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EXPERT SYSTEMS AND QUALITY CONTROL

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ABSTRACT

Like many other large companies, Aérospatiale is exploring the field of artificial intelligence and, in particular, expert systems : diagnostic aids and industrial applications, without neglecting other domains.

The project described here is a successful application on work planning. The purpose was, with respect to helicopter parts manufacture (rotor shafts, gear, casings, etc ...), to model the knowledge of a few specialists on optimised integration of quality inspection phases into production process layouts.

This problem is quite suited to expert systems because the domain is well defined, expertise is available, the specialist has already been appointed and the data to be processed is logical. Furthermore, this knowledge is hold by a few specialists only and it is important that their experience be preserved.

The success of the prototype computed with prolog has been confirmed through the evaluation phase and has allowed its industrialization.

The industrialization phase integrated the expert system into the existing production management environment and provides user friendly elements (explanatory module / dialogue module) making it easier to use by non-specialists.

The most significant results of this expert system are expected in production process layout quality with improved reliability and guaranteed repeatability ; financial savings are expected too with reductions in process layout preparation times that will mean a reduction in manufacturing cycles and costs.

1 – INTRODUCTION

The following paper describes an expert system application in a production process.

We have intentionally chosen to explain the process leading up to adoption of this technology rather than give a lecture on the techniques involved in expert systems, this being more than adequately covered by specialist reviews.

For this reason, this paper is being given by a «user» of the application who has taken part in its development, and not by a data processing engineer specializing in artificial intelligence.

2 – FIELD OF APPLICATION

Work planning.

In the manufacture of complex mechanical parts for helicopters such as gearwheels, casings, rotor shafts, etc .., work planning involves drawing up an operation sheet for each part indicating the sequence of machining phases for obtaining a part complying with its definition : this is the **operating procedure.**

The notion of compliance with the definition is important since it determines the quality of our products and necessitates the incorporation of checks in these procedures to constitute **quality control phases.**

Our development work has dealt with integration of these phases, taking into account the sum of knowledge to be called on in order to ascertain which checks are necessary and adequate to obtain optimum quality.

3 – OPERATION SHEET

PHASES	MACHINES	EYE BOLT SECTIONS	COMMENTS	TECHNICAL SHEETS
190	999	001	Mat. issue + Inspection	FT10 FT20 FT 30
180	T20	040	Turn	FT50
170	F20	040	Mill	PR3
160	T10	041	Turn	FRS80
150	F20	040	Mill	FT90
140	R62	040	Grind	FT110
130	E10	040	Thread	FT120
120	T20	040	Turn	FT130
110	911	040	Fit	
100	233	027	Hardness Test	
90	209	027	Conventional Dimension Check	
80	204	027	Magnetic Crack Detection	FT911
70	B31	052	Electrolytic Cadmium Plating + Inspection	FT140
60	204	027	Magnetic Crack Detection	FT911
50	236	006	Marking	FT962 - IND
40	260	027	Inspection	
30	990	056	Paint + Inspection	FT150
20	236	056	Marking	
10	299	027	Final Inspection + Archives	

An operation sheet covers diverse technical operations, in particular :

a) **Manufacturing operations**

Machining operations	Setting to dimension
Heat treatment operations	Modification of material characteristics
Protection operations	Coating of all or part of the component according to utilization
Identification operations	Marking of part references.

b) **Combined manufacturing/inspection operations**

These operations are specific to manufacturing technologies where it is not only the end result which requires checking, e.g. heat treatment oven temperature, appearance of parts prior to painting, etc ..., and for which it is more efficient to place an inspector locally rather than to send the parts to the quality control shop.

c) **Inspection operations**

These inspection operations call for both specialists and specific quality control equipment for their execution.

The remaining sections of this paper will deal with these operations in detail.

4 – INTEGRATION OF INSPECTION OPERATIONS

For these operations, consideration must be given jointly to :

The nature of the inspection check.

Its position in the general operating procedure.

4.1 – NATURE OF INSPECTION CHECK

These operations are covered by an ICDH (Helicopter Division Inspection Instruction) standard giving all inspection rules.

There are 3 main types of inspection checks :

SYSTEMATIC : Material issue inspection
Final inspection.

MATERIAL PROPERTIES : Hardness check

PROCESS : Dimensional after machining
Appearance prior to painting
Nital after grinding.

4.2 – POSITION IN GENERAL OPERATING PROCEDURE

The final position in the operating procedure is established in two stages :

The first stage, dependent on the above rules, establishes the position of the inspection operation in accordance with the machining technology employed.

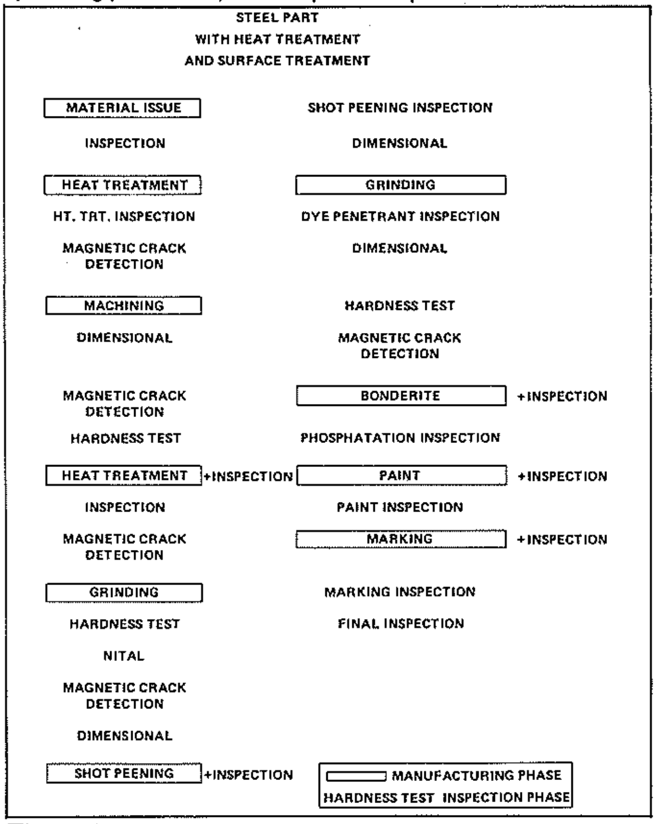
The second stage commences when this operation has been completed for all phases of the operation sheet and involves general optimization, particularly the elimination of redundancies. An example will serve to illustrate this procedure : Let us consider an operation sheet involving only production phases.

STEEL PART
WITH HEAT TREATMENT
AND SURFACE TREATMENT

MATERIAL ISSUE	
HEAT TREATMENT	GRINDING
MACHINING	
	BONDERITE
HEAT TREATMENT	PAINT
	MARKING
GRINDING	
SHOT PEENING	

REMARKS	GRAIN FLOW	DIMENSIONAL		MATERIAL HOMOGENEITY		HEALTH CHECK SEE PARAGRAPH 3: DYE PENETRANT INSPECTION (OTHER MATERIALS)				HEALTH CHECK SEE PARAGRAPH 3: MAGNETIC CRACK DETECTION (FERRO-MAGNETIC MATERIALS)				ETCHING ALWAYS CARRIED OUT BEFORE HEALTH CHECKS (SEE 3)	SPECIFIC	INSPECTION CHECKS / FAMILIES OF OPERATIONS CHARACTERISTIC OF MANUFACTURE		
	AFTER	AFTER	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	AFTER			
GRAIN FLOW CHECK MANDATORY ON MATERIAL ISSUE IF CALLED FOR BY DWG - SEE RELEVANT PARAGRAPH 3 FOR SPECIFIC CASES	F														S	MATERIAL ISSUE		INITIAL OPERATION
															S1			HEAT TREATMENT
		D4													S1	CASE HARDENING	WITH CASE HARDENING ALLOWANCES	CASE HARDENING
			(D4)													MACHINING OF ALLOWANCES		
		D5		H						M4		M1		C1	S1	HARDEN AND TEMPER		
															S1	CASE HARDENING	TOTAL	
		D5		H						M4		M1		C1	S1	HARDEN AND TEMPER		
		D6		H						M4		M1		C2	S1	NITRIDING		
FOR INDUCTION HARDENING ONLY		D1		H		R4		R1		M4		M1		C4	S1	OTHER FINAL HEAT TREATMENT (QUENCH, TEMPER, SULPHITIZE, INDUCTION HARDEN, ETC.)		
D5 - FOR CASE HARDENED ZONES D5 BEFORE FINAL GRINDING		D1		H						M4		M1		C3		MAGNETIC STEELS TS> 1450 MPa	GRINDING	
		D1	(D5)	H						M4		M1				OTHER MAGNETIC STEELS		
GRINDING OF TITANIUM ALLOY TO BE CARRIED OUT ONLY TO DWG SPECIFICAT.		D1		H		R4		R1						C6		TITANIUM AND TITANIUM ALLOYS		
ONLY ON Z100C17 (X-D-B) AND Z100CD17		D1		H		R4		R1						C5		OTHER NON-MAGNETIC METALS		
		D1		H		R4		R1		M4		M1				MACHINING BY REMOVAL OF MATERIAL		

By applying the rules appearing in the ICDH standard to this operating procedure, a non-optimized procedure is obtained.

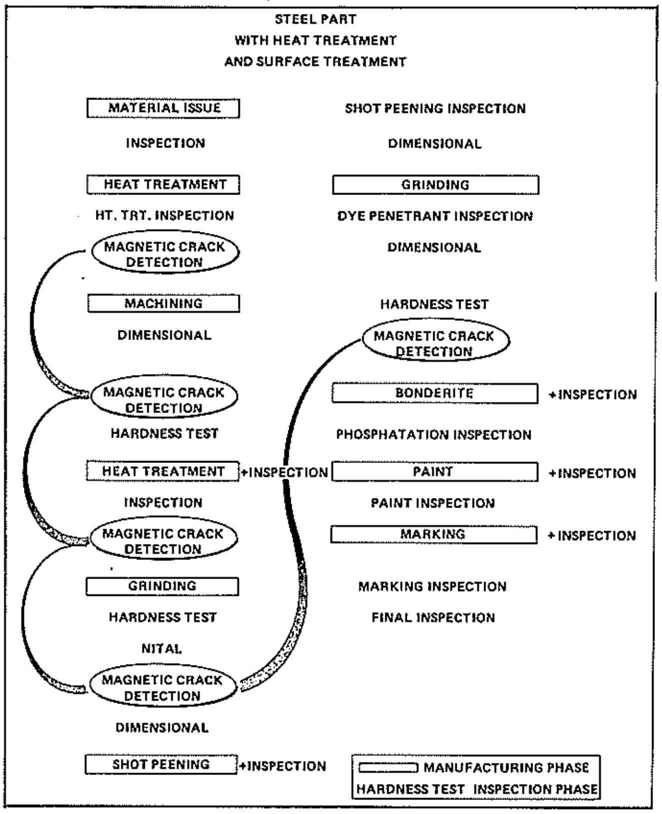


The optimization phase then follows.

OPTIMIZATION

This phase is at present performed manually by a Quality Expert with adequate technical knowledge. An example will serve to illustrate the expert's reasoning.

The present objective is to optimize the position of the magnetic crack detection operation.



It can be seen that by following the rules, 5 magnetic crack detection operations have appeared in this operation sequence.

If the optimization rules are now applied :

The first general rule specifies :

- A single magnetic crack detection operation per operation sheet for parts whose function does not jeopardize aircraft safety in the event of failure.
- Two magnetic crack detection operations for parts affecting safety.

By continuing the procedure :

- It is positioned after final heat treatment
- Unless heat treatment is followed by machining, in which case it is positioned afterwards
- Unless machining is followed by shot peening.

There are two possibilities :

1) If the part has a hardness $<$ 145 hB, magnetic crack detection is to take place first.
2) If the part has a hardness $>$ 145 hB, magnetic crack detection is to take place afterwards.

- Unless shot peening is followed by protective treatment.

There are two possibilities :

1) Protective treatment leads to embrittlement : magnetic crack detection is to take place afterwards.
2) Protective treatment does not lead to embrittlement; magnetic crack detection is to take place first.

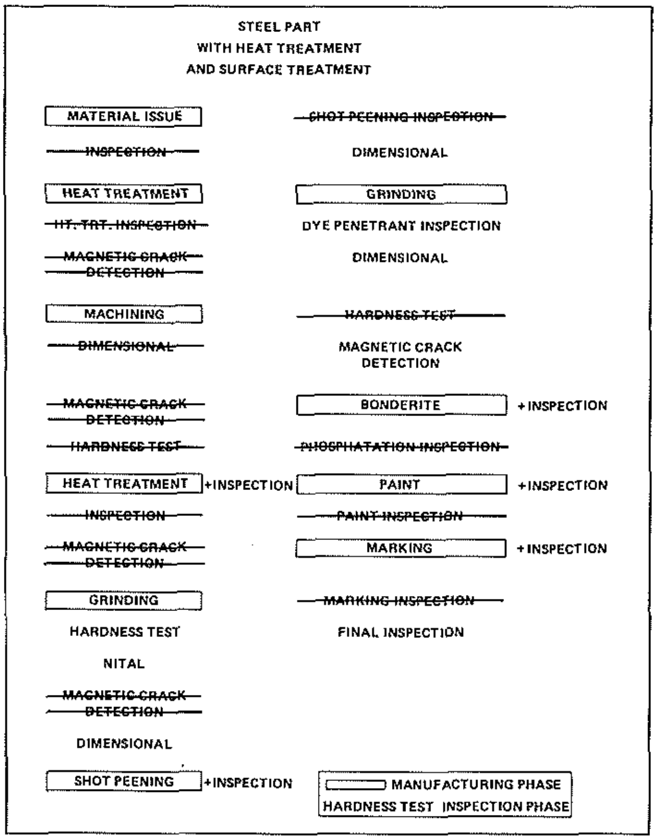
Since bonderite protection does not lead to embrittlement, magnetic crack detection is to take place first.

There is also another reason for positioning magnetic crack detection before bonderizing.

On this part, the bonderite is used as a bonding base for painting which must be carried out within 16 hours without any contamination.

Since magnetic crack detection causes contamination, it is not to be carried out afterwards.

This example provides an illustration of the reasoning which the quality expert must follow for each inspection phase to obtain a fully optimized operation sheet, the final result of which is shown below :



This operation sheet has been considerably improved since 14 of the 32 phases have been eliminated.

5 – COMPUTERIZATION OF THE PROCESS

5 years ago, we attempted to produce a computer program to integrate the inspection phases automatically.

The major disadvantage of the algorithm type program was the need to represent and program all possible phase combinations. The resulting system was so complex that any modification would lead to prohibitive costs. It was therefore abandoned. The following example shows the range of combinations for a single item.

(See flow chart opposite)

The difficulty in computerizing inspection phase integration meant that it still had to be done manually. This acted as a brake on development of a computerized CADAM process.

The arrival of Expert Systems in the industrial world made it possible to overcome this problem.

WHY AN EXPERT SYSTEM ?

It has already been seen that conventional data processing was unsuitable for resolving this type of problem.

On the other hand, all the prerequisites for introducing an expert system were present :

- Existence of an EXPERT
- Good DELIMITATION of the field being evaluated
- MOTIVATED user sector
- Existence of a written DOCUMENT on the field being evaluated, serving as a starting point
- Possibility of OPENING the system to external processes
- Data processing sector motivated by the interest in investigating new technology
- Possibility of development in cooperation with the University of Marseilles.

Since all these prerequisites were present, the project was commenced.

6 – PROJECT PHASES

- Phase 1 : Start of project, definition of problem
  Nov. 85 Jan. 86
- Phase 2 : Acquisition and modelling of konwledge
  Feb. 86 April 86
- Phase 3 : Construction of prototype
  May 86 Dec. 86
- Phase 4 : Evaluation and testing of prototype
  Dec. 86 Feb. 87
- Phase 5 : Industrialization
  May 87

6.1 – PHASE 1 : DEFINITION OF PROBLEM

OBJECTIVE : Examination of process to EVALUATE COMPLEXITY of formal rules.

METHOD : About 15 2-hour meetings with the expert

- Defining present process
- Relating the role of the expert to his environment
- Familiarization with fundamental notions of the field covered
- Defining decision factors used by the experts.

RESULT

- Inspection check positioning criteria ➡ choice of modelling methods.
- Hierarchy and sequencing ➡ GRAMMAR.

6.2 – PHASE 2 : ACQUISITION AND MODELLING OF KNOWLEDGE

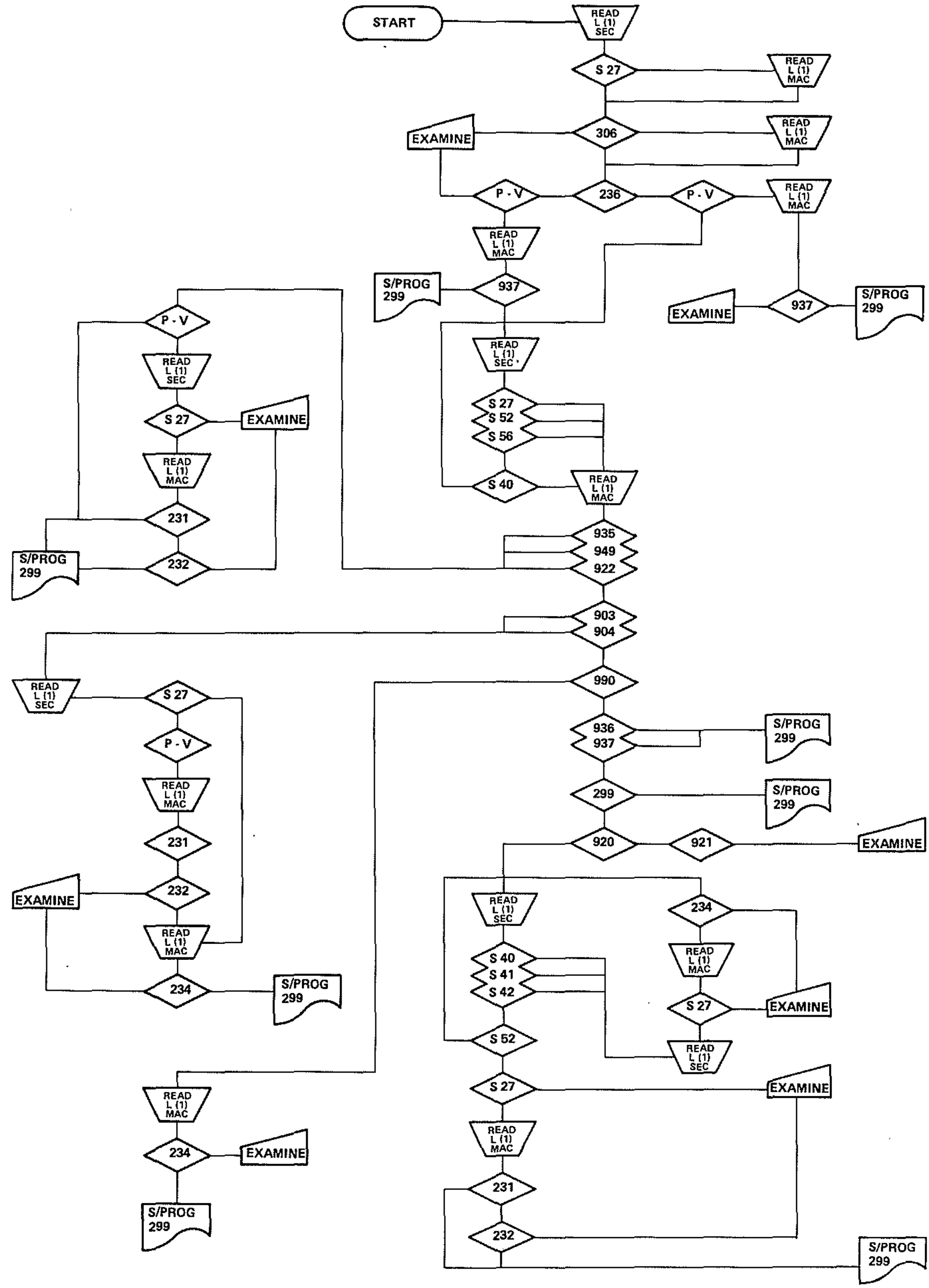
OBJECTIVE : IMPROVING AND MODELLING knowledge.

METHODS : About 30 meeting with MINUTES.

RESULTS :

- Creation of a grammar representing operation sheet breakdown
- Preparation of an evaluation report
- Choice of models to position the inspection checks.

PROLOG selected.


START
READ L (1) SEC
S 27
READ L (1) MAC
306
EXAMINE
236
P - V
937
S/PROG 299
S 52
S 56
S 40
935
949
922
231
232
903
904
990
936
299
920
921
234
S 41
S 42

6.3 – PHASE 3 : CONSTRUCTION OF PROTOTYPE

OBJECTIVE : Construction of prototype on our data processing site.

METHOD :

- At the University : Construction of the prototype in PROLOG II on VAX
- At Aérospatiale : Conversion of prototype to VM/ PROLOG on IBM 3090
- Optimization by creating a facts base
- Programming of test environment.

RESULTS :

- The prototype runs ➡ All elements are validated.

6.4 – PHASE 4 : EVALUATION

OBJECTIVE : Prototype evaluation on the basis of two criteria :

- Knowledge TRANSFER FIDELITY
- Computer resource CONSUMPTION

METHOD :

- By the expert in the presence of a data processing engineer
- Comparison of results of prototype with existing operation sheets
- Modifications.

RESULTS :

- Fidelity of knowledge on operation sheets tested (on 30 representative cases of complex operation sheets)
- Execution time : 0 s to 3 mn
- CPU consumption : 0 s to 30 s on a 3090
- Industrialization requested by Quality Control.

6.5 – PHASE 5 : INDUSTRIALIZATION

Around the constructed system :

- Programming of an EXPLANATORY MODULE
- Preparation of TECHNICAL DOCUMENTATION
- Programming a COMPLEXITY EVALUATION module for the operation sheets processed
- Writing a user interface
- User training.

7 – CONCLUSION

Results obtained for the first simulation runs tend to confirm our initial opinion.

From the quality point of view, reliability of the evaluation and particularly its absolute repeatability make it an essential Quality Assurance tool.

Its integration in our CADAM and production management systems eliminate the manual involvement problem mentioned earlier.

Knowledge held by only a small number of experts is now accessible to a larger number of non-specialists, without additional industrial risks, and this knowledge will be preserved.

Considering the human aspect, the role of the expert is increased since he need now deal only with complex technical configurations which the expert system cannot handle.

In terms of profitability, the operation sheet preparation cycle is considerably reduced and the direct cost for preparation has fallen significantly.

Taken together, these results now enable us to consider Expert Systems as a Major Quality Assurance Tool, and we have decided to pursue this technology in other quality fields.