One meeting 91/10	**Preparation** Project presentation to the experts. Discussion about the knowledge elicitation process	A specialist in Communication leads the meeting. The experts are invited to react to the project and to express themselves about their role in the process. The experts are more or less convinced by the system and prefer to reserve judgment.
PM3	Working Group One meeting 91/11	**Preparation** Interview simulation and discussion between interviewers and the working group.	Training the interviewers. Time control, elicitation control points, ...Observers react by reporting back on strengths and weaknesses of the interview. Cassette recorders are tested.
INT1 1 h	One interview per expert 91/11	**Interview** with open questions	The production process as it is seen by the experts, their convictions, their practice, their general experience. The first interview is easy to run, everybody wants to go ahead.
SM1	Working group	**Synthesis** Meeting	Weaknesses of the knowledge elicitation method. The strategy is modified towards a task more centered on historical data.
INT2	One interview per	**Interview** with semi-closed	Expert Reactions. Their opinion on their area. How

2 h	expert 91/12	questions One or two particular cases are studied	upstream and downstream areas are seen. . They reason out loud .
INT3 2 h	One interview per expert 92/01	**Interview** with half closed questions. Studying historical data	Discussion about production changes within several batches of the same product. Interesting cases. Opinion on action in case of missing data. Analysis of observed changes. Possible action to correct the production process.
SM2	Working Group and experts. 92/01 The communication specialist	Intermediate **synthesis**	All the actors in the elicitation process are gathered together to do a first review of project progress. The experts wish to go further in their cross-area discussion. The experience is seen as an opportunity to reflect globally on the process and its management. An « original » technique is proposed to pursue the interviews : The last interview will bring together : - an expert - a second expert in the role of interviewer - the Knowledge Engineer as an observer and moderator.
INT4 1h30	1 expert 1 expert Interviewer 1 Observer 92/02	Tripartite **Interview**	Elicitation of points of agreement and of divergence. Focusing on the specific point of view of each specific area and on relations between them.
SM3 3 h	Working Group Experts The communication specialist 03/92	Final **synthesis**	This meeting is the occasion for presenting the different points of view collected during the elicitation process. A set of raw rules are proposed to the participants who have to reject, modify or keep them. Direct exchanges characterized the meeting.

			There was a real discussion between experts to arrive at a consensus.
FM	Working group	**modeling** Meeting	Industrial project leaders and scientific leader bring together all the raw knowledge collected and from it model verifiable production rules. The first stages of production are chosen to test the system, so only knowledge available at these stages is taken into account. Sixty rules are created in this way and are controlled by a small set of metarules (which take into account the context of individual interpretation).
The end	92/06	The software is **ready** to use	CCMV Version 1.0 is ready to use. A test period can start.

Tableau 2-1 The knowledge elicitation process

These different stages took place over a relatively short time and written reports were made of each. The content of these documents constitutes the raw material of our knowledge elicitation process. The following diagram shows the chronological sequence of the stages.

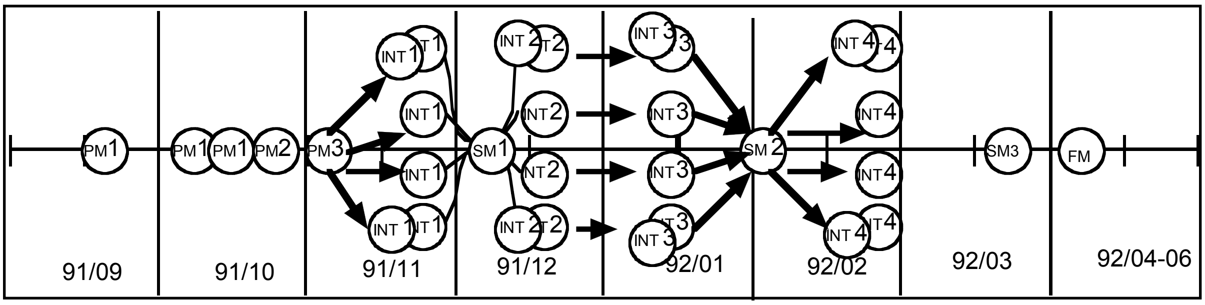


Figure 2-1 Timetable of the knowledge elicitation process

This figure demonstrates the density of the work at certain times, creating practical difficulties.

PM1: the main task of the working group is to manage the whole project, but these preparatory meetings are devoted mainly to planning the elicitation process. It is the occasion for deciding the best way to involve experts in the work, for agreeing costs and timing and for drawing up procedures concerning confidentiality and reporting . As the main part of the cost comes from time spent by experts, it is decided to limit the number and the length of the interviews. All meetings and interviews have to be reported and typed up. To insure confidentiality, recordings and reports must stay within the company and all reports will be validated before circulating. These precautions establish a climate of confidence between experts and the working group.

PM2: This meeting is considered as the most difficult to make successful. Its main objective - convincing experts that the system is advantageous for the company and indeed for them- is a challenging task for the working group. Such a meeting has to be very carefully prepared, and we think that the key points for success are:

- an official announcement that the project is starting.
- the presentation to each other of all actors in the project..
- a global presentation of the project (goals, tools, methods and timetable)
- comprehensive explanations about the concepts and principles operating in a knowledge elicitation process.
- assurances about confidentiality, and about how interview reports will be validated and circulated.

These points are general and can apply in a number of other situations.

Because of the number and rank of the participants (the meeting gathers together the company manager, project managers, interviewers and experts), the meeting is led by a specialist in communication techniques. Besides his role of leader in the meeting, the communication specialist makes recommendations for managing a communication process. He presents a model of behavior to have in mind when communicating. This model has three main components: Internal process (personal capabilities, methods, strategies,..), Internal State (beliefs, values, criteria,..) and External Behavior. This model may be a guide to evaluating the communication process. He proposed a general method inspired by Bandler and Grinder (no bibliography is given at this stage), based on « productive re-phrasing » . There are several approaches: reformulation by generalization (chunking up), by specialization (chunking down) or by analogy (lateral chunking). Other practical recommendations are:

- referring in the report to the experts' point of view rather than trying to elaborate a theory from their talk. The experts must recognize themselves in the report.
- paraphrasing the main expert sentences to check good understanding.
- checking generalizations and particularizations (Does the expert really mean « always » and « never », .?.)
- clarifying what appear to be cause-effect relationships.
- identifying the favorite manner of expression of the expert. (is he a visual, an aural, a kinesthesist,..?)

It is important to note that these recommendations were made on the initiative of the communication specialist and were not the result of research. However, we think that the design of effective knowledge elicitation methods would be an interesting field of research.

This meeting creates a climate of detente between the experts and the working group, and the experts are very curious to start the work. At the end of the meeting, dates are fixed for the first interviews.

PM3: Working group meeting to train the interviewers. Simulated interviews are carried out with the industrial project manager as the expert to be interviewed. Other interviewers and participants observe the interview, which is recorded. Each in turn plays the interviewer with the « expert » on different topics of the production process. The group takes stock of observations about the interviews and some classic drawbacks are discussed: poor listening skills, losing track of time, initial presentation too long or too short. This exercise is considered as very important by the interviewers for various reasons: they get useful information from the « expert » about the production process and, above all, they learn to observe themselves in the communication process and so are able to avoid personal implication in the discussion. We have to keep in mind that an interview is neither a mere verbal questionnaire nor an ordinary discussion.

INT1: This is the first series of interviews. Each series consists of 6 interviews and uses 4 interviewers and 7 experts (two interviewers carry out two interviews each, and one of the area teams is represented by two experts). The main objective of this interview is to establish the expert point of view on the production process. A model of the process must be made, either by a drawing, a diagram or a formal talk. This interview identifies the vocabulary, opinions, beliefs and other personal views of the expert. The interviewer concentrates on the genericity (or non-genericity) of the expert point of view. The interview is very open and the interviewers must say as little as possible. This is the opportunity to observe the usual manner of expression of the expert.

INT2: Second series of interviews. We can qualify these interviews as « semi-closed » because one or two « cases » have been prepared by the working group to be submitted to the experts. Cases are studied aloud by the expert, and the interviewer asks for explanations when he does not understand the corrective action proposed by the expert and the reason for it. In each area, the experts express the need for more complete documentation covering the areas other than own and say they need to refer to their own notes to understand the case history. The prepared documents, standard company documents, are not sufficient for them. The scope of these papers is often limited in their references to upstream and downstream areas. There is an exception with the control areas which have relations with each production area, but don't often work together. This interview demonstrates the side-effects of the compartmentalization of the production process.

SM1: First synthesis meeting of the working group: the group takes stock of the information collected from the first series of interviews and makes these initial observations:

- it is difficult to insure consistency of method and reporting style between the different interviewers.
- the method can lead to bias. Cases are too standard and the expert reaction is not very sharp. The case documentation is not precise enough to encourage thorough investigation. The written report is often corrected by the expert in order to transform it into a well-presented document on the subject in hand. The interviewer makes efforts to highlight sentences which might be suitable for creating rules later on and the expert tries to moderate the scope of these sentences. Now, with hindsight, we can say that it was too soon to establish any rules at this stage of the elicitation process.
- the information collected is reviewed with emphasis on its weaknesses (generalizations) and its strengths (statements capable of generating quality rules)
- some experts don't understand why they have to explain the production process which they say is very well described in the documentation. They think they should be focusing on their own area[7]. They also think that the interviewers should be more aware of how they, the experts, work.
- other experts say that they feel as if they are undergoing an inspection of their activities. This feeling however does not last.
- some technical problems can have serious consequences. For example, a bad tape recording can make it necessary to repeat an interview.
- most of the experts express their knowledge through examples. Some of them, by contrast, try to conceptualize and give a general value to their discourse. As the written report is a kind of synthesis, the second type of expression is simpler to report.
- All the experts recall past production batches to situate the case they are asked to study. When they find something « similar » in their own notes, they compare the two cases more precisely in order to explain the new one by what they know from their experience.

[7]However, if the general model is almost the same for each expert, the details are very different from one expert to one another. The experts' scope is limited to two or three areas, but they are curious to know how the process really works in other areas.

Interviewers work in their own style, but the meeting demonstrates that differences are minimal and that goals remain clear and homogeneous.

The experts try to find trends in the data available, and the working group decide to construct a series of relevant cases. A document containing seven cases is prepared for the interviewers. It is decided that the next interview will be two hours long to allow detailed study with the experts.

INT3: Some interviewers prepare the raw data of the cases so that any differences between cases are emphasized, and so that trends, if any, are evident. The resulting diagrams look like those below:.

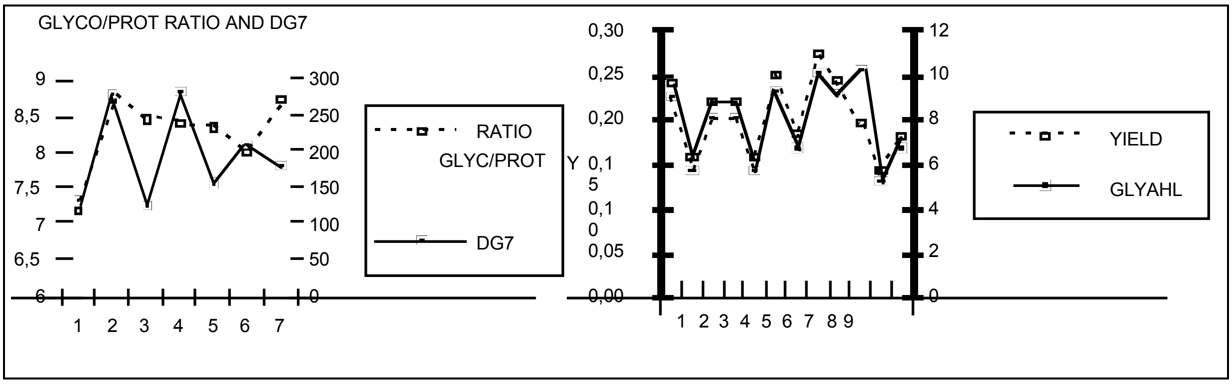


Figure 2-2 Two diagrams of indicative trends for some variables of a series

The interviewer has to establish how the expert will proceed to study this series. The stages generally followed by the experts are the following:

- first, they check consistency of the documents with their own notes. This is always done in case there are« odd » values for some variables of the batch.

-they then confirm this consistency by checking the correlation they think exists between particular variables, and weigh the variance of these variables in order to interpret what is relevant and what is not.

- they complete the case history with their own data which will confirm or de-confirm what they find in the documents. They search in their notes for reported comments about relevant production batches . The comments can be very important for explaining later changes in the variables, even outside the area of origin.

Unfortunately, the cases prepared by the working group do not contain « difficult » cases with real problems of quality. (The project managers do not wish to broadcast such « sensitive » information). The concrete result of the interviews, is that the general method for studying a case is well established, but interpretation of cases and action planning are not described. Only standard interpretations and standard action are invoked if the interviewer asks the expert to study some « textbook hypothesis ».

For example, the major quality criterion cited is the productivity of the production process . The other quality criteria are standard ones - sterility, animal reaction- This interview establishes that some events, reported inside only one area, can lead to some lowering of the productivity criterion (a broken bottle for example).

The recording technique reaches its limits in situations where the expert is very loquacious and refers to several different documents. The interviewer must pay attention to each detail and must persuade the expert to slow down to avoid any abridgment of the reasoning process.

SM2: First synthesis meeting of all the actors in the project. The leader of the meeting is the same as for the first big meeting. The experts give their point of view on the progress of the project, the methods and the information collected during the interviews. There are contrasting opinions: some experts are enthusiastic while others remain skeptical about the results of the knowledge collected. The most interesting thing is that the experts talk together in a very open way. It seems there are not many occasions for them to meet all together. There is a lot of information exchanged, but it is very difficult to manage such a meeting. The main result of the meeting is that agreement and differences of opinion are now emphasized. This is a very important guideline for the continuation of the elicitation work.

To complete the knowledge elicitation and to exploit the dynamics of this meeting, it is decided to bring together two experts for the last interview. One expert plays the role of interviewer and the other plays himself while the « knowledge engineer » observes and reports the meeting.

INT4: The tripartite interview. All the experts has their own documentation and use it either to ask questions or to answer and comment. For the first time, we can observe simultaneously the use of different sources on the same case. Real problems are treated and very interesting information comes to light. The knowledge material produced is more accurate and the reasoning process is well described. The most interesting thing is that, after a short observation time, both experts together start trying to find explanations for the problem under discussion. They are searching for a consensus on interpretation and diagnosis. Planning remedial action remains the sole responsibility of the area expert concerned. Important lessons can be drawn from such an interview:

- the simulated situation is close to the real one, where several people meet to find explanations for a quality drift.

- the interviewer is able to understand most of the reasoning process because he knows the global process well enough(it is the fourth interview).
- the experts are fully involved in the process of the interview and « forget » the observer.
- biases can exist if experts are in fact playing a different role than their own. It can be difficult to detect such role-shifts.

SM3: Last meeting of all the actors in the project. The working group has prepared « selected passages » of the different reports to submit to the whole assembly. These extracts are chosen on the basis of their relative importance for the tasks we have to model (drift detection, diagnosis and planning remedial action). A document is given to each expert. Extracts are numbered and discussed by the experts. Each of them can be rejected, accepted, modified or merged with another extract. Sometimes, the discussion between experts starts again on some difficult point. A score is given to each extract depending on the strength of the implicit (or explicit) rules carried in the text.

Specific attention is given to the list of quality criteria as they appear in the reports:

- sterility (standard)
- satisfactory output (quantitative)
- regularity of output
- « reproducibility » of the product properties
- just-in-time production

and for certain areas:

- clearness
- visual aspect
- biological activity better than the norm

It is interesting to note that this list is richer than that produced during INT3.

FM: Last meeting directly connected to the knowledge elicitation process. The working group uses the results of SM3 to design a first set of rules and metarules.

2.2.2 Knowledge representation

In the context of this project, task models were defined in advance to fit the functions that the system has to perform. The task of drift detection is based on statistical analysis of the historical data base. Drift interpretation and remedial action are the two tasks to which the expert system is devoted. Both tasks can be carried out either for a simulation, in which case new values must be proposed for initial production parameters in downstream areas, or for a real production, when only actions allowed in upstream areas have to be proposed.

All the knowledge is represented by production rules - If (premise) then (conclusion). This kind of representation is sufficient for our objective and we designed 60 rules divided into three groups of 20 rules controlled by metarules. Metarules are easy to formulate because they treat particular situations. Examples of metarules include the following:

- if context is a simulated situation, then modify initial production parameters.
- if context is a real situation, then try only feasible remedial action..
- if context is a real situation and some data is missing, then calculate it with the help of the historical data base and then avoid any conclusion using this calculated data.

The first knowledge base we produced dealt only with the early stages of production .. Rules focus on either explanation of a drift or on possible remedial action. The rules remain general and the reasoning goes only to two levels in depth. The next chapter will present an example of a reasoning session using the knowledge base.

While only a small part of the knowledge might be used for the current expert system, all the knowledge is kept in a report[Mil92] to be used if other stages of the production are treated by a later, expanded system. The validation of the knowledge base is done by a simple check and this is probably sufficient given its small size. The complete system is tested with real data before being installed in the production areas.

3. The system is user-friendly and encourages traceability

The following diagram presents the main screen used by the operator to place the current production alongside the past batches:

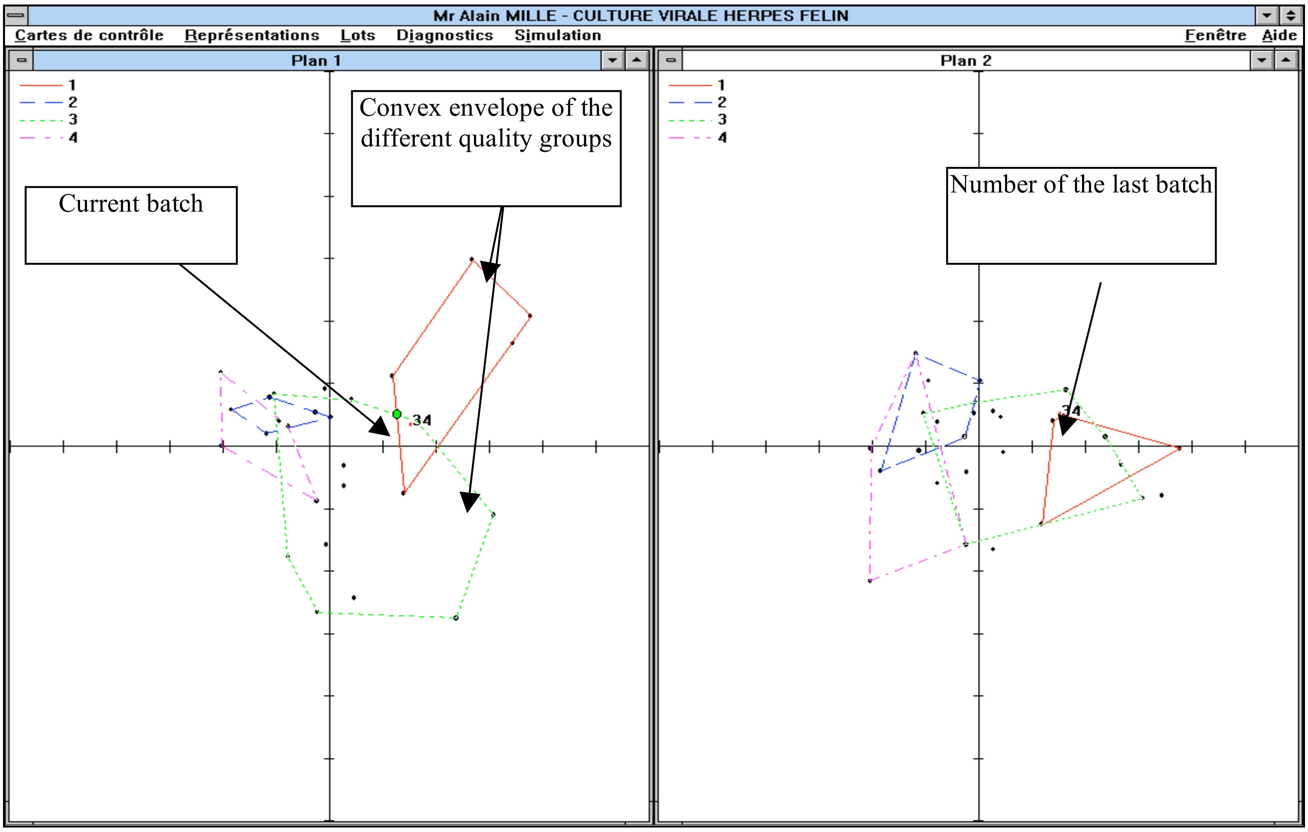
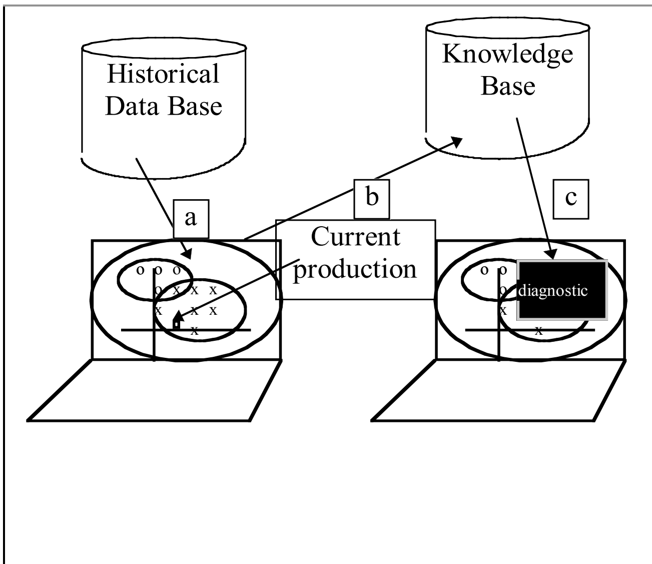


Figure 3-1 Multivariate control map

The following figure presents the principle of a session based on the respective roles of statistical analysis and the expert system. The software is used as a decision helping system.



The operator can get (a) a diagnosis either from the actual parameters of the current batch or from simulated parameters. As soon as the production parameters (real or simulated) are keyed in, consistency with the historical data base is checked through statistical analysis. The batch is then placed in a quality group on the multivariate control map according to the degree of similarity to past batches belonging to that group. The current production is highlighted on the multivariate control map. If the statistical analysis produces a diagnosis of possible drift, the expert system is triggered to give explanations (b). Explanations and remedial action are displayed (c), printed and logged in a special file.

Figure 3-2 General description of a typical session using the decision-helping system

The following is a typical printout from such a session:

--

Numéro du lot : 151

Le : 04 / 08 / 94

20 :05 :58

--

Complémentation

RAS

Coherence quantitative

26.0335

Les valeurs que vous avez indiquées pour les paramètres de culture virale représentent une combinaison relativement exceptionnelle par rapport aux valeurs observées pour l'historique.

La saisie ne comporterait-elle pas une erreur ?

Coherence qualitative

3.3259 RAS

Affectation qualitative :

2.4686

3.6828

3.6167

4.0167

3.3847

2.4686

1

1 (Groupe de qualité prévu pour le lot).

D'après ses caractéristiques par rapport à l'historique, le lot pourrait donner une récolte virale présentant un titre relativement faible.

Diagnostic à faire par le système-expert.

Numéro du lot 151

Le : 04 /08 /94 à 20 :06 :12

Variables pesantes (Paramètres qui pourraient être en cause) :

Paramètres	**Niveau**	**Effet**
Volume en culture virale	**3**	**0.0740**
Fin Ampli. Cell.	**1**	**0.0490**
Concentr. Cell. Cult. virale à J0	**1**	**0.0400**
pH fin Cult. Cell.	**1**	**0.0390**

Paramètres soumis au système expert :

Volume en culture virale

Concentr. Cell. Cult. virale à J0

Compte rendu de l'analyse du système expert :

****

Pour le diagnostic concernant la variable

« concentration cellulaire en culture virale à J0 »

je travaille sur une valeur « saisie »

****

Pour le diagnostic concernant la variable

« volume en culture virale »

je travaille sur une valeur « saisie »

*********** diagnostic r27 ***********

La concentration cellulaire est plutôt faible en considération des situations observées dans l'historique. Les opérations de numération et de préparation du milieu se sont-elles déroulées correctement ?

Tableau 3-1 Typical printout of a decision-helping session

A detailed description of the functions and implementation of the system is available in [MilPia94 et al].

4. Discussion: Toward a Case Based Reasoning System implemented in a multiagent context

4.1 About the multivariate control map

A multivariate control map may be drawn up if the production parameters discriminate sufficiently between batches: A clear distinction is needed at least between the « very good » group and the « unacceptable » group. As an alternative to the use of discriminant analysis for the definition of quality groups, a principal components analysis of experimental data [**Sab83**] could be performed. In the present state of the project, this technique is only used for simulating the values of quality parameters using data restoration.. Analysis by multivariate control map risks becoming blocked if any data is missing. To overcome this problem, we designed a procedure to restore missing data. In the same way, the production parameters were separated into two groups according to their power of discrimination:

- major parameters used alone to position the batch
- minor parameters keyed in, but not used directly to position the batch.

This precaution reduces the number of computation blockages due to missing data, but at the same time, requires attention to the correlation between observed quality and diagnosed quality to be sure that the major parameters are in fact discriminating enough. The global study of the production process, taking into account final controls, has not yet started. It will need major discriminant parameters for each stage of production .

4.2 About the knowledge elicitation process

We discuss our work here in the light of recent research contributions to the field of Knowledge Acquisition. This research field is now very active and interested readers can find a relatively complete state of the art in [AKS92] or in [KriDav91]. Methods for the firsts stages of the Knowledge Acquisition Process are presented in [ReiRue87].

4.2.1 Knowledge acquisition as the modeling of expert tasks

The knowledge acquisition process is generally presented as the modeling of expert tasks and consequently much effort has gone into defining generic tasks to make modeling easier. Since the pioneering works

[HRWL83], several proposals were made by Chandrasekaran [for the first time in 1987] and by Breuker and Wielinga at about the same dates. These first works lay the foundations for most of the Knowledge Engineering Tools and several commercial frameworks are already available. Interested readers can find an overview of these tools in [ABB92],[WVS92] or [Ste91]

This approach is based on the assumption that it is possible to identify the tasks of an expert, or of several experts, by observing them as they solve a problem. This is often the case, but if it is true that there exist only a few generic tasks, it is also true that there exist generally a great number of variants and the generic task identification does not help us with what the experts do in detail. Nevertheless, such a framework is a very useful guide to the knowledge engineer in his work. If the expert task is very close to a generic one, there is some chance that the generic problem-solving methods in the tool being used will work. The assumption is made that re-using can avoid a lot of effort for the design of knowledge based systems.

In our context, the problem given to the experts was new to them, and for the question « How do you do that task? », we had to substitute « how would you do that task? ». Even then, we failed when working with a single expert because the tasks of diagnosis and remedial action are by nature multiexpert. Because of the compartmentalization of the production process and the fact that the tasks were mainly new for the experts, we had some problems in helping them design methods for diagnosis and remedial action. We used the three tasks - quality drift detection, drift explanation and planning of remedial action - as starting points to get partial contributions from each expert. It became evident that we needed to elicit specific sub-tasks from each expert according to the production stage in which they were involved. We then had to define how the different sub-tasks contributed to the goals of the three generic tasks.

The **task** of « drift detection »is carried out by the statistical analysis software and is exclusively based on data similarity measurement. The contribution of expert knowledge is minimal for this task.

For the **task of explaining « quality drift »**, we collect the individual opinion of each expert. The experts make some assumptions about upstream and downstream events, and by putting these different points of view side by side, we could emphasize where views coincide and where they differ.. We decided to retain only common points of view for our system, but it would be interesting to investigate the real reasons for the disagreements. As a model for finding a consensus, the last interview (INT4) was the most important. This method of solving problems collectively is already used in the company when a serious problem occurs. When a special group is formed to investigate the history of a batch , one expert per area is asked to work with the others to find explanations and solutions.

The **task of planning « remedial action»** is new for the experts (except when the drift detection concerns a simulated production) and consists mainly in the adaptation of an old solution to a new situation. They have to decide what process parameters may be modified to correct the drift. As the production process is controlled by strict protocols, it is not easy to see what can be attempted without violating the protocol. What is more, the area experts can only take action in their own area and it is not easy to guess the possible consequences upstream. There is at present no way to consult the others in order to validate a decision about the production process. For all these reasons, the knowledge acquisition remains weak for this task. However a test period could be used to try out some solutions and to learn from experience.

4.2.2 The multiexpert context is a major characteristic of our work

One of the major characteristics of our project is the **multi-expert context**. Specific books about knowledge elicitation such as [FirHel91] or [Vog89] recommend that a multiexpert approach be avoided Each elicitation process is independent and must remain independent to avoid any bias. This recommendation finds its origin in the initial works of Newell and Simon [New82] who focused on the modeling reasoning of one expert to propose different knowledge levels. Nevertheless, we have found in the literature a few works treating the multi-expert situation. MEDKAT[1985] is presented as automating the Delphi method to gather information from multiple experts in[BucWil92]but no details are available on how to merge these items of information. AQUINAS [BooBra87] is a very powerful software tool for obtaining and modeling expertise. One of its components allows the representation of multiple knowledge sources in expert hierarchies. Each node of a hierarchy represents either an individual, an aspect of an individual, a group, or an independent source of knowledge. Information can be elicited independently then weighted and combined to derive joint solutions to problems. The system makes the assumption that different knowledge sources do not overlap with each other and does not take into account any cooperative solutions. We use this assumption for the task of explanation but we fail to do the same thing concerning the planning task. As claimed by [Gai89 we think that it is difficult to validate such a merging process except if the merging is a kind of generalization. The use of multiple knowledge sources is well suited to our case, but could be better used in a multiagent environment, working on a cooperative basis. More recent software tools such as those described in [WVS92] or [Ste91] allow multiple knowledge sources but seem to have the same limitations as AQUINAS.

Some results of Psychology research on human decisions seem to demonstrate that, in general, operators do not « see » what is not usually of their responsibility. This would explain why, in our project, experts in one area often forget about events in other areas and important information is missed.. The work of Hoc in this direction is described in [Ric90]. This observation means that it will be difficult to get spontaneous consensus among the experts from different areas. We think that a multiagent approach would avoid the need for a complete consensus when knowledge is elicited.

« How to maintain the knowledge base? » is also a major question in our case. The knowledge base has to evolve in several directions:

- completion of the knowledge concerning remedial action, probably by using experience.
- completion of the knowledge base to cover other areas of production or control.
- updating of the information related to process elements which have evolved.
- updating of the information if new parameters are identified as important by the statistical analysis system.

We do not have a good answer to this question. We think that the first modifications of our expert system will not be very difficult to integrate into the maintenance of the knowledge base but some mechanisms to detect inconsistencies must be added in the future to help the knowledge engineers. There is already such a mechanism to detect changes in the production process that would suggest updating of the historical data base, and we have to find something similar for the knowledge base.

As we can observe from different interviews such as INT3 and INT4, it is evident that the experts use their particular experience to explain new cases. Some batches are used as prototypes of their class of quality to explain what is the matter with a new production assigned to that class. Similarities are used in our system to assign a quality rank, and we think that we could use the existing batches of the same group to explain why this batch belongs to that group. A part of the work is already done by a specific treatment named « heavy variables » which puts in order the most important variables of a batch to explain the quality assignment. If we get some relations between variables and one of the production parameters on which we can play to modify the parameter, it will be possible to infer more easily from trends in the variables what action to take. Unfortunately, these relations are not easy to see, and there is no explicit model of the biological process. The constant references of the experts to problem cases, in order to find similarities with the one being studied, make us think that it would be useful to store the batches as cases with attributes indicating action taken on the production process and other useful information. Learning from cases [Kol93] [RiesSha89] would be the best way to synchronize with the statistical analysis system, which is based exclusively on the qualitative and quantitative values of the parameters stored in the historical data base.

The following diagram summarizes how we think our system could develop in the future to include all the elements of this discussion:

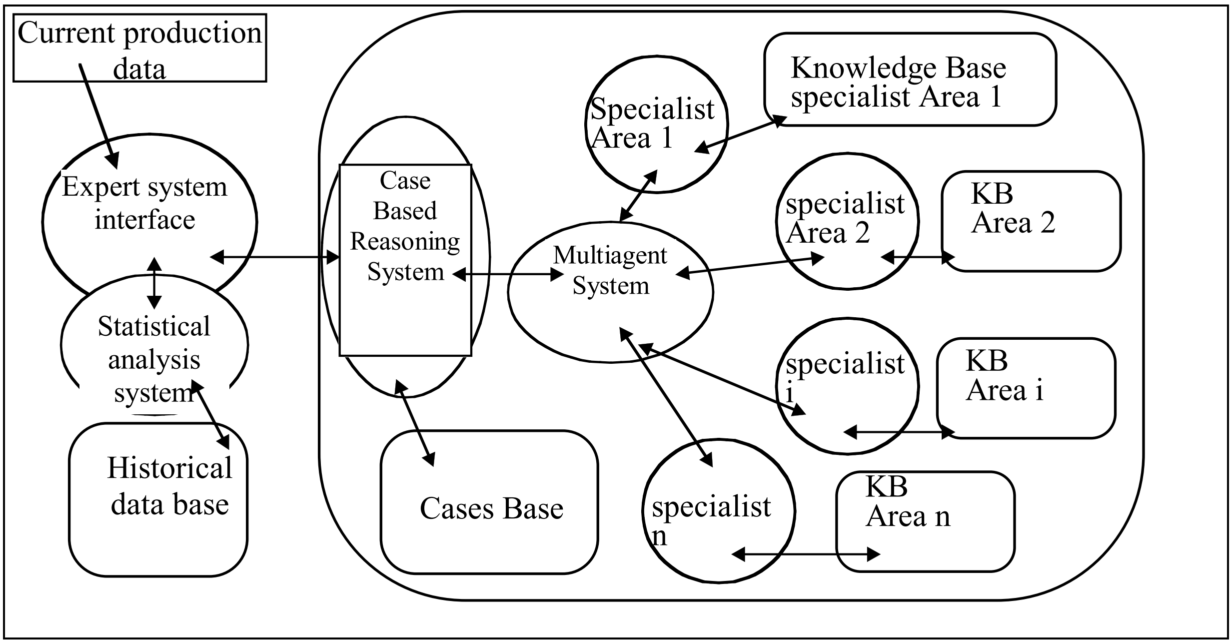


Figure 4-1 Proposed architecture for future development

Every « specialist » in the diagram above has a specific reasoning process according to its task and, moreover, may use the knowledge representation that best fits its needs. Past cases are ranked according to the results of the statistical analysis and their description helps decide which is the best case to adapt. The adaptation is submitted to each expert for their agreement. In case of major disagreement, another cycle can be started with another case. This system takes advantage of recent works in the domain of cooperating systems as presented in [Ros93]. This approach is also advocated in « la Revue Internationale de Systémique » (1994, Vol 8, N°1) devoted to Distributed Artificial Intelligence.

5. Conclusion

This article aims to report our real experience in an industrial context. Multiexpert knowledge elicitation makes the process more complex but brings with it a great deal of useful information, especially concerning cooperative interpretation tasks. An aid to decision-making needs to provide good explanations, i.e. explanations easy to understand by any operator. Explanations using past cases seem to be well suited to our situation because most of the knowledge is to be found in past batches.

The discussion in paragraph 4 is an important part of this article and represents an effort to place our work in the context of recent research on knowledge elicitation and acquisition. Using generic tasks could help to implement an expert system but it is less useful if the tasks are too general. Multiexpert approaches will pay off in a multiagent environment, since each expertise is kept as it is expressed, and the mixing of different kinds of knowledge can be avoided.

Maintaining the Knowledge Base should be easier with a Case Based Reasoning approach[Aam91] because the reasoning process evolves along with the historical data base.

At the end of the paragraph 4, we proposed a future development based on a multiagent approach. The overall complexity of the software would be considerably increased, but the resulting system would be much more effective.

BIBLIOGRAPHY

Aam91	Agnar Aamodt, A Knowledge Intensive Integrated Approach to Problem Solving and Sustained Learning, Thesis, University of Trondheim, 1991, 301 pages.
ABB92	Patrick Albert, Isabelle Bousquet et Eric Brunet, Kads Tools, an Industrial Workbench for the Kads Technology, 10 pages
AKS92	Nathalie Aussenac, Jean Paul Krivine, Jean Sallantin: Editorial sur l'acquisition des connaissances, Revue d'Intelligence Artificielle, vol N°6, N°1-2, pages 6 à 8
BooBra87	John H Boose, Jeffrey M Bradshaw, Expertise Transfer and complex problems: using Aquinas as a knowledge-acquisition workbench for knowledge-based systems., in Readings in Knowledge acquisition and learning (Morgan Kaufmann 1993), p 240-251
BucWil92	Bruce G Buchanan & David C Wilkins, Readings in knowledge acquisition and learning,Morgan Kaufmann Publishers, 1993, 907 pages
Cam83	M Camand, M Precausta, Une unité de production de Vaccins, Biofutur N°17, Octobre 83, pages 26-30
Cos84	A Costecalde, Suivi de Qualité de fabrication par analyse des données, 1984, Revue AFCIQ, VolXX, N°1, pages 31-36
FirHel91	Maureen Firlej et Dave Hellens, Knowledge Elicitation, A practical handbook, 1991, 188 pages
Fon86	J Fontaine, A propos de la production des vaccins contre les virus animaux, Ann. Méd. Vét, N°130, 1986, pages 253-265
Gai89	Brian R Gaines, The Quantification of Knowledge- Formal Foundations for Acquisitions Methodologies, Methodologies for intelligent systems, 4, 1989, Elsevier Science Publishing, Zbigniew W Ras Editor, in Readings in Knowledge acquisition and learning (Morgan Kaufmann 1993), p 462-474
HRWL83	Hayes-Roth F, Waterman D & Lenat D (1983) Building Expert Systems, New-York, Addison-Wesley.
Kol93	Janet Kolodner, Case Based Reasoning, Morgan Kaufman Publishers, 1993, isbn 1.55860.237.2, 668 pages
KriDav91	JP Krivine, JM David, L'acquisition des connaissances vue comme un processus de modélisation : méthodes et outils, Intellectica 1991/2,12, pages 101 à 137
LMN77	J Lebart, A Morineau et N Tabard, Techniques de la description statistique. Méthodes et logiciels pour l'analyse des grands tableaux.1977, Dunod, 351 pages
Mil92	Alain Mille, Rapport de fin de contrat, Système Expert CCMV,Juillet 1992,300 pages
MilPia94	Alain Mille, Daniel Pialot et Al (JM Becker, P Lecointre, A Michel, JM Pourprix, T Simoni, M Stelman), Système Expert de contrôle prédictif de qualité en production industrielle:Association d'une approche statistique et

	d'un système expert., Rapport interne non encore soumis à publication, 1994, 18 pages
Pia90	Daniel Pialot, Analyse multidimensionnelle des résultats d'essais de cuisson d'un gateau. Propositions pour la mise en oeuvre de cartes de controle multiparametriques. in Actes du colloque « Méthodes statistiques et agro-industries », Angers, 9 pages
New82	Allen Newell, The Knowledge Level, Artificial Intelligence N°18-82, pages 87-127
ReiRue87	Judith Reitman Olson, Henry H. Rueter, Extracting expertise from experts, Methods for knowledge acquisition, Expert Systems, August 1987, Vol 4, N°3
Ric90	Jean François Richard, Les activités mentales, comprendre, raisonner, trouver des solutions. Editions Armand Colin, Série Psychologie, 1990,435 pages.
RiesSha89	Christopher K Riesbek, Roger C Shank, Inside Case based reasoning, LEA, Publishers, Hills dale, Newjersey, 1989, 423 pages
Ros93	Jeffrey S Rosenshein, Consenting Agents: Negotiating mechanisms for multiagent systems, 13th IJCAI, Chambéry, France, 28/08/93-03/09/93, pages 792 à 799
Sab83	R Sabatier, approximation d'un tableau de données. Application à la reconstitution des paleoclimats, 1983, Thèse de 3° cycle, USTL, Montpellier
Sap90	G Saporta, Analyse des données et statistique, 1990, Editions Technip, 493 pages
Ste91	Luc Steels, Commet: A Component methodology for knowledge engineering, Work package 2/3/4 du project esprit CONSTRUCT, 63 pages
Vog89	C Vogel, Génie Cognitif, Masson 1989
WVS92	Bob Wielinga, Walter Van de Velde, Guus Shreiber, The Kads Knowledge Modelling Approach, Projet de recherche Esprit 5248, 20 pages