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Expert system development for hard disk drive failure analysis

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EXPERT SYSTEM DEVELOPMENT FOR
HARD DISK DRIVE FAILURE
ANALYSIS

A Thesis

By

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ABSTRACT

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The Computer's Hard Disk Drive is a complex high technology device, diagnosis of a failure is difficult even using sophisticated test equipments. These Drives are expensive and returning a new one when it fails within the warranty period is not an option. The failed drive must be tested and repaired. In the repair process the analysis and diagnosis of the failures is a key point in the process where decisions regarding the repair process that the failed Drive will follow. Therefore, there is a requirement to perform an effective analysis and provide an accurate diagnosis. The standard system utilized for diagnosis was based on human capacity, this study proves that the deficiencies of the standard failure analysis method does not provide satisfactory results. On the other hand, this study proposes alternatives that incorporate the expert's knowledge and makes it available for analysis technicians, analyzing every Drive.

To my parents, brother and sisters

To Ericka

Thanks for all the support and advices

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CHAPTER 1

EXPERT SYSTEMS FOR HARD DISK DRIVE FAILURE ANALYSIS

The computer industry produces each year millions of personal computers. Such personal computers contain different components such as Hard Disk Drive (HDD), CD writers and many other components. These devices come from different manufacturers, and when one of these components fails, the computer manufacturer receives a customer complaint, and the rejected computers. The customer has to disassemble the computer, replace the broken part, and send the defective device to the manufacturer.

HDD is a basic component in a computer. It's performance is integral in personal computer performance. HDD for personal computers has a 1 to 3 year warranty. When a HDD fails and the PC returns to the computer manufacturer, they remove the HDD and send it back to the supplier. The HDD should be repaired or replaced by the manufacturer according to the terms of the warranty.

The broken HDD is sent to the manufacturer to be repaired. When the returned HDD arrives at the manufacturer's facility, they are tested to verify their performance.

Failures are sent to the Failure Analysis Area (FAA) to be analyzed and to determine a repair disposition. The disposition serves as the repair instructions that refer what to part should be replaced or what test should be performed to each unit.

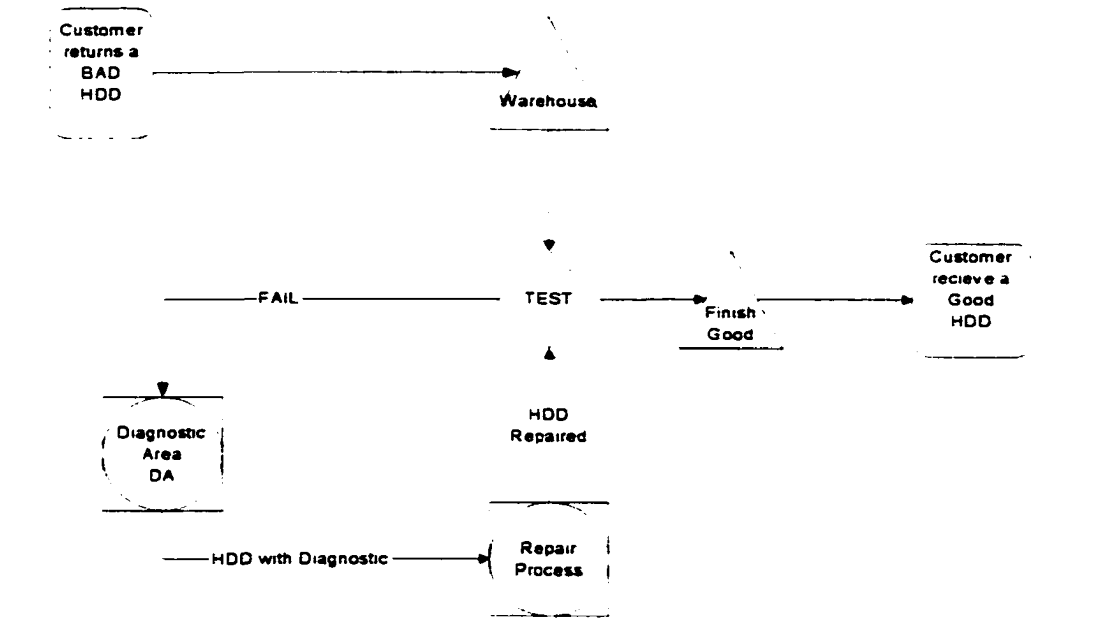

Figure 1.1 HDD failure flow. General view.

Failure Analysis Area (FAA) has technicians that analyze the failed HDD. Based on the failure code that the HDD has, the technician runs specific tests to determine the cause of the failure, the analysis is based on data tables recorded on the HDD during test. In order to analyze HDD correctly, the technician must follow specific instructions for each failure code. These instructions are the guide for the technicians.

The current methods used to measure failure diagnosis effectiveness are not reliable. Therefore, the current metrics do not provide an accurate image of what is happening in the area. The performance of the area seems to have problems, but nobody realized the enormity of the problem, until doing a Repeatability and Reproducibility Study (Gage R&R) for a Six Sigma Project. It was found that the technicians had low scores in Repeatability and Reproducibility. The results of this study got the manager's attention and a deeper analysis was requested. Gage R&R studies were performed to determine the real size of the problem, the studies were done on the higher demand products and all technicians in FAA were evaluated in these studies.

There are some questions that come to mind: Why has there not been prior detection? Why there are high levels of variation in Analysis?

When HDD is repaired the parts are pulled apart, different components are reassembled into the housing of the repaired drive. The damaged parts were sent to different repair processes. The system tracks the drive, but the part number is pasted to the housing of the drive. The drive's housing is assembled with different components; consequently, the HDD that comes out of the repair process will be totally different. Therefore, if it passes or fails, it is not a direct relation with the failure that was analyzed in FAA. The effectiveness of the diagnosis is been measured as pass/fail rate, based on the serial number. That is not a reliable measurement of performance.

The first R&R study revealed that the technicians had low performance when they were evaluated against others. That means that when technicians gave a diagnosis, another technician gave a totally different diagnosis. Some of them presented a low performance even as they were being evaluated themselves.

The Repeatability and Reproducibility study was the tool chosen to determine the performance of FAA technicians. The R&R study has the ability to determine the differences between technicians, between shifts, and also evaluate the technician against himself / herself. This study had the advantage that it was focused on technician performance and collected data of what was the actual diagnosis.

Several R&R tests were performed on different products, technicians and shifts; in order to determine the potential causes of diagnosis variation. The first difficulty was how to determine the masters to set the references. The manuals and reference flows were taken as the references; nevertheless, technicians were not following these flows. When technicians were asked about why they were not using the reference material, they said that the information in those manuals was incorrect. The problem was becoming more and more complex than what it looked like initially. The final decision was to perform planned experiments on the top 5 failure codes for the products with the highest volume. The idea was to determine whether the flows and references provided an accurate diagnosis or not.

The experiments' results showed that the pass / fail rate for the HDD analyzed following the flows and references was high. Then HDD masters for the R&R study were determined following the reference material.

The R&R analysis revealed that the low repeatability and reproducibility scores were a general problem and were not related to one product, line or shift. The problem was complex, and when technicians were asked why they were not following the references, they said that they were trained to follow different procedures. The procedures that they were using were informal. They had hand written notes, not all of them had the same understanding of what they should do and what decision to take.

The repair process has test equipments that filter the defective components, these equipments were masking the low performance of the FAA, but the effectiveness of the repair process was being reduced, due to the low performance of FAA.

One of the root causes of the problem was that when technicians were trained, the experts that trained the people gave them "notes and tips," they introduced their information informally. There were a lot of "expert advices" that were not documented, but technicians applied these in their analysis. Besides, some technicians were trained by experts (person to person), and there was not a defined procedure for training. There were many other issues; for example, some of the experts made changes to the analysis process, but they did not validate their changes and conclusions statistically. More detailed root cause analysis is explained in chapter 3.

Due to problems resulting from lack of expertise on HDD failure analysis, incorrect knowledge management and documentation, and the human factor involved in the current process, the idea of implementing an expert system was considered. The Expert System could avoid the use of informal information, and reduce the risk of human error.

CHAPTER 2

EXPERT SYSTEM CONCEPTS AND PREVIOUS RESEARCH

2.1 Expert Definition

Experience to solve problems makes people valuable in organizations. People succeed because they have special skills to solve problems. Through time they get knowledge based on experimentation, knowledge is a key factor to solve a problem. Consequently, people develop expertise and they get this through experimentation and observation of events. They mix this knowledge with what they get through training, reading and talking with other experts. They also have the "intuition" to make correct decisions, but people cannot attain expertise if the foundations of knowledge are not solid. When the affecting factors to get expertise are not reliable (information management system, training material, feedback), people are creating "false expertise", if the experts perform experiments without solid statements, they are generating "partial knowledge".

In the Information Technology Industry (IT) the evolution pace generates a short life cycle products. Therefore, the chance to get expertise over one product is very small.

Experiments should be sharp, there is no time for long time experiments, and failure causes should be determined as soon as possible.

Experts are defined to be the people that have the knowledge of a certain area or activity by getting knowledge through research and experimentation. They develop heuristic rules that are applied to solve situations effectively.

The idea of having experts in the organizations could be positive, but also experts have many disadvantages [Ignizio 1991, p3]:

- Experts may become ill, retire or quit the company.
- Experts could have low motivation.
- Experts have limitations of time and place. They cannot work more than certain amount of hours daily and weekly. Also they cannot be in several places at the same time. Besides, they have a limited capacity to manage data and not always are capable of finding interactions.
- They have a learning curve, even with the best training, a person requires time to become an expert
- Having an expert is expensive usually the experts earn much more than a typical worker performing the same job.

An Ideal situation would be that experts would be available all the time, in the right place and at their top skill level to the make the best decision. Due to these disadvantages that experts have, there is a necessity to have something that would avoid these experts disadvantages. Expert Systems (ES) help us to support experts, and reduce the expert's disadvantages; because, these disadvantages create a high cost impact.

2.2 Defining Expert Systems

Also known as "Knowledge Based Systems" Expert Systems (ES) cold be defined as follows: "An Expert System is defined herein as a model and associated procedure that exhibits, within a specific domain, a degree of expertise in problem solving that is comparable to that of a human expert" [Ignizio, 1991].

Expert Systems are a branch of Knowledge Based Systems. "Expert Systems is a generic name assigned to a class of software programs that have the ability to interact with a user, define a concern and tailor a solution" [Tuthhil & Levi, 1991]

Expert Systems are the package that contains the expert's knowledge. All this knowledge is combined in a system to facilitate the decision taking process without the direct interaction with experts. The basic idea of ES is to avoid all inconveniences that experts have, and to share all expert's knowledge with decision makers providing them a solid base to take correct decisions.

Most applications of Expert Systems are focused in problem solving applications. Several strategies can be followed in order to solve a problem. Watherman refers to 10 categories for Expert Systems [Whaterman,1986]:

Waterman's categories of Expert Systems	Use
Interpretation	Inferring situation descriptions from sensoring data
Prediction	Inferring likely consequences of given situations
Diagnosis	Inferring system malfunctions from observable events
Design	Configuring objects under constraints
Planning	Designing actions
Monitoring	*Comparing observations to expected outcomes*
Debugging	Prescribing remedies for malfunctions
Repair	Executing plans to administer prescribed remedies
Instruction	Performing diagnosis and prescribing instructions
Control	Governing overall system behavior

Table 2.1 Waterman's categories of Expert Systems

Expert Systems could be also classified by functions: Analysis Based, Synthesis Based, Instructional Based and Memory Resident Aids.

- *Analysis- Based system* Interpretation, prediction and diagnosis categories have similar functions and could be grouped in the analysis based functional group. Those systems receive inputs from the system and they analyze this information to provide specific results.
- *Synthesis Based Systems* Those applications contains heuristic knowledge and rules as tools to analyze and solve problems. Design and planning systems are common based on heuristics knowledge to analyze data and make

conclusions. In design is used to support new designs and provides information on laws and paste experience.

- *Instructional Based Systems* Instructional systems could be similar to analysis systems. Those systems include heuristic knowledge to perform the analysis; an instructional system could detect and make a diagnosis based in heuristic rules.
- *Memory Resident Aids* Those systems are designed to function in the background of the other systems. Those systems support some functions of the other systems.

Despite Expert Systems are effective solutions for decision taking processes; they have some disadvantages:

- Expert system do not recognize cultural factors, if these were not specifically included in the design
- Expert System is not aware of its limitations
- Expert System is not as flexible as human.
- Expert System does not evolute; unless, it has been defined that function in its design, and it will be limited to the considerations taken in the design.

2.3 Other Systems For Decision Taking

2.3.1 Rule Based Systems

Those types of systems are based in IF – THEN conditions. These systems represent expert's knowledge, through a set of rules. One or more conclusion could be generated from several inputs. These systems are effective solutions for some areas. For example, specific cases where the expert is involved and where has a direct relation in the decision process.

2.3.2 Decision Support Systems

The systems developed in computer bases to provide recommendations to managerial decisions are called Decision Support Systems (DSS). The DSS contain tools to analyze information from multiple sources (databases); these systems perform the analysis and provide recommendations to the decision taker. The DSS are used to programming production, forecasting, financial services and many other applications.

2.3.4 Heuristic Programming

Heuristics rules are intuition related. In expert's intuition is represented by heuristic rules. These rules were developed through years of experience; they are in the memory of the expert. Heuristics are frequently referred as "rules of thumb". Heuristics are used for expert to reduce the options to follow. By busing heuristic rules expert will get an acceptable solution but not always is the optimal.

The use of heuristics is justified in those cases, for which more formal analytical procedure are proved to be less effective. Heuristic Programming is not commonly used. It is applied for unique situations, for situations where is not possible to apply an analytical method. Heuristic programming does not warranty to reach the optimal solution.

2.3.5 Neural Networks

Neural network is a data-modeling tool, this is able to capture and represent input/output relationships. The motivation for the development of neural network technology stemmed from the desire to develop an artificial system to perform "intelligent" tasks, similar to those performed by the human brain. Neural networks resemble the human brain in the following two ways:

1. A neural network acquires knowledge through learning.
2. A neural network's knowledge is stored within inter-neuron connection strengths known as synaptic weights.

2.3.6 Algorithms

Algorithms are used to solve problems in which inputs are numeric, this type of system processes this inputs with mathematical operations, relationships and always have an output. For more complex decisions, a Decision Support System should be considered. Commonly algorithms are the base for any system, but is not used alone as a tool to solve problems.

2.3.7 Artificial Intelligence

Artificial Intelligence (AI) tries to simulate human thinking process by using computer hardware and software. AI is focused in try to solve problems as the humans do. Expert Systems are considered a branch of AI; even though, AI has more ambitious goals than ES.

ES and Decision Support System are considered the first generation of AI. A second generation is the systems that can "learn" from what happened in their surroundings. In this learning process the computer receive patterns of data; by using algorithms, the system transforms data in useful information. This generation is called the neural computing.

2.4 Analyzing Human Knowledge

2.4.1 Human Knowledge

Expertise is based on knowledge; consequently, in order to develop knowledge, thinking and reasoning process is required. Knowledge come from experimentation, talking with other experts, reading and many others ways, but always a reasoning process is the key factor that change an experience into knowledge.

2.4.2 Human Thinking

Thinking is defined as a goal-oriented activity focused on problem solving. The main characteristic of thinking process is that the problem statement is new to the individual.

Thinking process is the base for effective problem solving. Thinking is defined as a process that develops the current understanding, and the ability to modify it. Experts use deductive and inductive reasoning to state thesis, and solve problems. Nevertheless, t they are not aware of this process, they never stop and reflect about their thinking process.

Psychologist defined thinking as a reflecting process. Bigge (1982) defines the principal aspect of reflective thinking:

1. Recognition and bounding of a problem.
2. Formulation of approach
3. Consequence of approach
4. Field test hypotheses
5. Resolution

2.4.3 Getting Knowledge

To solve a problem, data should be collected. Nevertheless, data are not useful until they pass through an analysis process. In this process noise data is removed from useful data. After this analysis, data is transformed in useful information. When this information is available, knowledge appears. Thinking is the ability to create knowledge model that faithfully describes the object and exemplifies the action that can be performed on and with that object.

Knowledge-based systems try to emulate expert mental models for problem solving. This model types and knowledge bases have two common links:

a) The sources of knowledge

b) The people who have the task of acquiring the knowledge and representing it for computer use.

The ability to form ideas and state those ideas is dependent upon the individual's ability to tap long-term memory. Knowledge-based systems thus require both declarative and procedural knowledge [Tuthill and Levy, 1991.p.35]

"***Declarative knowledge*** is a descriptive representation of knowledge. It consists of factual statements about people, places, and things. Although, domain experts with declarative knowledge possess synthesized relationships and classifications of people, places, and things, they are not always capable of providing explanations. Truths and associations of truths are the principal attributes of declarative knowledge domain experts.

Procedural knowledge results from the intellectual skill of knowing how to something. It has both psychomotor and cognitive components. Procedural knowledge is sometimes difficult for Knowledge Engineer (KE) to acquire when it is second nature to its human source. Tasks may be so well known to the expert that he discovers he con not express the hows and the whys.

Procedural knowledge is prescriptive knowledge. It is explanatory and employs declarative knowledge for an action. A course of action and the associated procedures are the outputs of most domain experts. Procedural outputs include step-by-step sequences and "how to" types of instructions. Procedural knowledge can also be represented through algorithms. Algorithms are often presented as flow charts in books, technical manuals, and job aids. Having a procedure to do a task, however, does not necessarily correlate with having the skills to perform it."

2.4.4 Knowledge Levels

Knowledge level could be classified in three types: Facts, Concepts and Rules. [Tuthill and Levy, 1991.p.38-45]

Facts - Facts are arbitrary relationships between objects, symbols and events. Facts help in the discrimination process.

Concepts - The next knowledge level is concepts. Concept put together several objects, events or symbols with common attributes. Concepts are conceived in the mind and result from abstracted ideas about classes of things.

Rules - Rules are the third level of knowledge. Rules are sets of operations and steps used to accomplish a goal, solve a problem, or produce something. They are displayed using decision tables, analogies, complex diagrams, and illustrations. Rules are developed from analysis of facts and concepts. The facts are generally refined and linked; the concepts have clarity of focus. Rules consist of declarative and procedural statements and serve as guide for actions.

2.5 Problem Solving

The problem solver establishes a plan for a course of action. He /she uses problem representation through a mental model and suitable knowledge to carry out the plan. Successful problem-solving efforts are predicated on success at each point in the problem-solving model.

2.5.1 Surface vs. Deep Structure Approaches

General problem solvers tend not to probe deeply or look at long-term implications of a situation. Rather, a strategy is adopted that "tests the waters" by cursory attempts at resolution. This approach is also referred to as surface similarity, since on the surface the problem looks like something that is familiar.

If the problem does not have a readily available solution, a more serious approach is undertaken. This approach involves a more carefully planned and systematic attempt referred to as deep structure approach, since it moves from the short term memory processing of the original concept of the problem to symbolic representation of the problem in long term memory.

2.5.2 Stages of problem solving

One schema for problem solving cites three steps: recognizing the problem, forming a representation and pattern matching long-term memory for a solution. [Tuthill and Levy, 1991.p.44-45]

- ***First Stage***. A stimulus provides recognition of a problem situation or space. The stimulus may be sensory stimulation or a memo, progress report, budget analysis, etc. A co-worker, supervisor, or other individual may surface the awareness of the problem or problem potential.
- ***Second Stage***. Forming a representation consists of accessing declarative knowledge and models that pattern match to a current, recognized problem situation. If the match is exact, the problem solver moves to the third stage with a precise plan of action. If there is less than a threshold match, the problem solver forms hypotheses and proceeds with and informed commonsense resolution approach.
- ***Third Stage***. This stage involves the triggering of procedural knowledge that matches stores algorithmic performance actions with the problem in order to move the problem state toward a goal state. The algorithm is a well-defined, tactical procedure for resolving exact matched patterns, and is more strategic when the informed commonsense approach is used.

2.6 Knowledge Reliability

ES need to explore and manipulate knowledge with the risk of uncertainty. Two basic types of indicators are commonly associated with human knowledge: certainty factors and probability.

2.6.1 Certainty Factors.

Domain experts make recommendations in the form of advisories. Using certainty factors and confidence rating factors, domain experts can accommodate uncertainty and ambiguity. Certainty factors are used to create a numerical or graph-type measure of the confidence of a conclusion.

2.6.2 Probability

Probability is the numerical indication of the chance of an action occurring. It is the ratio of the number of times that a particular outcome takes place in relation to the total number of attempts. In contrast with certainty factors used to designate a number on an arbitrary scale stating the extent to which a solution is valid, probability is mathematically obtained but not exact.

2.6.3 Knowledge Longevity

Knowledge is not forever, nothing could be considered today as dynamical changing as knowledge is. Consequently, there is a concern about knowledge life cycle. In the ES development the times that the system is modified is a basic metric of performance. This metric is directly related with knowledge longevity.

The focus of knowledge longevity is in terms of system considerations. Included in these characteristics are permanent, static, and dynamic knowledge.

- ***Permanent. Knowledge*** that is an integral part of an application that will not change (natural laws, physics, etc.).
- ***Static Knowledge*** that remains constant over a period of time buy is likely to change at some point in the application (policies, procedures, etc.).
- ***Dynamic. Knowledge*** that can change from one application to the next or even during use (ROI, patient information, etc.).

2.7 Reasoning.

"Reasoning is the process of working with knowledge, facts, and problem solving strategies to draw conclusions". [Durkin, 1994. p.91]. Humans reason in lines similar to backward and forward chaining using deductive and inductive reasoning. A method of reasoning that is used to relate an unknown to a known is analogical reasoning.

2.7.1 Deductive Reasoning

The purpose of deductive reasoning is to identify or formulate a chain of assertions. Besides, when reasoning is used to deduce information based on logical relation of known information, is called deductive reasoning. Deductive reasoning is a powerful formal system because symbols are established, validated, and transformed into a logic chain. Conclusion follows premises in deductive reasoning.

2.7.2 Inductive reasoning

Inductive reasoning starts with a given data set and has a goal of finding the attributes that formed the set. Inductive reasoning moves from the specific to the general, it is required to arrive to a general conclusion based on a limited set of facts. Thus, the major distinction between deduction and induction is that inductive reasoning has a set of attributes to satisfy.

2.7.3 Analogical Reasoning.

Analogical reasoning is a logic system that works from what is known and understood as a standard and compares the problem in question to that standard. Thus, two systems are compared or contrasted to arrive at a premise of conclusion. This reasoning base requires insight and understanding to form an appropriate analogy.

2.7.4 Commonsense Reasoning

Commonsense reasoning is a collection of personal experiences and facts that humans acquire over time. Once again, knowledge-based systems are not capable of commonsense reasoning at his time because of the massive database that would be required, access time, and other factors.

2.8 Previous Research on ES

Expert System have been widely studied and implemented in many different areas and industries. The examples go from medical, construction, computers, information, plastics, chemical, oil and space industry. Different approach has been used in different cases. The increase on the development and implement of Expert System is based on computer development. Nowadays the computer availability allows to run an Expert

System without any problem. Consequently, the Expert System will be developed faster and will be applied more often in many other fields.

Domain experts are successful at the cognitive processing applied to solving problems. These people tend to have a tuned awareness from which they perceive, process, store, and recall information. They have strategies for storing information or knowledge sets in short and long-term memory

Experts develop complex strategies to process information, select what is relevant, use what they require immediately, and store what they may need to draw upon later. In addition, they have the ability to store and link information, synthesizes that information, and builds new or additional links. The ability to synthesize information depends upon the presence of the information to be synthesized and the quality and quantity of the models.

In the article "Cognitive Task Analysis and Innovation of Training: The case of Structured Troubleshooting"[Schaafstal, Maarten Schraageen and Van Berlo,2000], troubleshooting is defined as follows: "The process from the identification of symptoms to taking appropriated corrective actions". Also discuss about training novice technician and how to improve it.

They developed a new method for training of troubleshooting based on the study done around 1990 in the Royal Netherlands Navy. In this study, TNO Human Factors were ask to evaluated troubleshooting skills from technicians that were in charge of repair radar systems.

The results showed were very interesting:

a) 40 % of the problems were solved accurately

b) Students were not very systematic in their reasoning process, they get an average of 50%

c) They did not understand how the system work, they get an average of 60%.

Other interesting point was they did not found a high correlation between the knowledge test and troubleshooting performance.

A cognitive task analysis is an analysis of the knowledge and skills required for proper performance of a particular task. The framework consists of three elements:

- Analysis of the tasks that have to be carried out in order to accomplish particular goals (the goal of troubleshooting can be described as bringing the system back to its normal state),
- Analysis of the knowledge and skills required to accomplish these tasks (for instance, system knowledge and measurement skills), and
- Analysis of the cognitive (thought) processes of experienced and less experienced and less experienced technicians.

Based on the two preliminary studies and the literature studied, two conclusions can be drawn about the troubleshooting performance of novice technicians:

a) They lack a systematic approach in troubleshooting, resulting in a lack of goal-directed problem solving.

b) A functional understanding of the installations they have to maintain.

They summarized the problems of novice troubleshooters as follows:

1. *Information overload:* The information in the documentation that is critical for troubleshooting is either too difficult for a novice to extract or is simply not available.
2. *Lack of a hierarchical organization:* Novices do not have a hierarchically organized cognitive framework that is suitable for troubleshooting.
3. *Inadequate mental model:* Novices lack a functional understanding of how the radar works and thus do not troubleshoot logically.
4. *Inadequate system understanding:* Novices inadequate mental of the radar are partially attributable to missing underlying system concepts.
5. *Lack of strategies:* Aside from the lack of an appropriate mental model, Novices lack a functional understanding of the fault isolation procedure and its implicit strategies. Novices need to develop robust, flexible troubleshooting strategies that are based on a functional understanding of both the system and the procedures in order to cope with unexpected occurrences while troubleshooting and to recover from any errors they may have made.

Thus the training of troubleshooting should contain a number of elements:

a) System independent strategy for troubleshooting that prevents information overload an ensures a consistent approach across systems

b) Functional models of particular systems (system specific)

c) Underlying domain knowledge of various types (system specific).

Barthélemy, Bisdorff and Coppin in their article "Human Centered Processes and Decision Support Systems" study the role of human factor in decision support system, they related assisting tools that can be used. They expect human strategy to fit the process and to have interesting properties such as "noise acceptance". [Barthélemy, Bisdorff and Coppin, 2002]

There is a natural variance due to human factor. Therefore, they propose mixing standard methods and cognitive techniques to reinforce and to extract the strategies established by the expert operator. They define that communications suppose three levels of structure.

a) Level 0 (Digital step)

b) Level 1 (Linguistic step) Despite the great success in designing, analyzing and classifying computer languages, several failures made in this approach uncertain in domains like language understanding, processing and translating,

c) Level 2 (Cognitive Step) where the notion of utterance replaces the notion of sentences.

They talk about the nature of decision-maker and how decision-makers are becoming hybrid (human and software are mixed), they do not share the same information.

Designers had problems to organize the information, and the experience, they have problems to document them. This failure mode information as well as an effective analysis should be documented in a Failure Mode and Effect Analysis (FMEA). This document forces them to rate failure risk and estimated how often the problem will happen. There is a new technique called Anticipatory Failure Determination (AFD), this can be helpful when dealing with failure modes. The most strategic difference is how it leads development personnel to examine failure modes.

Because of its nature, the AFD process and the steps it takes to solution can sound to abstract. This technique follows 6 steps.

1. Formulating the problem
2. Identify success
3. Localize the failure.
4. Formulate an invert the problem and amplify it
5. Search for solutions
6. Formulate hypotheses and test

O.P. Goyal wrote an article about evaluated troubleshooting skills. He define that troubleshooter generally needs three types of skills:

1. *Human skills* to be able to work for results and have effective communication with people. The atmosphere should be appropriate to create, motivated, and lead effectively.
2. *Conceptual skills* to be able to understand clearly the problem using multidimensional thinking to arrive at an accurate definition of the problem.
3. *Technical skills* to be able to use professional knowledge, methods, experiences and technical activities involved in the process of troubleshooting.

He designs a test to evaluated troubleshooting skills on process engineers involved in process analysis, design and contracting. For designing this type of test not only expertise is required also the answer should be tested and show reliability.

In his article "Expert System Integrating Construction Scheduling With Cad Drawing", Shiou Qing [Shiou Qing Wang, 1994] presents an ES that produce a master schedule for construction based on CAD drawings. Using databases to determine tasks time, Shiou's ES develops a schedule with expert assessment. In a creative solution Shiou presents a ES that based in a task that should be done as a first step op a project, the ES elaborate the master schedule. In other case after the drawing is completed, a team of experts should meet and develop the schedule. This ES provides this schedule reducing time and errors.

Expert systems are connected with knowledge, experts are the bases of expert systems, and they have the knowledge. ES research tries to understand the knowledge management and how the experts get the knowledge.

2.9 Expert Systems Development Methods

There are several methods used to develop and implement the Expert System, in this section most complete methods are analyzed. The method that best fits the requirements for Hard Disk Drive Failure Analysis will be selected.

The steps described below [Payne and McArthur, 1990] gives a methodology to develop an Expert System. Compared with other authors, they provide three basic steps and define the structure that support the Expert System. The steps proposed are:

1. Discovery of a Problem
2. Evaluating alternative solution domains
   - Scooping the system
   - Identifying appropriate experts
3. Choosing an implementation environment
   - Designing the knowledge structure
   - Extracting knowledge and formulating rules

- Prototyping
- Validation and extension
- Field testing

Durkin refers to 6 phases regarding to Expert System development [Durkin, 1994], those phases are similar to the steps proposed by Payne and Mc Arthur. They add Documentation and Maintenance phases, the last phase is necessary to keep the system updated. The model has the following phases:

1. Assessment
2. Knowledge acquisition
3. Design
4. Test
5. Documentation
6. Maintenance

Phase four provides feedback to Knowledge Acquisition phase. During Expert System testing, new knowledge is generated. The testing phase also provides feedback to the Design phase; the system is adjusted and modified based on test results. Maintenance phase is related with the Assessment phase through reformulation of new concepts; these new concepts should be added to the system.

Andriole proposed 9 step methodology, in his "prototyping design blueprint' he describes the process to develop an Expert System [Andriole, 1986]:

1. Requirement Analysis
2. Modeling
3. Method Selection
4. Software Selection and Design
5. Hardware Selection and Configuration
6. System Packing
7. System Transfer
8. System Evaluation
9. Feedback

1. ***Requirement Analysis*** – The requirements are the system goals, the goals should be oriented to the end user. In this step the operation requirements for the system are defined. There are other considerations for this step: the financial, time lines, and technical constrains. The quality of the system is supported by the quality of the requirement analysis; this first step is key in design and development process, in order to get a successful system. Sometimes the Requirement Analysis step is hard because the experts not easily define their support needs

2. ***Modeling*** – There are many ways to represent the functional model of an Expert System. There are flow charts, process maps, mathematical representations and storyboards to model the ES. Storyboard are one of the most popular tools for functional modeling because they create a picture with a description of the users relation with the system and their requirements.

3. ***Method Selection***- The Method Selection could be classified in four categories [Andriole, 1989]:

- *Decision analytic* – This category is related to utility/value modeling methods, cost-benefit, probability modeling methods and multi attribute methods.
- *Operations Research methods* use statistical methods (inferential and descriptive), optimization techniques, queuing theory and simulation methods.
- *Management Science methods* include milestone charts, Gantt charts and critical path methods.
- Computer science includes conventional algorithmic methods used to combine, refine, store, route and create data and information for specific problem solving objectives.

4. ***Software Selections and Design***- There are wide offer of software for Expert Systems. Therefore, the team should evaluate each possible option based on

requirements analysis. There are two software types for Expert System development, the shells and programming. Each of these options has advantages and disadvantages, Andriole recognized five components for expert system software: Dialogue, Inputs, Display, Language and Programming. The dialogue is basic in an expert system; the user should interact with the software. It is hard to make an objective software selection, most software selection are bias. Trying to evaluate too many software options could be overwhelming.

5. ***Hardware selection and configuration*** – This step is a software selection consequence. Software decision will guide hardware selection. Hardware selection should consider capacity of the memory and speed to support data processing; besides, cost-benefit analysis is recommended to support the decision.

6. ***System Packing*** This stage of the process includes: software documentation, support and training. A good user's manual makes life easier for the user, as well as a good training. Decision Support System that is not documented properly it would fail.

7. ***System Transfer*** – as much as the user understands the system, the better transfer from design to the field. If user is involved as much as possible in system design, the smoother the transfer will be.

8. ***System Evaluation*** should be performed. If the system is not evaluated, the success will be limited. The correct evaluation will provide the correct feedback.

9. ***Feedback*** is a key element of the process. Feedback and evaluation are involved in all previous stages. The final system evaluation and feedback phase will provide elements to make the adjustments to have a system that fulfill customer expectation.

2.10 Expert Systems Evaluation Methods

The system evaluation and feedback are the last steps in the Andriole "prototype design blueprint." System evaluation will determine system effectiveness. System performance evaluation, customer needs satisfaction, reliability of the system, and many other characteristics should be graded and recorded. Next step on evaluation is to provide the feedback to determine the weak points of the system and reinforce those points. There are three methods for Expert System evaluation: Subjective, Technical and Empirical.

Adelman [Adelman, 1992] developed a table that contains three levels of measure of effectiveness for an ES: DSS user interface, User-DSS-Organization and Organization-Environment.

2.10.1 The Subjective Methods

These methods evaluated the expert system since the end user perspective. Explicit identification of measures is required, because those measures will be the bases to develop the system. These measures will be the criteria to guide the Expert System developer into the right track.

The system measurements of effectiveness should be developed and stated by the team that is going to use the system. That means how well the system will meet their requirements.

Adelman [Adelman, 1992] described that there are five subjective methods: multi attribute utility technology (MAUT), cost benefit analysis, dollar equivalent technique, decision analysis, and MAUT based cost-benefit analysis.

The multi attribute utility technology is used to score the elements of an ES that has many attributes. The MUAT is used to divide in small pieces the elements of ES; the score could be defined subjective or objective. The main categories are divided in sub categories until the measure is clearly defined, validated and reliable.

The MUAT has the following features:

A) Compressive enough to score the effectiveness of ES.

B) Capacity to determine the differences.

C) Compressive and independent attributes.

Cost benefit analysis is evaluated through probability trees, from a main task or main category going through subcategories and assigning probability of occurrence of each one; the results could be related with the cost.

The MAUT- cost benefit analysis combines the previous techniques trying to select the best option. For this type of analysis Adelman [1992] defines six steps to develop a MUAT-cost based system:

7. Divide the problem into areas over which benefit and costs can vary almost independently.
8. Identify distinctly different actions or levels in each variable that increase in cost benefit.
9. Asses the relative benefit and cost of each level in each variable.
10. Asses the relative benefit in one variable against another by assigning relative weights to variables.

11. Calculate the delta benefit to delta cost ratio for each level for each variable as one moves from the lowest to the highest level of each variable.
12. Use an optimization algorithm to calculate the efficient frontier defining the most beneficial package for varying degrees of total cost.

2.10.2 Technical Methods

As the subjective methods, there are different types of technical evaluating methods with different perspective. Technical evaluation methods are divided in two groups, the first is the analytical methods that evaluate the elements of the system, and the second group evaluates analytical methods matching requirements. Technical methods are used to evaluate software performance; also those methods can be used for a cost analysis.

Andriole [Andriole, 1989] classifies the analytical methods in four categories: decision analysis, operation research, management science and computer science. Decision analysis uses probability modeling methods. Operation research uses statistical methods. Management science uses scheduling methods and computer science uses algorithmic and artificial intelligence methods.

2.10.3 Empirical Methods

The empirical methods evaluation methods are based on the decision maker's perspective. The objective is to determine the difference of decision taker performance, with us without the ES. There are two basic types of experiments to evaluate ES with empirical methods, the first is the "one factor at a time." It is when the performance of the decision taker is evaluated with and without the system, only based in modifying one factor. The second method of experiment is the "factorial design." In this type of experiment many factors are evaluated at the same time in different combinations to provide information of expert system performance related with different factors, and find interactions between the factors.

2.10.4 Validation

Experiments should be valid to apply conclusions. There are several methods to determine the validity of experiment results. The experiment should be valid because if it is not, the results are not useful. Andriloe [Andriole,1992] defines four types of validity for an experiment: construct, internal, statistical conclusion and external.

Internal Validity, that means that the independent variables control the dependent variable and are not affected by noise factors. Experiments should include randomization to determine validity.

Construct Validity is that the measured variables are not confounded and it means accurately what we are looking for.

Statistical Conclusion Validity is the ability of the experiment to provide reliable results with a reasonable error level between independent and dependent variables. Type I and Type II error is about results conclusion should be considered to determine statistic validation of results.

External validity is about the generalizations of results, if the results could be applied to different process, then the system has external validity.

CHAPTER 3

HARD DISK DRIVE FAILURE ANALYSIS PROCESS

In the Hard Disk Drive (HDD) warranty repair process, one of the key steps in the process is the Failure Analysis Area (FAA). In this step, the HDD gets a diagnostic code and is repaired based on this diagnosis. Therefore, the accuracy of diagnosis becomes a major issue in the repair process. In this chapter is presented a description of the repair process and FAA to explain the process. Additionally, the misdiagnosis problem is defined and the metrics for ES are set.

3.1 The Computer Hard Disk Drive Warranties Process - General Overview

The computer industry produces millions of personal computers per year. Each of these computers has a Hard Disk Drive (HDD) inside for information storage. Consequently, the information storage industry produces large quantities of HDD per year. Although HDD have good performance and low percentage of warranty claims, this low percentage multiplied by the millions of HDD produced per year results in a significant quantity of HDD that the manufacturers must repair or replace due to customer warranties.

The HDD are manufactured and distributed all over the world. When a HDD fails, the customer returns it to the computer manufacturer. This study focuses on the diagnosis process for the warranty returns in the HDD manufacturer facility.

Due to the cost of HDD, replacement with a new item is not a first option. That is why the HDD manufacturers have repair centers. In these repair centers, the HDD are tested, analyzed, repaired and returned to the customer. In the repair process, a Failure Analysis performed to provide a repair code to rework the HDD. This step of repair process is where the Expert System will be implemented.

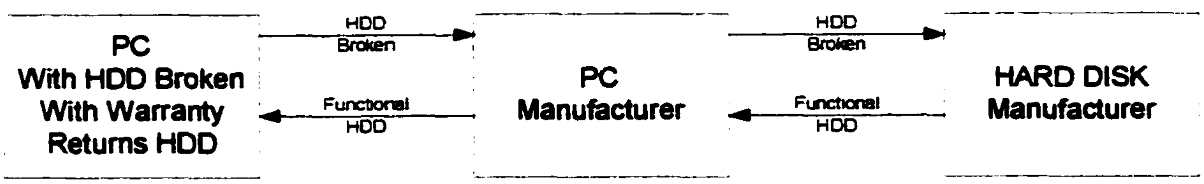

Figure 3.1 Flow for a HDD from manufacturer to customer and the warranty return

3.1.1 Failure Repair Process Description

The process for a HDD warranty (Figure 3.2) starts when the HDD returns to the manufacturer. This reject will be tested, analyzed and repaired. The HDD can follow different paths through the repair process. The first step is to test the basic functions of the HDD (turn on/off condition). If the HDD starts up, then it is able to run the performance test; the HDD will be tested in the final tester equipment (FTE). This final tester runs drive through several tests for a long period of time. Tests are done in stressing conditions to verify that the drive is writing and reading the information correctly. Any writing or reading errors are recorded into the HDD, there are specific numbers of errors allowed, if the HDD exceeds the limit it will fail the test. If HDD fails at FTE it is sent to FAA.

In FAA, a Failure Analyst provides a repair code. This repair code is going to be a "shop order" in the repair process. They are going to repair the drive following the instruction of the Failure Analysis Area.

After the HDD is repaired, it is tested again in the FTE. If the HDD passes the test it will be inspected, packaged and sent back to the customer. However, if the HDD fails, it will be sent again to FAA for analysis.

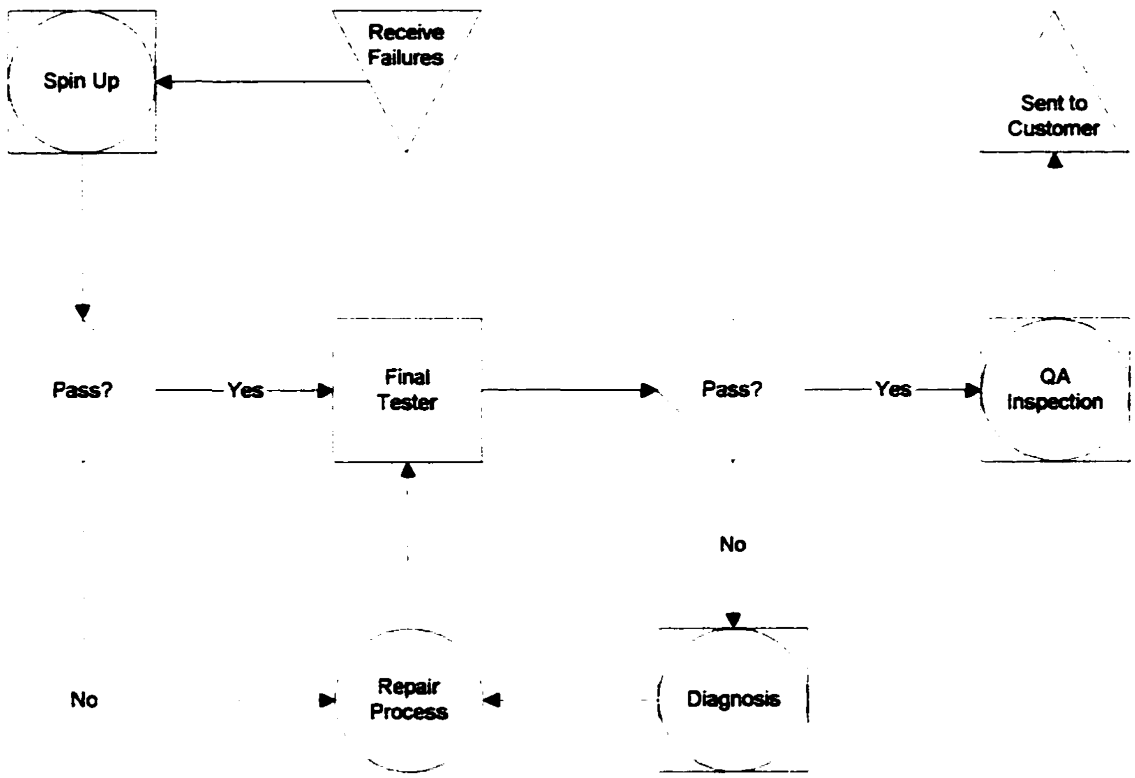

Figure 3.2 Repair Process Flow - Overview

The Failure Diagnosis Area performance has not been satisfactory for a while. Several improvement projects have been done in order to try to fix the problem and some have been partially effective, but the problem remains there because the root causes have not been addressed.

The HDD models that arrive to FAA are different based on the capacity of the drive, customer interface, speed, density and some other product characteristics. There are 8 families divided in two groups. The characteristics are similar, but the analysis could be different from family to family even though they have the same failure code.

3.1.2 Diagnostic Process

After final testers finish a cycle, failures are sent to Failure Analysis Area. In this area technicians analyze the failures and determine the root cause. They assign a repair code that is the command (what to do) for the repair process, e.g. Replace component 09673.

Failure Analysis has three steps:

1. The first step is *database consult*, it is when HDD arrives at diagnosis area (Figure 3.3), the history of the events of the HDD is analyzed. A technician verifies where the HDD comes, if it is the first time that the HDD, has it failed or not, what was the previous failure and what was the previous diagnosis. They make decisions based on this information.

2. The second step is *failure analysis*, this is based on the failure code. The technician consults information from the result tables. This information is utilized by the technician to determine failure cause. The analysis procedure is defined in the Analysis Flow Charts, the tests on diagnosis flows changes regarding the model.

3. The third stage is the *reporting results phase*. The technician records the information in a spreadsheet, and also they record the information into the system.

The system has the ability of tracking the HDD history, this system is an "electronic traveler". These records are used to calculate the accuracy of the diagnosis, but the metrics are not a very effective. The technician's performance is also calculated from this database.

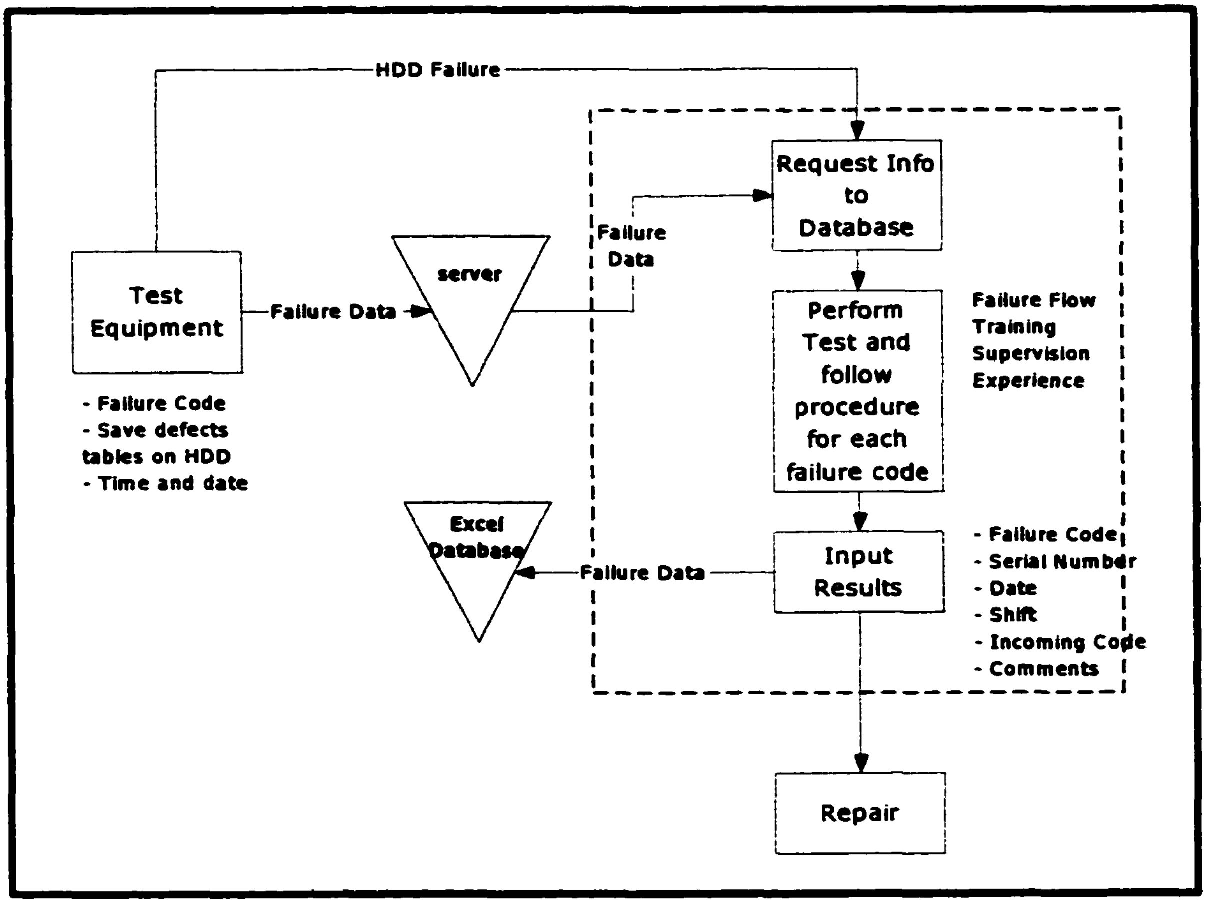

Figure 3.3 Diagnostic Process Flow

The current FAA performance metrics are not reliable. Evaluating the accuracy of the diagnosis is difficult. When a HDD goes into repair process, each component never is assembled in the original HDD.

3.2 Problem Description

The Failure Analysis process is done by technicians. They make decisions based on the criteria set up in the process instructions and failure analysis flows. Based on previous research it was known that the diagnosis for the HDD failures was not effective. Failure analysis flows were modified very often, because they had not been effective. The problem had not been addressed correctly. The previous improvement efforts were focused on Failure Analysis Process changes.

The FAA process is highly human dependent. Therefore, the diagnosis error could derive from the technicians themselves. Human Factor and ergonomic issues were some of the issues involved in the FAA low effectiveness performance. The experiments done showed high variation between the repair code designated for the same piece in two different analysis trials, even if it had been analyzed by the same technician. The root cause analysis and evaluation of technician performance is described on Chapter 4.

3.2.1 Economic Evaluation of the Problem

Measuring the Failure Analysis Area performance is not an easy task. Consequently, the total costs of lost opportunities were undetermined. For this analysis two different types of cost were determined: The direct FAA costs, technicians, supervisors and materials required. The second type will be determined by the cost of the lost opportunities or the cost of wrong decision making.

FAA operations costs are $181,160.00 USD per year (Table 3.1). The cost of making a wrong decision could vary greatly. Cost differentiation could occur even with same failure codes as repair diagnosis differ.

Table 3.1 FA Cost Analysis

Concept	Count	Year
Technician	26	$ 131,040.00
Supervisor	2	$ 12,960.00
Engineer	1	$ 21,600.00
Maintenance		$ 2,300.00
Equipment		$ 13,260.00
Total expenses per year		$ 181,160.00

CHAPTER 4

EXPERT SYSTEM FOR HARD DISK DRIVE FAILURE ANALYSIS

An Expert System could be developed using several method, some of them were described in the chapter 3. The previous methods were combined in order to obtain the method that best fits project requirements. The method that is going to develop the ES for FA is a combination of the methods described in previous chapter, this method has the following nine phases:

1. Problem Discovery, Definition, Measuring and Analysis
2. Determine the end user and system requirements
3. Evaluate project feasibility
4. Identify the experts
5. Software Selection and Hardware requirements
6. Expert System Design
    a. Develop Structure of knowledge
    b. Develop Rules
7. System Testing
8. System Documentation
9. Maintenance and Feedback

4.1 Problem Discovery and Analysis

In the Hard Disk Drive Warranties process a key process for business success is the Failure Analysis Area; here the HDD is analyzed and a repair code is given. The accuracy of diagnosis has a direct relation with material usage, and time to repair. These are key process metrics. FAA analyzes a high number of HDD, for personal computer HDD the amount processed is approximately 23K HDD per month. This high volume causes a lot "Work In Process Inventory" (WIP). The process demand causes that volume of analyzed HDD becomes more important than accuracy on diagnosis. Regardless FAA performance is a key point in business success, the current FAA performance metrics are not accurate. Consequently, the level of improvement based on these metrics are not valid because the baseline data taken for improve is not reliable. Currently there are three metrics used to evaluate FAA performance: Production, Type of Disposition, and Diagnosis Effectiveness.

The current metric "Type of Disposition" is used for tracking the type of material that is being replaced. Based on these metrics the performance is determined, nevertheless, the metrics are confusing, and FAA performance is like a "black box." Besides the weak metrics, the process has too many failsafe systems down-stream that help to correct a wrong disposition.

In the current system an HDD is analyzed at FAA and a repair code is assigned. FAA records the HDD serial number before sending it to repair. When HDD arrives at the repair process all elements are pulled apart. The housing or base keeps the serial number label, but that does not mean that it is going to be assembled with its original components. After the HDD is repaired, it is tested, but it has different elements. The only element that is still related with the serial number is the housing. Consequently, the effectiveness report currently used is not valid because it is based on Serial Number and as it was explained, the HDD is not being reassembled with its same components. There is a requirement for a more accurate FA process measure.

Because FAA is a key step on HDD warranties process and its metrics were not valid, some studies were performed to evaluate the real FAA situation. To determine the value of misdiagnosis, two measures were defined: Diagnosis Effectiveness and as a secondary metric the score of Reproducibility and Repeatability (Gage R&R) of the technicians.

The Diagnostic Effectiveness study consisted of special runs in which a set of HDD with specific repair diagnostics were sent to the repair process with the special instruction that nothing should be repaired except the FAA diagnosis, and every single HDD should be reassembled with its same components. The experiment results obtained were 54% to 64% of acceptance yield, these results were not satisfactory. The objective was to improve this acceptance yield. In these experiments several problems regarding to analysis process were found. Measuring the Diagnosis Effectiveness could be the best choice for evaluating FAA performance, but this metric is not been used because it is not easy to obtain. This type of test took 5 days to be completed for a 30 drive sample. It is not an feasible option.

The R&R study is a process evaluation tool, in this case it is being utilized for technician evaluation. The technician performance is being evaluated in this test, the metrics shows the technician performance within, versus the master, between technicians, and technicians versus the master.

4.1.1 Measure Diagnosis Accuracy

Measuring diagnosis accuracy is a tough task. The current FAA effectiveness measure is a cross-reference table. This cross-reference is done based on system data and shows the Percentage of Effectiveness, the Percentage of Effectiveness is defined as the ratio between passed HDD over analyzed HDD. These analysis are done by failure code, model, and family of products. This metric is not reliable, because when a HDD goes from FAA to repair process, the HDD is disassembled, and these components take several paths. Consequently, the HDD is not reassembled with its same components. The component that FAA marked as failure, is changed, and a repaired. The component is assembled. E.g. HDD is sent to repair process, the FAA repair diagnosis is motor replacement. When the HDD arrives to the repair process it is disassembled the other components are sent to containers, the motor is replaced and the HDD is reassembled but other components are assembled in this HDD. That is why the system based on compare the diagnosis against pass – fail status based on the serial number is not accurate. Consequently the decisions taken based on this metric are not reliable.

An accurate way to measure FAA accuracy and performance is by doing experiments and following HDD through the repair process. If the HDD is assembled with its components, and mixing components is avoided, the result of the analysis is valid. This process is very complex because the repair process is an automatic line. This type of experimentation provides reliable information. On the other hand, it is very time consuming, and does not include the noise caused by the process. The improved process become more complex because there is not a direct measure to evaluate the accuracy of diagnosis, and this is the key output of the FAA process.

To evaluate the accuracy of repair diagnosis, a sample of specific failure codes were analyzed and a repair code was assigned to each HDD. The pieces were followed through the process to avoid any mix of material and to make sure that only the diagnosis repair instruction was done. In the regular process the material is mixed, if a HDD is sent to be repaired and the motor should be replace. For the evaluation of the top failure code the following steps were done: First a technician analyzes the HDD and assigns a repair code to each of them. The second step was to send the analyzed HDD to repair process and followed them through the process to make sure that only the technician diagnosis was followed. Finally the repaired HDDs were tested at Final Tester Equipment.

The results are shown below in figure 4.2, the pieces got a 64.3% of yield, this number cannot be considered as a good performance, even if it is considered that raw material is a defective HDD that had already failed on the field. Most of the replacement components are recovered material. The average yield is 61.1% in a monthly basis, with a minimum value of 60.3% and a maximum value of 62.5%.

It could be observed that the special run did not have a significant difference against the regular acceptance yield of HDD that had been analyzed and repaired, but even that there is no significant differences. Severe deficiencies were found in the failure analysis process. Besides the Failure Analysis Method used has severe deficiencies itself as redundancies, ambiguous criteria, and variability on criteria as well.

Several deficiencies were observed while the technician was analyzing the HDD for failure code A-01, the most common observation were: The process flow determined to analyze a HDD failure was not been followed, the technician showed doubts in several steps of the process when he was asked about some concepts. Some criteria were ambiguous, that could be considered noisy factors in the analysis and diagnosis process. In this sample almost all repair codes on this A-01 failure code are been sent to motor replacement. For FA diagnosis evaluation, the motor replacement codes were classified on five types regarding type of test that had been performed to the HDD. Only three were found in the sample and the yield (see figure 4.1). They were different from one type to another as the occurrence as well.

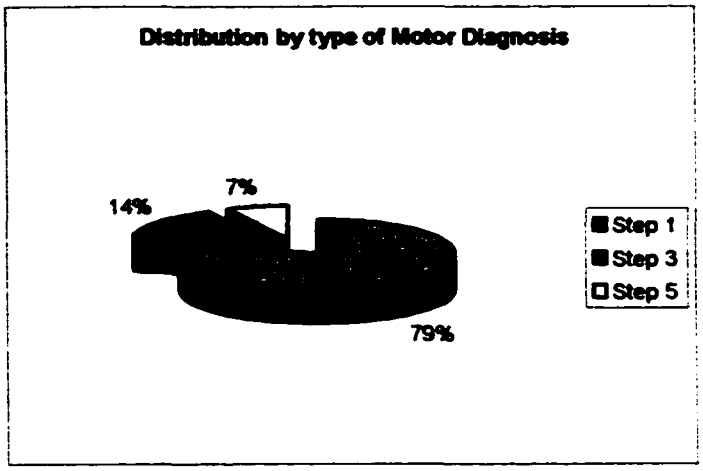

Figure 4.1 Type of Motor Diagnosis for A-01 Failure Code

In this research it was found that certain criteria to make decisions had inherent variability. The decision taken over those criteria was not correct. When the analysis of a failure is done, the characteristics analyzed should be repeatable, and it is not valid to assign specific repair code based on information that is not reliable.

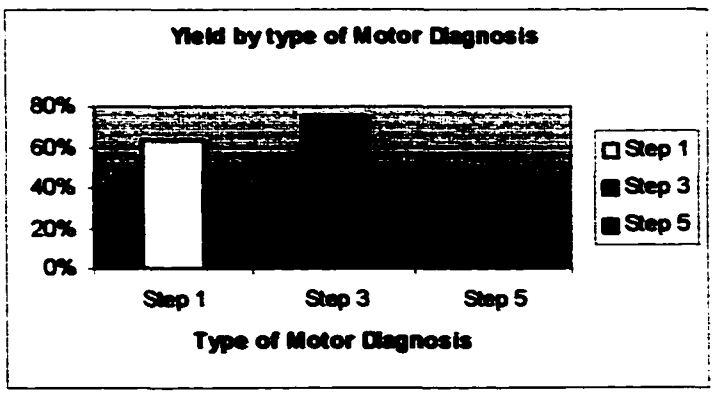

Figure 4.2 Acceptance Yield by Type of Motor repair code.

The sources of variation observed in this analysis vary between technicians, this is due to their skills and knowledge level. In Expert System could be considered as the solution for the diagnosis problem, because this type of systems contains ether the knowledge of the experts and provides to the user a powerful tool for failure analysis and diagnosis.

4.1.2 Evaluating Technician performance

The Failure Analysis Process (FAP) is based on the technician and his/her knowledge. There are process flows that should be followed in the FAP. The technician is the responsible to perform the HDD analysis, but his/her job quality should be evaluated. A Repeatability and Reproducibility study was done to determine the performance of the technicians that work at FAA. The technicians never receive feedback about the accuracy of their diagnosis.

4.1.2.1 The Repeatability and Reproducibility on Failure Analysis Process

The tool used to evaluate the performance of diagnosis of the FAA technicians was the Repeatability and Reproducibility Study (Gage R&R). The R&R were done for the five more frequent failure codes from different products. The intent was to simulate the way as the technician receives a HDD. Drives from the top five failure codes were selected, the study results are shown below for one shift (See Appendix A).

GAGE R&R Study Results

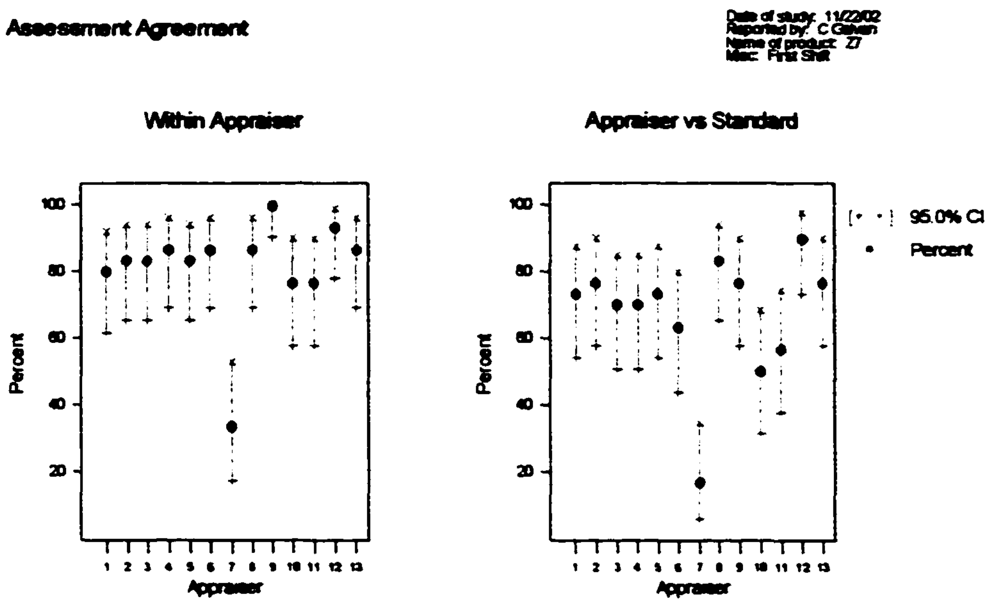

Figure 4.3 Percent of Repeatability Within Appraiser and Appraiser vs. Standard First Shift Technicians

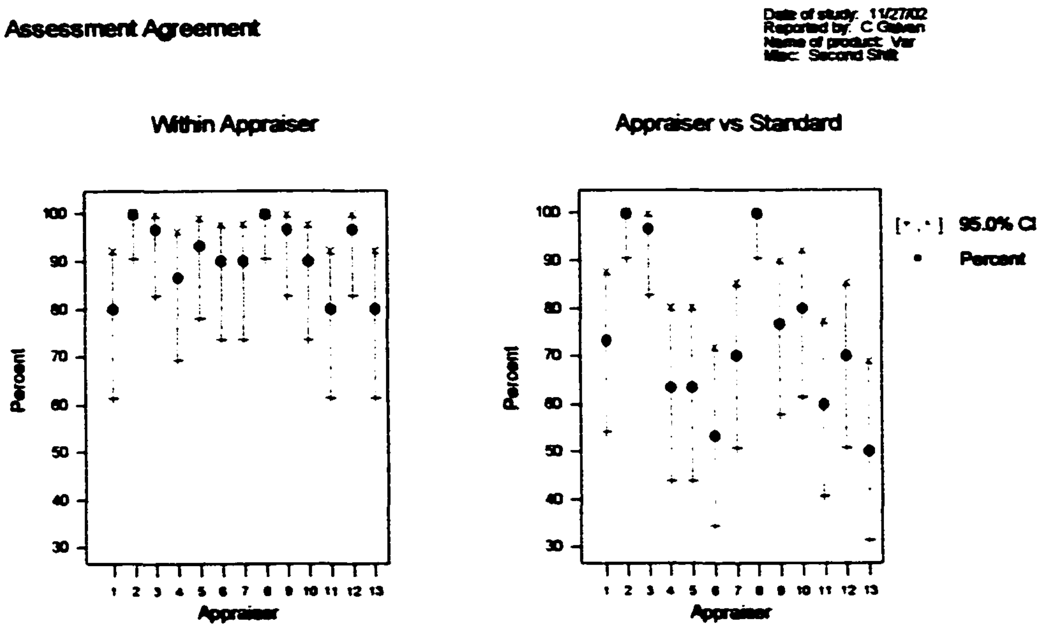

Figure 4.4 Percent of Repeatability Within Appraiser and Appraiser vs. Standard Second Shift Technicians

The graph (Figure 4.3) shows large variation in the "within appraisal", the "Appraisal vs. Standard" shows lower variance. The variation within appraisal is a concern but the low percent that the appraisal got when they were compared against the master is critical. In this group nobody was over 20% that means that the probability of assign a correct diagnosis for an HDD is low.

Table 4.1 shows the values for confidence intervals for the "within appraisal" that means that the technician has consistency in his/her criteria for HDD diagnosis. The results were not satisfactory, the worst tech got a 33.3% of Matched diagnosis.

Table 4.1 Result of the R&R study for the FAA technician

Within Appraiser

Assessment Agreement

Appraiser	# Inspected	# Matched	Percent (%)	95.0% CI
1	30	24	80.0	(61.4, 92.3)
2	30	25	83.3	(65.3, 94.4)
3	30	25	83.3	(65.3, 94.4)
4	30	26	86.7	(69.3, 96.2)
5	30	25	83.3	(65.3, 94.4)
6	30	26	86.7	(69.3, 96.2)
7	30	10	33.3	(17.3, 52.8)
8	30	26	86.7	(69.3, 96.2)
9	30	30	100.0	(90.5, 100.0)
10	30	23	76.7	(57.7, 90.1)
11	30	23	76.7	(57.7, 90.1)
12	30	28	93.3	(77.9, 99.2)
13	30	26	86.7	(69.3, 96.2)

Matched: Appraiser agrees with him/herself across trials.

Each Appraiser vs. Standard

Assessment Agreement

Appraiser	# Inspected	# Matched	Percent (%)	95.0% CI
1	30	22	73.3	(54.1, 87.7)
2	30	23	76.7	(57.7, 90.1)
3	30	21	70.0	(50.6, 85.3)
4	30	21	70.0	(50.6, 85.3)
5	30	22	73.3	(54.1, 87.7)
6	30	19	63.3	(43.9, 80.1)
7	30	5	16.7	(5.6, 34.7)
8	30	25	83.3	(65.3, 94.4)
9	30	23	76.7	(57.7, 90.1)
10	30	15	50.0	(31.3, 68.7)
11	30	17	56.7	(37.4, 74.5)
12	30	27	90.0	(73.5, 97.9)
13	30	23	76.7	(57.7, 90.1)

Matched: Appraiser's assessment across trials agrees with standard.

The score Between Appraisals, and all appraisals vs. standard are always lower than within Appraisal and Score vs. Appraisal, but for the FAA is critical that means that the probability of providing an accurate diagnosis is near zero.

In order to take baseline metrics for FA technicians performance, and failure analysis area the mean and standard deviation of some metrics were considered. The percentage that the technician agrees with himself in both trials and technicians agrees with the master. A basic statistic analysis is shown in table 4.2 for first and second shift.

Table 4.2 First and Second Shift R&R scores

1st shift

Variable	N	Mean	Median	TrMean	StDev	SE Mean
Within	12	85.28	85.00	84.67	6.58	1.90
Appr vs Mstr	12	71.67	73.30	72.00	10.96	3.16

Variable	Minimum	Maximum	Q1	Q3
Within	76.70	100.00	80.83	86.70
Appr vs Mstr	50.00	90.00	64.97	76.70

2nd shift

Variable	N	Mean	Median	TrMean	StDev	SE Mean
Within	13	90.78	90.00	90.32	7.35	2.04
Appr vs Mstr	13	73.58	70.00	73.33	16.76	4.65

Variable	Minimum	Maximum	Q1	Q3
Within	80.00	100.00	83.35	96.70
Appr vs Mst	50.00	100.00	61.65	85.35

From data shown in table 4.3 differences in the mean and in the standard deviation can be observed between shifts, besides the standard deviation has a high value for both shifts, this metric shows high variability in the current FA process. In both shifts the larger variation was in the comparison between appraisal diagnosis and the master value. The first shift got a 10.96 standard deviation, it is a high value for standard deviation.

Other analysis that show relevant information was the Analysis of Variance (ANOVA) done to the Gage R&R data, in the ANOVA the differences between shifts were compared and it was found that the second shift has better performance. Although, the believe that the experts are in the first shifts. The 2^{nd} shift technician got a better performance in the score Within appraisal they also got a better performance in the score Appraisers vs. Standard, this measure represents how the technicians are doing their job compared with a master value. In both metrics 2^{nd} shift got a better performance.

The fact that significant difference was found in this study, showed that high variability was involved in technician diagnosis. Therefore, the repair code assigned to the HDD was not been accurate.

A high R&R score for "appraisal vs. Master" and all other tests, it does not represent an accurate diagnosis. Therefore the master should be validated, if the master is not validated the results are invalid.

Other studies also confirmed the differences between shifts. Different repair codes were evaluated, the same week the differences between Technician repair codes assigned to HDD showed significant differences. Based on a weekly report the repair code "motor replace" showed significant differences in proportions between shifts. With a sample sizes calculation the results are valid.

Table 4.3 ANOVA results, differences between 1st and 2nd Shift

```
One-way ANOVA: Perc betw 2 versus shift
Analysis of Variance for Perc bet
Source     DF        SS        MS        F        P
shift       1       586       586     3.88    0.060
Error      24      3619       151
Total      25      4205
                                   Individual 95% CIs For Mean
                                   Based on Pooled StDev
Level       N      Mean     StDev  ---+---------+---------+---------+---
1          13     81.28     15.73  (---------*---------)
2          13     90.78      7.35              (---------*---------)
                                   ---+---------+---------+---------+---
Pooled StDev =    12.28               77.0      84.0      91.0      98.0

One-way ANOVA: Percent app. vs std versus shift
Analysis of Variance for Percent
Source     DF        SS        MS        F        P
shift       1       246       246     0.79    0.384
Error      24      7481       312
Total      25      7727
                                   Individual 95% CIs For Mean
                                   Based on Pooled StDev
Level       N      Mean     StDev  --------+---------+---------+--------
1          13     67.44     18.51   (-----------*-----------)
2          13     73.58     16.76         (-----------*-----------)
                                   --------+---------+---------+--------
Pooled StDev =    17.66                  64.0      72.0      80.0
```

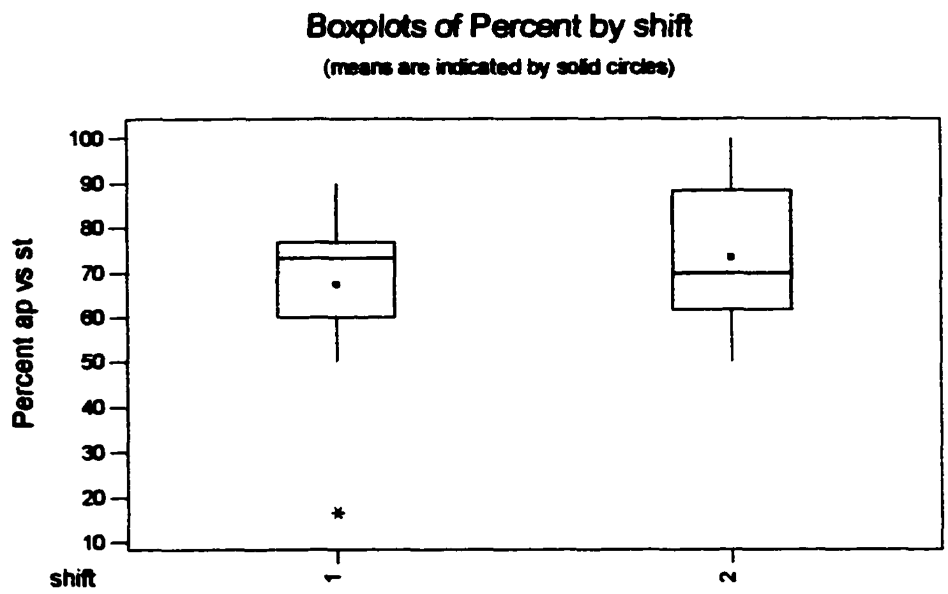

Figure 4.5 Box Plot for shift evaluating Appraiser Vs. Standard Value

The "Motor Replace" repair code was not the only repair code that showed differences of proportions between shifts, also the "Rewrite" repair code also shows differences in proportion by week. Further in this analysis the accuracy of diagnosis will be addressed. Not all codes presented severe differences. For example the "Head Change" repair code do not have enough statistical evidence to say that there is a difference between shifts.

Table 4.4 Proportion Test and Sample Size for motor replace code

```
Test and CI for Two Proportions

Sample       X      N  Sample p
1           88    122  0.721311
2           26     49  0.530612

Estimate for p(1) - p(2):  0.190699
95% CI for p(1) - p(2):  (0.0299030, 0.351496)
Test for p(1) - p(2) = 0 (vs not = 0):  Z = 2.32  P-Value = 0.020

Power and Sample Size
Test for Two Proportions
Testing proportion 1 = proportion 2 (versus >)
Calculating power for proportion 2 = 0.53
Alpha = 0.05

              Sample  Target  Actual
Proportion 1    Size   Power   Power
    0.730000      83  0.8500  0.8523
```

4.1.3 Root Cause Analysis

Based on previous studies it was found that there were severe deficiencies on the Failure Analysis Process. The defect was determined by the high variability on the R&R scores and effectiveness on diagnosis done by FAA, the low effectiveness and the high variability on repair codes assigned to the different failures are the Effects or Failure that should be analyzed to find the current and potential causes. For Root Cause Analysis in this project, several tools were used for the analysis, the Ishikawa diagram, the System and Relationship Map (SIPOC), and Failure Mode and Effect Analysis (FMEA). The objective was to identify the sources of variation on the FAP.

4.1.3.1 Cause and Effect Diagram

A first step was to construct a fishbone diagram to find the root causes of the problem. This tool is used to solve a single effect or problem at a time. The effect considered is a wrong diagnosis. For this project the effect is the incorrect Failure Analysis, the team had a meeting to have a brainstorming and to try to figure out all the possible causes. From this brainstorm session many potential causes were identified.

Based on Ishikawa (fishbone) diagram, many potential causes were discovered, these causes were scored and the team made a selection based on the criteria used to evaluate the Failure Mode and Effect Analysis (FMEA). The causes were score based on severity, occurrence, and detection to determine the risk priority number RPM and priorities were set up.

In the Cause and Effect diagram analysis (Figure 4.6) it can be observed that the MAN branch is one of the most significant causes, MAN involve several causes as training procedures that were not defined, (deeper analysis is addressed further in this chapter). There are not enough knowledge to identify correctly the meaning of the results of each test run to the drive, the use of informal information has a close relation with the informal training, one follows the other. Most of the MAN causes are associated with knowledge, how to get knowledge and knowledge management, that has a direct relation with the expertise level and the experts. MAN causes also has a common cause that is that the Analysis Process has a highly human dependency and as a system is not robust. It has been observed that the HDD analysis is extremely difficult for a person, because he needs to manage a bunch of information that is not presented in an understandable and friendly format. Consequently, the interpretation will be extremely different from one operator to another.

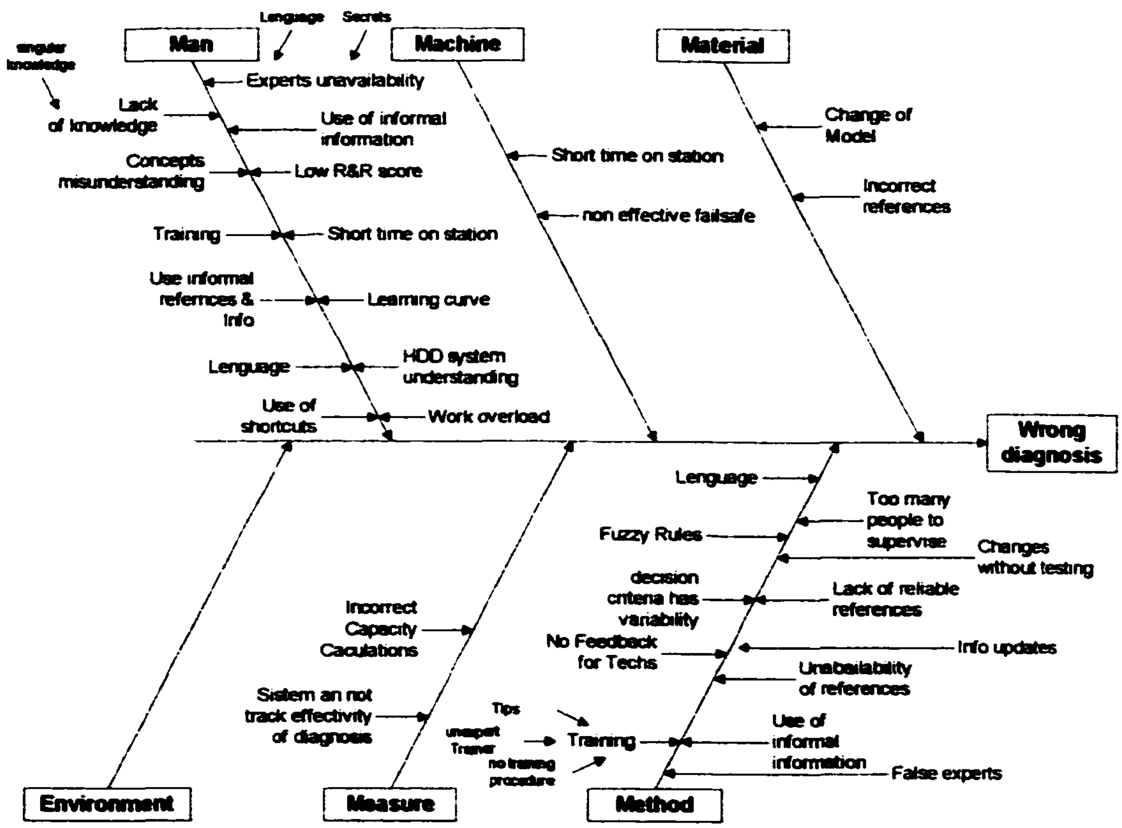

Figure 4.6 The Cause and Effect Diagram for wrong diagnosis problem

Another key factor is communication. It is related to the MAN and METHOD branches. This fact is that the people that make the failure analysis are not electronic engineers, most of the time they are people that have high school at the most. In the best case they are electronic technicians.

The training about how the drive works is not provided in advance. The training that the technician receives is provided from other technician. The person that is in charge of the training is the lead of the analyze station. This training procedure is a potential cause of a incorrect repair code, because the trainer should understand almost as well as the designer the document of reference that they are going to use for the repair code assignment.

The line leader receive "tips" for a better repair disposition of the failures, but the question that should be asked here is "How accurate these "tips" are?". All these "tips" or advice are not written in a formal document. Then the next question would be, "Why these tips are not documented?". The reasons are very different. One reason could be that the experiment done for a specific failure code was informal, or the diagnosis code were change for reduce material usage. Some products did not start the reparation process in the same facility, then the process were transferred, those movements are most of the time from one country to another. This fact create another noise factor in communication, because the "tips" are transmitted from someone to another a lot of information is lost in this communication process. Some of the causes of losing the information are the following:

- Different language (spoken). The computer business has a lot of manufacturing facilities in the Far East, then the "tips" go from the designer to the process engineer and then from the process engineer to the lead of the group of analyzers. In this simulation the information is translated once or twice.
- Different language (written) Reference documents are in English then the written references are at the line but are not available to the diagnostic technician due to the language.
- Time. Informal information is extremely vulnerable to time factor, as this information is not located in a database the information will be lost. Time is a natural enemy of keeping information in papers and memory.
- Knowledge envy. Sometime people do not like to share information that they have found on their own.

Those "tips" are taken as decision rules but due to those rules is not documented; those "tips" are the Heuristics rules. Heuristics rules are related with the intuition, the intuition that expert could have are due to heuristic rules that he has developed trough years of experience and those rules are in the memory of the expert.

The MACHINE (Figure 4.6) has almost any cause related, the station has just a fixture where HDD is connected to a computer and it not considered by the team as a cause of incorrect diagnosis problem. In this analysis the team did not noticed that the program that has been used at the FAA present several ergonomic and discriminative problems.

In the MEASURE (Figure 4.6) branch the team observed that the measure system had severe deficiencies, the methods to measure the diagnosis process did not provide useful and reliable information. The R&R studies to evaluate technician are done occasionally and only then just for special projects; consequently, this measure is not easily obtained. The effectiveness report as it is described above is not utilized and it is also inaccurate, the percentage of the disposition type or repair code does not provide sufficient information about FAA performance. Therefore, a critical point to start an improvement project is to define and determine an accurate and reliable measure system to evaluate the accuracy of diagnosis.

The METHOD branch of cause and effect diagram also shows many system deficiencies specially in regards to, training, the knowledge management, the use of informal information, and the reference manuals are presented in a foreign language creating a knowledge barrier for the technicians. The heuristic rules that were used in the failure analysis area were not effective. Based on the experimental results the heuristic rules were not valid and the use of those rules is one cause for the low accuracy in the diagnosis of a failure. There is written information in a binder at the line but that information is not advantageous for the technician, due to that info that creates a language barrier not allowing them to consult the references and written information of the failure analysis process. At times the elapsed time that a technician stays in the same position was variable and could be considered a noise factor, when demand is stable this factor is not a cause for concern. In any case there will still be a risk because the demand and products in IT business change very often.

FAA people should reach the expertise level in a timely manner due to the computer industry is high pace in technology improvement. Reducing the time period of the learning curve is a key factor as well. Another issue discovered in the root cause analysis is the "fuzzy" rules, that refer to many rules that are not clear decision criteria. Besides, in some steps of the failure analysis process some tests have severe variation in the results obtained, meaning that if one of these tests is performed to the same HDD over and over, each time the result will be different, and the decision rule did not consider that variation.

In the MATERIAL branch the team did not consider almost any issues, it was determined that the incorrect information in the process instructions were more related to the method branch. The team did not consider that the HDD could be a source of variation itself, in other studies it was found that there were variations on information that related to the from HDD in some tests.

4.1.3.2 System and Relationship Map

The Relationship Map is used in complex projects that include different departments or sites. The objective of this map is to get the general picture of the system and identify the weak points or where the output has been affected. The System Maps

(SIPOC) is commonly used for business processes and it is focused on the relation gaps between the process and the suppliers and customers.

In the relationship map it is observed that there is a relation between engineering and Failure Analysis Area (FAA), in this case the engineering department is responsible for providing the concepts and diagnostic criteria to the FAA technicians, also they are responsible for FAA performance (the quality department receives the customer returns, for warranties facility these returns are HDD that has been already repaired). For these returns the analysis is deeper and the knowledge level required to analyze these HDD is higher. The results of the analysis for these drives are posted into a database. For these returned HDD´s the level of analysis is more in depth because there are few and there is the need to figure out why after much testing the HDD has failed for the customer. The type of analysis done by Quality at their labs is much better that FAA can do at the line, there are two significant differences the time available and the equipment, besides the technical level is different. The engineering department does not use the experience that Quality gets from these HDD analysis, therefore the FAA procedure do not advance. The dashed line between Engineering and Design represent the weak link and relation that those department had, The reality is that the knowledge about how a HDD works is not sufficient, That lack of knowledge is one of the causes of the problem of low accuracy on FAA diagnosis, but is very difficult to determine the amount of missing knowledge.

In the relation map (Figure 4.7) it is observed that the relation between Design and Manufacturing is strong but it is not as strong with the warranties facilities. Also in the relation map it is observed that Quality Failure Analysis gets information from the system and has a contact with the customer but there is not a direct information link between what they found and FAA area. When Quality found the root cause of a HDD failure a corrective action is done in the process but, the information and knowledge obtained from the investigative process never arrives to FAA.

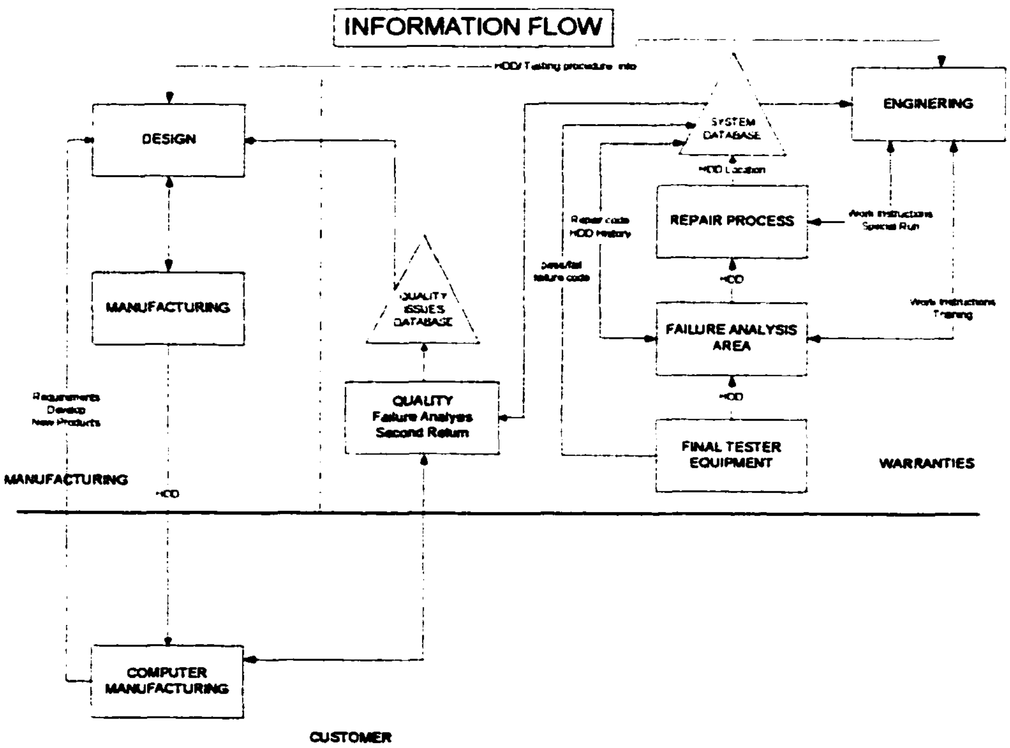

Figure 4.7 Failure Analysis Area Relationship Map

In the System Map (Figure 4.8) it is observed that the Customer Gap Analysis refers to the fact that the repair process sometimes ignores the FAA repair disposition in order to meet the material usage goal. In this type of process, material cost reduction is a key metric to be successful. Due to low accuracy on diagnosis it is a common to ignore the FAA repair disposition and retest the HDD to give it another chance to pass at the Final Tester. A main point in Customer Gap is the lack of feedback, however, we can know if we are doing something right if no one give us feedback. In this particular case FAA did not receive any feedback from its customer.

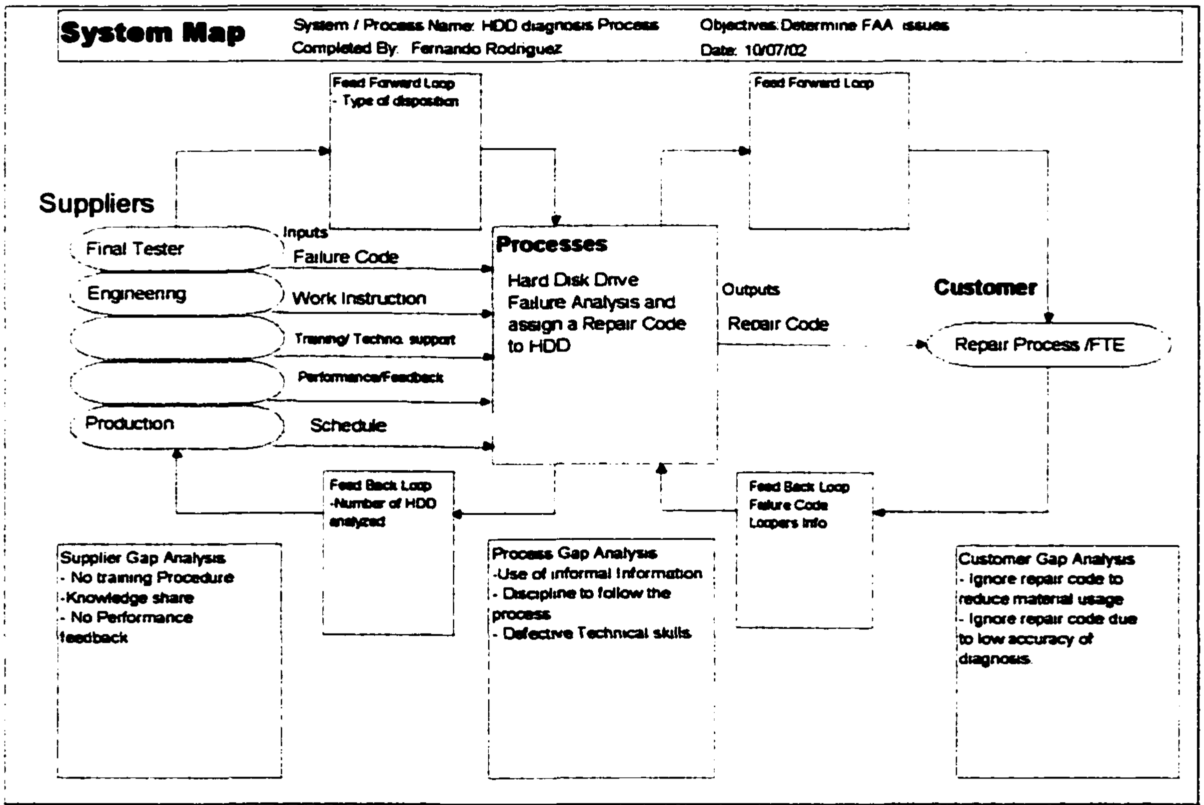

Figure 4.8 The System Map for Analysis Area

The only feed back that they can get is the loop control, that means that the technicians can get at the beginning of an HDD analysis the history of the HDD and determines, if the HDD has make a loop, and he/she can check if the previous failure code was the same or a similar code. This kind of feedback is valid only for few repair codes, nevertheless it remains, a common practice and it does not make much sense.

In this System Map it is observed that the source of knowledge is engineering. This department is responsible for providing the work instructions to perform the analysis and to give modifications to these instructions when new knowledge is generated. Also the Engineering Department is responsible for the performance of the FAA and also providing an accurate and reliable system of feedback on technician performance.

As it was defined in the relationship there is no relation between FAA and Quality Analysis of failures, these two areas should have a closer relationship to share knowledge since the QA level of knowledge is higher it establishes itself as a good source of knowledge to improve FAA process.

4.1.3.3 Failure Mode and Effect Analysis

Potential Failure Mode and Effect Analysis is a failure analysis tool widely used in the automotive and other type of industries to prevent situations before they happen. In this specific case the FMEA was applied to identify and evaluate the causes of the failure misdiagnosis problem, the FMEA provides scoring on Severity, Occurrence and Detection. These approaches provide a better understanding of what cause has the higher impact or what could be addressed first. Also, the FMEA provides based on experience, a guide to future similar experiences, e.g. if a new product is coming to warranties process, the failure modes would be similar and preventive actions could be addressed before become a major issue.

The FMEA developed this project (Appendix A) and is a stage of the entire HDD FMEA repair process. The stage related with FAA has all the possible failure modes related with diagnosis process, also, there exist other points downstream in the process that are connected with FAA.

One of the most common issues detected with the FMEA was the lack of control for many criteria. Many performance indicators just do not have any control mechanisms that score a high Detection grade raising all the steps on the procedure that do not have process controls. Most of the causes of the failures on assigning the correct repair code to a HDD failure is related with knowledge management, training procedures, level of HDD technical knowledge of technicians, understanding the test that they run to analyze the HDD, the quality of the information of the Analysis Process Instructions, and many others. The knowledge management is a common cause incorrect diagnosis.
The lack of feedback for technician performance has the highest RPN (Risk Priority Number) score. This cause has a high occurrence and there is no current control to reduce its effect. The lack of feedback minimizes knowledge development, as the technician is not able to identify his/her mistakes without a feedback system. Even with the R&R studies they do not get a feedback of their own performance; behind this lack of feedback there is the HDD demand, that pressure the technician to do Failure Analysis incorrect.

The incorrect repair code assigned to a HDD Failure is also one of the highest RPN scores. The occurrence is high but also the lack of controls to promotes this incorrect practice causing a high RPN. The causes of incorrect diagnosis could be related to the inaccuracy and deficiencies on the Failure Analysis Instructions; besides, the system does not provide a mistake proof mechanism to avoid human errors.

4.2 System Requirements

The Expert System for HDD failure analysis and diagnosis has the objective to solve current system deficiencies. In order to set up the objective and develop a system that solves the needs, the system requirements should be analyzed. For Payne and McArthur (11) state that,

> "The goal of an expert system is to build a system that will enable the operators in our manufacturing plant to perform at a level of reliability equal to that of the plant 's more skillful engineer and more experienced operator working in tandem"

They also advertise that the above mentioned is too ambitious a goal, and they talk about the "hope to capture at least some of the expert's skills in very focused problems". In this goal they are setting the boundary for the Expert System, of which can not solve all the problems in a specific plant. Even addressing one area, the Expert System objective may not cover all the knowledge and ability of the experts. For the HDD failure analysis system there are some basic differences in types of analysis based on the step of the process where the HDD had failed, that is the first requirement.

As it has previously been described the technician diagnosis has high variability. The second requirement for the system is to provide a solution to the human factor. A complete automated system of HDD failure analysis probably is not possible due to process and product restrictions, but the ES should eliminate the human error . The ES should also prevent errors from the actual system or from the operators themselves. A key component of the Expert system should include a mistake proof feature.

The current system provides several reports to evaluate the performance of the process, these reports show the amount of HDD analyzed and the proportions of repair codes by product family. These reports do not provide a very clear vision of FAA performance, but these metrics and reports should, in any case, be provided by the system. Besides these reports, the amount of HDD by station is a recommended metric to provide the data required to compare the performance between stations or technicians, nevertheless this metric came from a brainstorm session and could be a redundant metric when the Expert System is fully implemented. The R&R test should be performed under a specified frequency to verify that the system is working properly although, the time frequency could be change based on the results. The evaluation should be done between stations and shifts.

As it was discussed earlier, there is a system that allows tracking of the HDD by serial number, but due to the repair process the serial number can not be used to determine if an analysis of a HDD was correct just by tracking if it passed the final tester after having been repaired. The current method used is the following, first HDD of specific failure code are analyzed and a repair code is assigned to each of them, after that a technician follows the repair process and makes sure that the HDD is reassembled with the same components and determines the pass HDD rate, of which will be the effectiveness rate for failure analysis and diagnosis process.

Software development people had the idea of a System that could be modified by others, that means that not every time that a rule needs to be modified the System designer needs to modify the program. The owner of the process should be the actual person that modifies the rules, therefore the rules modification should not be a highly software knowledge requirement task because not all the engineers or other people that can be in charge of the System rules has high software knowledge and skills. The idea is that the rules of ES should be easy to modify.

All the Expert System requirements for failure analysis of HDD are the following:

1. Develop a ES for analysis of HDD failures on testing equipments
2. Fail proofed system to avoid human and system error chances.
3. Reports by failure code, by family of product, and technician
4. R&R verification
5. Effective repair codes
6. Easy to modify and add new rules.
7. Managed and consulted in by net.

Based on the current metrics some of the goals for the ES are:

- Repeatability and reproducibility rate of diagnosis above 97 percent
- Reduce the repeatability standard deviation value (variation between technicians) from 10 to 3 percent.
- Reduce to zero the chances for human error and personal interpretation of analysis procedure.
- Accuracy of diagnosis also known as effectiveness of diagnosis at least in 10%
- Reduce the time of analysis and diagnosis to 25 percent to have a better capacity.
- Reduce waiting time from fail to repair.
- Reduce WIP current measure to1,150 units

4.3 Evaluate the feasibility

ES project feasibility is determined by two main factors. The requirements defined on analysis phase and the resources available for the project. The ES development depends on these two conditions for possible implementation.

The ES success is based on the correct definition and requirements, Adel man [1992, p.41] refers to Boar [1984] who says: "60-80% of all Systems problems can be traced to inaccurate requirements definitions. Adel man [1992] also refers to Andriole {1989] who argues that:

" The [development] process itself is anchored in the quality of the requirement analysis. If the analysis is conducted poorly then the system will fail. If the system is conducted well then the system has a better chance to of succeeding."

Then, the success of the system is directly related with the quality of requirements analysis. If the requirement analysis is done incorrectly the development will be done over weak bases and the probability of success for the System will be low. The resources available for each project will vary depend in the importance and complexity of the project. An economic analysis should provide enough information to support the investment, the analysis should include the benefits of the ES development, and the system requirements are tied with the objectives of improvement and the benefits that the ES will obtain. The ES development phase is conditioned to manager approval; consequently, the requirements, objectives, and benefits should be attractive for the investment.

The objectives for this project have been defined previously, the benefits from the development and implementation of ES are attractive to consider the possibility of investing on ES development, the increase on R&R score up to 97% with a reduction on variation between stations from 10 to 15 percent to 3 percent, that will reduce the risk of an incorrect diagnosis and provide a consistent criteria on repair code assignment for failure HDD that are being analyzed. Besides, the improvement in failure analysis results there are other secondary improvement effects that should be considered. For example the increase of production capacity due to a faster diagnosis is estimated at least 25%; and the reduction in throughput time from final tester to repair process; furthermore, the WIP will be reduced due to reduction in queue at Failure Analysis Stations.

4.4 Experts Identification

There are two different figures that are key in the process development, the expert and the knowledge engineer. The expert is the person that has the knowledge and the knowledge engineer is he who gains the knowledge and builds the Expert System. The function of each one is very different but both of them need to have close communication. About expert domain Tuthill / Levy [1991, p.244] express that: "Domain experts have the tendency to preserve their knowledge and dole it out only as required".

They focus on the knowledge base and the rule set and show less concern for user interface and operational constraints". The above mentioned should be considered at the time of selecting an expert. Some authors like Ignizio [1991] defines the expert as "the person that have expertise in a specific domain, also called domain experts". Beerel [1987, p.118] expresses that not all information that can be provided by an expert is correct. The current knowledge of the expert could be modified with new experiences. He describes as a person that:

- Identifies issues relevant to the problem
- Solves complex problems
- Explains results and how these were arrived at
- Learns continuously and restructures knowledge

- Identifies exceptions (which can be as many as there are rules)
- Applies not the absolute letter of the rule but rather its spirit
- Is human!

Before making the process of expert Identification and Selection, the idea of what is an expert should be clear. An expert is the person that has the knowledge and has applied it successfully, that does not mean that the expert is infallible in his/her decisions. Expert selections should be made carefully, some authors refer to this step of the development as the "bottleneck" of ES development process. There are some situations that should be considered in the domain expert selection to avoid conflicts in future phases of the project, Ignizio [1991, p.112] describes these situations:

- The term "expert" can be used for people that are not real experts, and this term is frequently applied to them that have "the job done". The risk to recruit this kind of "expert" is that the system will be based on their heuristic rules.
- Not all the real experts want to reveal their knowledge, in some cases they do not want to provide any information.
- Some real experts do not understand how they made decisions, they do not have a defined procedure or strategy to solve problems.

It is a fact this work with experts is not an easy task, dealing with experts means dealing with human nature, since humans are complex and not easy to understand. Trying to get the knowledge from the experts means that the knowledge engineer needs to be involved in a labyrinth of the human mind, besides dealing with the personal and psychological side of the experts. The expert identification is not an easy task, as it was pointed out earlier this stage is the bottleneck of the ES development process and the selection of the correct expert is a key factor that will impulse ES success.

Beside the expert selection the knowledge engineer that will lead and develop the project should be properly selected and supported. Payne and Mc Arthur [1980, p.38] say that: " knowledge engineering is the process of making this knowledge available in a form that can be interpreted by a computer". Then the knowledge engineer will be the link between the experts and the system.

The following rules were applied as a guide to expert selection:

- An expert should be ale to understand how he /she arrives at the conclusion and clearly understand the process that he / she used to find the solution
- Understand the objective of the project
- Have a satisfactory performance in the field that will be considered domain expertise.
- Good communication skills

Besides these points it can be added the points that Ignizio [1991, p.116] recommend for an Expert selection:

- Organization can provide candidates who can be considered as those that have enough experience in the specific domain
- Select the domain experts as the ones that are above and beyond the average performance
- Verify expert consistency through a reasonable time period
- Select an expert that is able to communicate his / her knowledge

- Select an expert that is able to dedicate enough time to the project

The Expert selection for the HDD Failure Analysis Expert System was done based on the previous descriptions, and the selection process was not an easy task due to different causes and the type of organization. The knowledge about the HDD functions is limited.

This Expert System is being developed in a warranties facility. In the organization structure there is not a direct link between this facility and the design teams; consequently, the communication is limited. Besides the fact that the communication with the real experts is limited there is a fact that the engineers and technicians change frequently from company to company, due to economic circumstances, the rotation of technical people is calculated around 15% in quarterly bases. The experts are located far away from the facility where the ES is being done and that fact makes more the Expert selection task harder. Design centers are located in other sites and the designers are extremely busy persons. They are focused on the new products and most of them do not have enough time to support projects at warranties facilities. They answer some questions related to very specific and critical situations. Furthermore, the models of HDD that warranties are dealing with are already antiquated for designers. There are other Experts that are working in HDD "New Built", in those facilities there are people that have many years working in HDD industry and they are running the same HDD models that warranties facilities, but they are located in the Far East and the contact is minimum. In that case, the Expert identification process would be very difficult and time consuming.

Due to all the facts exposed above the expert selection is limited to warranties facility and occasionally some advice over specific issue can be solved by some design engineer or quality engineer at design centers. The Expert selection was done in warranties facility with the following results:

In the Failure Analysis Area there are not any experts, due to the low knowledge over the HDD functions and how it can be analyzed, the technicians low knowledge level of how HDD works, and that most of them do not really understand the whys of the analysis process steps. The policy is to hire an electronic technician because they have a higher knowledge in electronics and they should have a better understanding of how HDD works and how to analyze it, but to hire people with electronic knowledge does not assure that they will understand easily how the HDD works and analyze the failure accurately. The hiring process requirements are acceptable, but that is only the first step, the following steps are in regards to appropriate training as, but the technicians have been trained with the classic method of which the "expert" in the area trains the new one. At the beginning some people from the Far East came to train the first technicians, but that is not a effective training method either.

The process engineers were more focused on the productive process and other facets. The real experts were founded in a Quality Failure Analysis Lab. In that lab some engineers had received training from the designers and some of them had been in contact with them to solve some problems, thus they really understand the HDD functioning.

The identified experts have some problems in expressing their knowledge but they showed the disposition to work collaboratively in the project and they had good communication skills, these sometimes are not seen very often in experts. Their performance is recognized by the organization and by their supervisors and also they had been working long enough to be considered candidates for the project, nevertheless one expert quit the company during the project.

These engineers are dedicated to answer customer claims on rejects, then the analysis that they do goes far beyond the quick analysis that is done at the line. Therefore, it may be a good idea to incorporate all their knowledge in the short and quick failure analysis that should be done at FAA. There could have happened that no expert was found and for that case there are some alternative methods to develop the Expert System.

Knowledge engineer selection is also a key step in the ES development process, if Experts are properly identified and the knowledge engineer does not provide the support to the experts the ES will not succeed. Ignizio [1991,p.117] describe some points that should be considered in the knowledge engineer selection:

- At least two knowledge engineers should work in the ES development and at least one should have developed and successfully implemented a ES before.
- The KE task is to identify and build the model of knowledge.

In the ES development for HDD failure analysis, the first recommendation cannot be accomplished due to it being the first ES that is developed at this facility; therefore there is not any KE available. Nevertheless, as the ES can be developed with alternative methods also the fact that there is not a KE with previous experience available will not slowdown the ES project development. The previous experience on implementing Es that is recommended but was not encountered in this project. In this case the KE has to accomplished some others skills described by Durkin [1994, p. 46-48], these skills are:

- Ability to evaluate the feasibility of the ES project
- Communication skills
- Software knowledge
- Ability to organize human knowledge and provide the computer system with the correct inputs.
- The KE has to be responsible for the system development, testing and maintenance.

Based on the skills suggested by Durkin the KE for this ES was selected, two KE´s were chosen and one of the experts also took some KE functions regarding Knowledge structuring. In the knowledge structure a third person provided some help but he was not considered as a KE because he did not have all the skills required.

4.5 Software and Hardware selection and requirements

There are different types of software that can be used in ES development, the types of software are divided in: shells and programming languages. Durkin [1994] refers that the languages can be classified as rule based and object base; and the shells can be classified in Rule Based, Frame Based, Induction and Hybrid. Hardware selection could be a consequence of software requirements, but at the same time could be a constraint.

4.5.1 Software Selection

There are many evaluation features for software selection, the cost, user interface, and support are the main features that should be considered for software selection. This ES can be considered as a special case that can not be developed as most of ES, in this project the subject that is being analyzed is a complex computer device with the ability to "answer" to the "questions" asked. Therefore, software selection has some extra features that have to be considered when software is selected. As it was described in chapter 3 the HDD failure is analyzed based on the data of the testing process that is recorded in the HDD. For the analysis, the data should be extracted from the HDD and interpreted. Some extra tests are also performed to observe and analyze the performance of the HDD on specific functions.

For the project two options were considered at the beginning, an ES shell and a Program, the shell is a software called EXSYS that provides the basis to develop decision trees for the different failure codes presented in the HDD. The program selected was the Lab View from National Instruments, this software has the feature to interpret the readings from electronic devices. That feature fits in the scheme of HDD communication requirement for analysis.

It is desired that the software should has the ability to communicate and get information from databases and the current information system; Slap, Hillman and Moore [1998] express that:

"When an expert System is coupled with resources such as databases, models, and communication tools, it is transformed into a powerful decision-support system (DSS)".

Tuthill and Levy [1991, p.70-71] gives a list of questions that should be answer to make the software selection. They advise that the software selection should follow the problem and end user requirements instead of selecting a software which the KE or experts feel comfortable. It is recommended that the program will not be a "black box" that only provides the recommendation, but notes and explanations are highly recommended to be included. The questions that they suggest for evaluation were used to evaluate the different options to develop the ES, besides the questions proposed by Tuthill and Levy some others were added to complete the analysis and the result is the following list of questions and answers:

1. What tools are available?

Currently there is a software program to communicate with the drive, this software is very simple and has severe disadvantages regarding human factors and ergonomic deficiencies. Some alternative tools were gotten for this project.

For the ES project there are two options that are going to be analyzed:

a. Expert System shell called EXSYS

b. Object program named Lab View

2. What are the tools' abilities in the terms of user interface flexibility, structures and functions?

The objective referring about system abilities is to avoid as much as possible the human acting in the decision making process. The requirement comes from the previous studies where it is observed that the variability on failure analysis comes from the technicians. It is not fair to say that technicians cause all the variability, it is also important to recall that some tests show variability on results.

In the software selection process is important to understand and verify that the software supports the structure required. In the HDD analysis the sequence is to perform a test and make a decision based on the feedback that the HDD gives or make a decision in the command that HDD does not perform. When the technician has the results, the answer can be a repair code or can also be another test to perform. Basically, it is structure or a decision tree. The tree alternatives meet the requirement for this requirement.

The abilities requirements is to provide a friendly user interface and with user it should be understood that by the technician that is doing the analysis of the failure and also by the Knowledge Engineer that defines the rules and modify them when it is required. It is important to remember that the HDD repair process varies very frequently based on cost reduction and process improvement issues. Therefore, a requirement for the ES is that the programs or rules should be easy to modify.

3. What are the levels of vendor support?

All options have support, the options were selected from references from people that have previously worked with them, besides the software that are being evaluated are widely used in the industry and scientific research.

4. What are the hardware requirements of the tools?

Each failure analysis station has a personal computer, but some of them have low memory capacity that makes for some slow applications. There is no restriction to increase RAM memory to reach higher speed requirements.

Expert System shells commonly requires a PC that supports windows98

Lab View Program requires a PC windows XP

5. What are the initial costs of the tools?

For the initial cost it was defined as the initial investment that includes the initial training required then the initial cost for the option were:

Table 4.6 Initial cost for different software options

	License	Initial Training
EXSYS	$ 15.000.00	none
Lab View	$ 3.000.00	$ 3.000.00

6. What are the licensing restrictions?

The program Type II Lab View generates a executable file, that means that is not required to have one license for each computer whish is going to run the ES failure analysis program (in FAA there are more than 10 machines. The executable programs is a real solution).

7. What training is available?

The expert system shell EXSYS has minimum training cost due to the simplicity in the use and application. This software (ES shell) has user features and provides interactive training modules and customer support via Internet. The tutorial has six basic lessons and six window tours, these lessons and tours are enough training to develop a successful application.

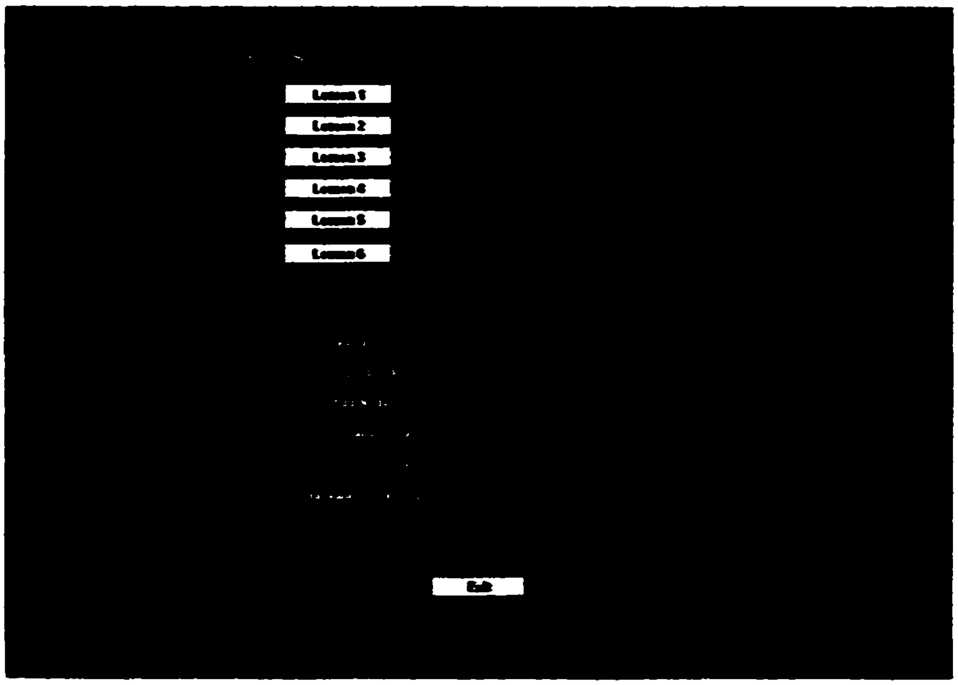

Figure 4.9 Easy Corvid Tutorial

Lab View is a programming language, even though it is a program very user oriented and has friendly interfaces it is not very easy to use at the beginning. The fact that this software is able to communicate with the HDD makes the modules or programs more complex than doing it in the shell, therefore some training is required. Training is available on site or at the supplier center and the cost will vary regarding the amount of the licenses purchased. With the purchase of the License, the Program Manuals are included, but an electronics knowledge level is required to understand the applications. For that reason, the training is more complex and the programmer requirements are different than Expert System Shells.

Besides the previous question used to determine tool considerations, Tuthill and Levy proposed a second set of questions to evaluate the tool selection, these questions will be considered as a second block of questions:

8. Which tools support this scheme?

As it was previously described the ES that is going to be developed to support HDD failure analysis can be done using different tools. It was selected one Expert System Shell, one object programming tool and a programming language. The tools selected were EXSYS for expert system shell and Lab View for object programming.

Lab View was included in the list because it is a tool that can solve several issues related with communication and data interpretation between system and HDD and provides the capacity of reducing the human factor in the failure analysis process.

9. What is the project's budget and does the tool (s) meets the budget?

The budget for this project is not defined. Consequently, the project has no economic resources assigned. The proposal is to evaluate the best choice and make the requirement for the amount required. There is not a limit but based on the proposal the top management will take the decision based on cost benefit analysis. The plant manager can spend up to $5,000 USD per each individual project. If the project requires more resources those should be discussed and approved at higher levels.

4.5.2 Hardware Selection

Hardware selection goes together or is a consequence of the software selection, anyway, the hardware requirements should be considered as a primary factor in the project cost, and if the hardware is not already available the cost could be significant. Fortunately, for this project, the FAA has a personal computer for each technician, meaning that the hardware is already at the place, though the hardware requirements needs to be analyzed to evaluate the cost of the upgrade. The current capacity or characteristics of FAA machines are limited. In the FAA area there are 12 machines, 9 with 64M in RAM running at 240Mhz and the other 3 has 32 at RAM and 144Mhz. Machine characteristics are also related with the production capacity of HDD´s analyzed. The Expert System Shell EXSYS from Corvid has lower requirements to run than the current PC that are in the area and do not require any change. The situation is different for the second option. In the testing process it was found that the current windows 98 version is not able to support the Lab View application, therefore, the Windows XP version is required to support the Lab View programs. This upgrade has an extra cost caused by the Windows System upgrade and the PC hardware upgrade to support the system.

CHAPTER 5

EXPERT SYSTEM DESIGN AND TEST

5.1 Expert System Design

The previous points were the bases for the Expert System design, as the other steps the design and testing phase are key for the ES success. A good design will deliver a reliable accurate HDD failure analyzer tool to the end user.

From the Expert Systems types described by Durkin [1994, p244], the HDD failure analysis matches the description for the forward-chaining type of system: " The operation of a forward-chaining system begins with initial formation about the problem being asserted into your working memory. You can accomplish this in a number of ways, such as obtaining the information from a database, sensors or asking the end user."

Working memory includes the heuristic rules that are going to be obtained from the experts. Another characteristic of the forward-chaining rule based system is that they can provide intermediate results. One of the problems was the use of weakly based heuristic rules.

For the forward-chaining (FC) design, Durkin [1994, p276] propose 8 step methodology, as it was identified the HDD failure analysis ES as a FC rule based system, the steps proposed are the following:

1. Define the problem
2. Define input data
3. Define data driven structure
4. Write initial code
5. Test the system
6. Design the interface
7. Expand the system
8. Evaluate the system

*Step 1,5,7 and 8 are covered in other sections

5.1.1 Definition of the input data

When HDD is in the final testing, all the results of the tests are been recorded inside. Those data tables should be analyzed to determine the root cause of the failure and provide the correct repair code. Besides the data recorded into HDD, there are other tests that can be done to the HDD to get some extra information. The issue is how the current system manages the data that comes from the HDD and how this data is used to take a decision. The current method used to get the data from the HDD has severe deficiencies and the risk of human error for this process is high. In the current FA process the failure analysis is done from data recorded into the HDD. Analysis process starts when the technician input a command into the workstation; then the workstation communicates with the HDD and interact with it and displays the response, the response will be interpreted by the technician and compared with the knowledge base that he/she has and takes a decision based on the information received. It could be a determination (repair diagnosis) or could be a more information request. The path that the technician follows in the standard system is based in "failure analysis flows" that provide them the steps to follow, and the decisions to take for a specific failure code.

The information received from the HDD is received in the computer and it is displayed on the screen in a MS-DOS format, the technician interprets the data to take the decision. In this step of the process, the risk or the probability of make a human error is higher.

Two types of ES were developed for HDD failure analysis, the difference between the systems is the way that the information is analyzed. The first type of input data is the one that has already being interpreted by the technician. Based on expert system shell this type I system, it is focused to provide the technicians with all the experts knowledge. In the other hand, type ES type II will get the information directly from the HDD; therefore, data interpretation will be done directly from the HDD.

As it was discussed earlier the data interpretation has a high risk of error due to the system is not easily to be interpreted because data is displayed on hexadecimal format. Besides, numbers are displayed on the screen and they move up to the top very fast, the technician needs to make a pause to observe the numbers, and that makes very difficult the data interpretation process.

The Type I system uses input data that comes from the technician, the rules are displayed on the screen with the possible options for that specific rule. The technician performs the test sending a command to the HDD, and the HDD sent the information that is displayed on the screen. Then the technician analyzes the information and provides the input to the system. This type of system solves the deficiencies in the current failure analysis process, the analysis flows used in the expert system shell has the expert knowledge inside. This type of ES provides improvements to the process regarding the failure analysis information used, but it still having weak points were human errors could cause an incorrect analysis of the failure.

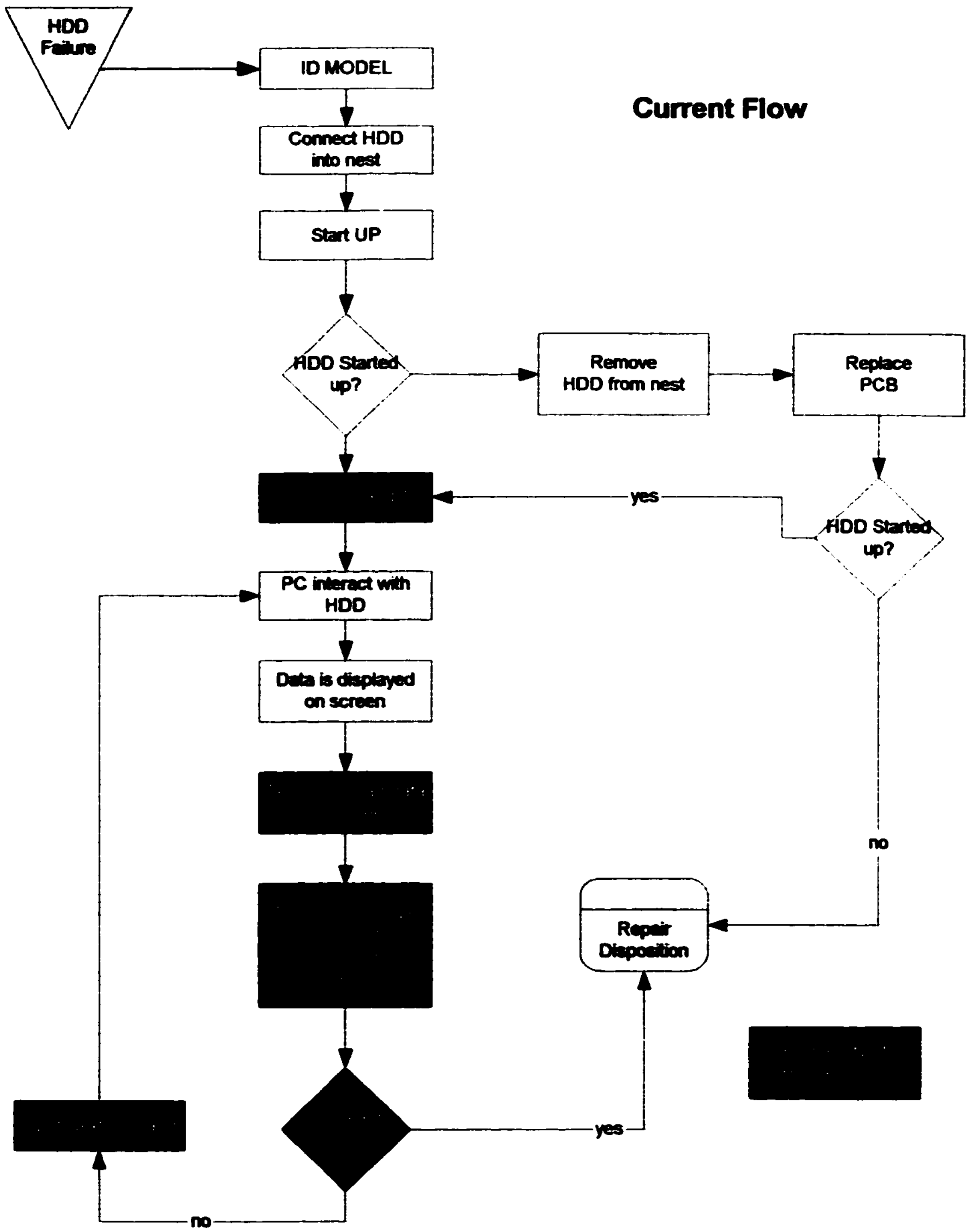

Figure 5.1 Current HDD Failure Analysis Process

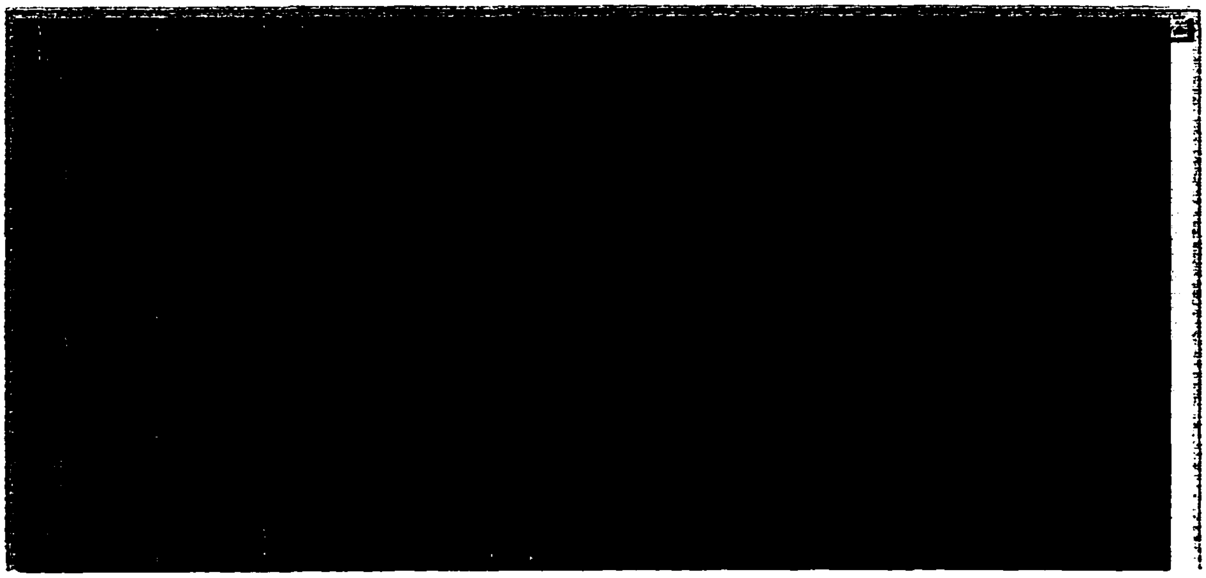

Figure 5.2 Screen demo of list of hexadecimal numbers that needs to be analyzed by technician

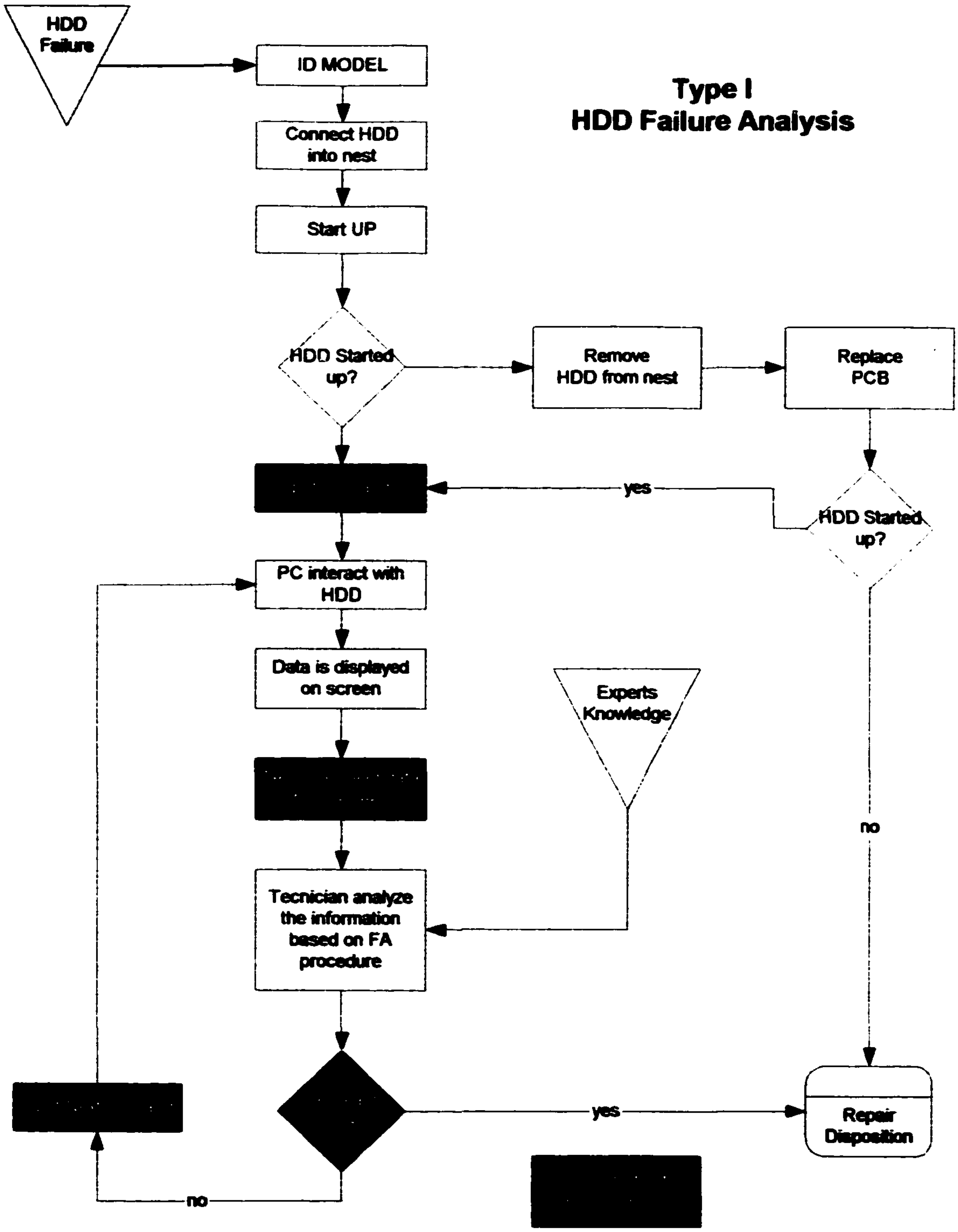

Figure 5.3 Type I HDD Failure Analysis Process Flow

Type II system is able to reduce the deficiencies of Type I program. In this system the System sends a command to the HDD and it performs a test, then it sends information back to the System. In this type II system, the information is received, analyzed, and a decision is taken. This ES method was developed because the ES shell still having the human error probability. As it can be observed in Figure 5.3 the Type II system provides a failsafe process, nevertheless the program should be extensively tested to avoid "bugs" into the program.

This ES program (ES Type II) requires a higher technical level for development. Due to the communication process in both ways is not easy to get, the program require some expertise in programming with these tools. The technician or may be the process engineer not always be available to modify the rules or create a new program for a new failure code. As it is explain before the program receives the information from the drives, it has to interpret the data, it compares with the rules that was defined, and takes a decision. All the decision criteria that the technician has should be included in the program.

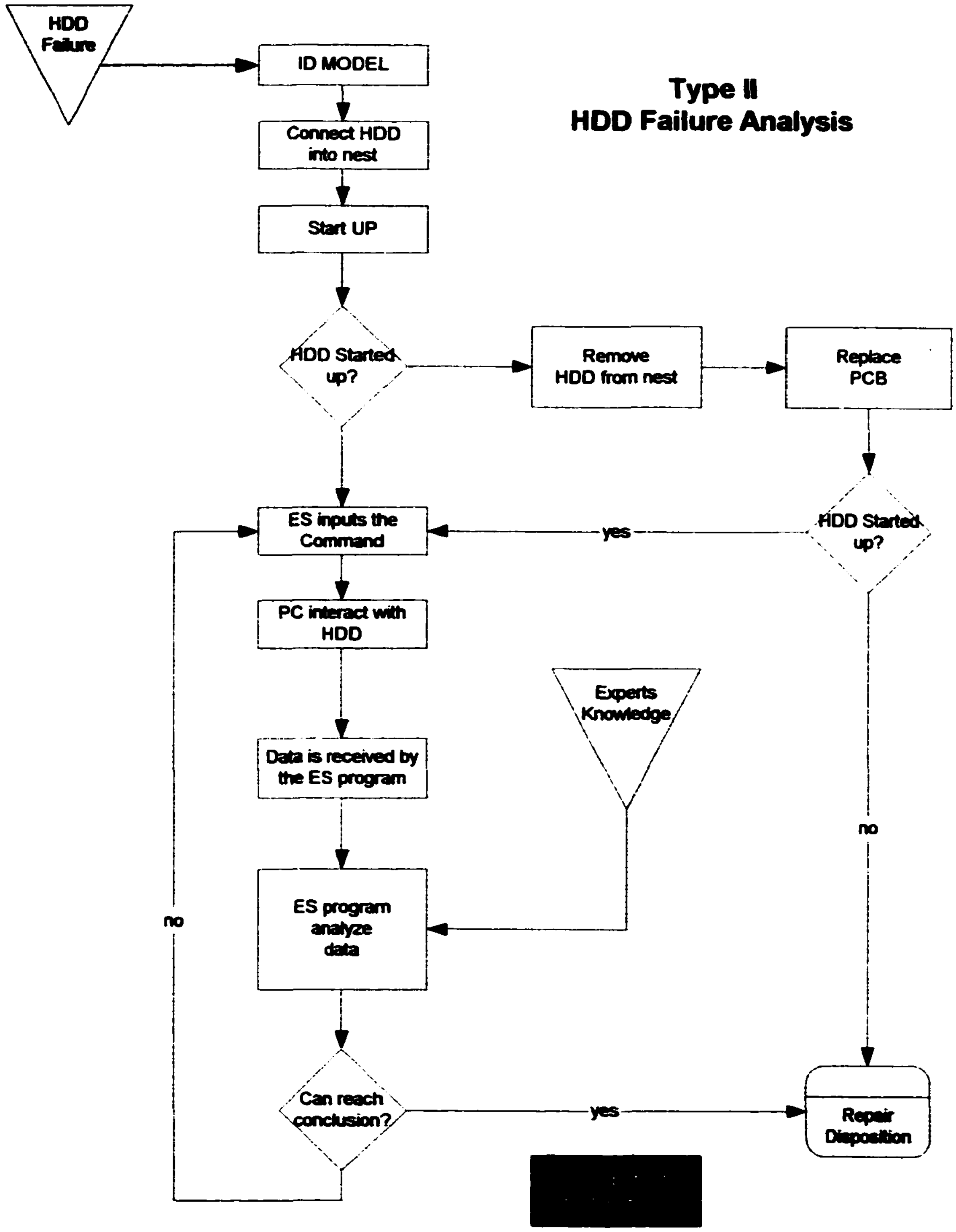

Figure 5.4 Expert System Program (ES Type II)

5.1.2 Define Data driven structure

Data driven structure is based on current flow that is been used for analysis, but at this step of the design the current process will be redefined by the experts and tested, in order to determine the best analysis process for the HDD failure. In the analysis process the current flow has many deficiencies in its flows. In order to set the project boundaries, the volume of failures by model was analyzed and a specific model was selected.

The first step was to get together the experiments and analysis that as been done previously, related with this model. The information was in isolated projects and special analysis and studies, but that information was not always properly documented by the technician that makes failure analysis or by the engineer that did the experiment. There is a tendency to automate the analysis process with a program that has been successfully used in other type of disks, but there are technical barriers that make this process not possible. The ES type II will solve this issue in a limited scenario, even the language or icon programming tool used is able to communicate with the tester and sent information to the internet that will make the system more complex and that may will be done later because is not part of the analysis and solution of this project.

It is important to understand how the current rules were generated. The rules for analysis are defined for the designer of the disk drive; he starts the process of design, makes prototypes and tests them. When the process of design is ready the drive will be released for production and the designer give a set of recommendations based in his knowledge of the product and the experience earned during the prototype testing stage. He / she releases a document that is used for the diagnosis of failures, from production line and also from customer returns.

After the designer release the document to diagnosis a failure, he / she is moved to a new project and hardly will be in contact with the drives that fail in production area or the ones that fail on the field. Only in some special cases that production has a higher failure rate or a customer requires a change in the design, they will be in touch again with the same product. Then the documents that they created to help the people that will analyze the failures are fairly incomplete, due to lack of feedback. Besides, this document will be written in a technical way then it is not very easy to understand; therefore, these documents cannot be used in failure analysis and diagnosis in a practical way.

Based on the failure analysis flow that has been modified by the experts, the rules for the expert system started to be developed. Top 1 failure that represent the 6% of all HDD tested the flow reviewed is shown below. Changes made by the experts can be observed in the flow (Figure 5.4), besides the classification of repair codes to provide a better control on repetitive failures, they also modified the commands that are the instruction provide to the HDD. The changes in commands cannot be shown due to confidentiality of the information. The improvements on command will be discussed further in this document. The information flow that was taken as the base for the ES is the shown in figure 5.4, the other failure codes flows worked in this project are available at

Appendix A, both type of system used the same flow but the difference between them is that the decisions were made differently.

In the ES shell or type I system the decisions are made by the technician, then he/she receive the data from the HDD that are displayed on the screen and he calls the knowledge that has in his/her memory or consult the failure analysis flow. This process is a potential failure risk because there are too many flows and models that the chances of calling wrong information stills there. In this failure code, as in the tops the technicians have the decisions rules very clear in their memory, but not always are the same. There is no warranty that they do not mix information even in those top failure codes.

Expert System Type II (Figure 5.3) has a different data management, in this type of system data are received by serial port to the program. This is a key feature of Lab View program, this type of programs are focused to that type of applications; therefore this ES type has the ability to reduce or eliminate the data manage and interpretation done in other systems by the technician. The rules are the same for both systems, the new failure analysis flows reviewed and modified by the experts provide a improved base for System development. Regardless they use of the same failure flow, the way that system I and II manage the data are completely different, because system type II need to simulate the technician reasoning process.

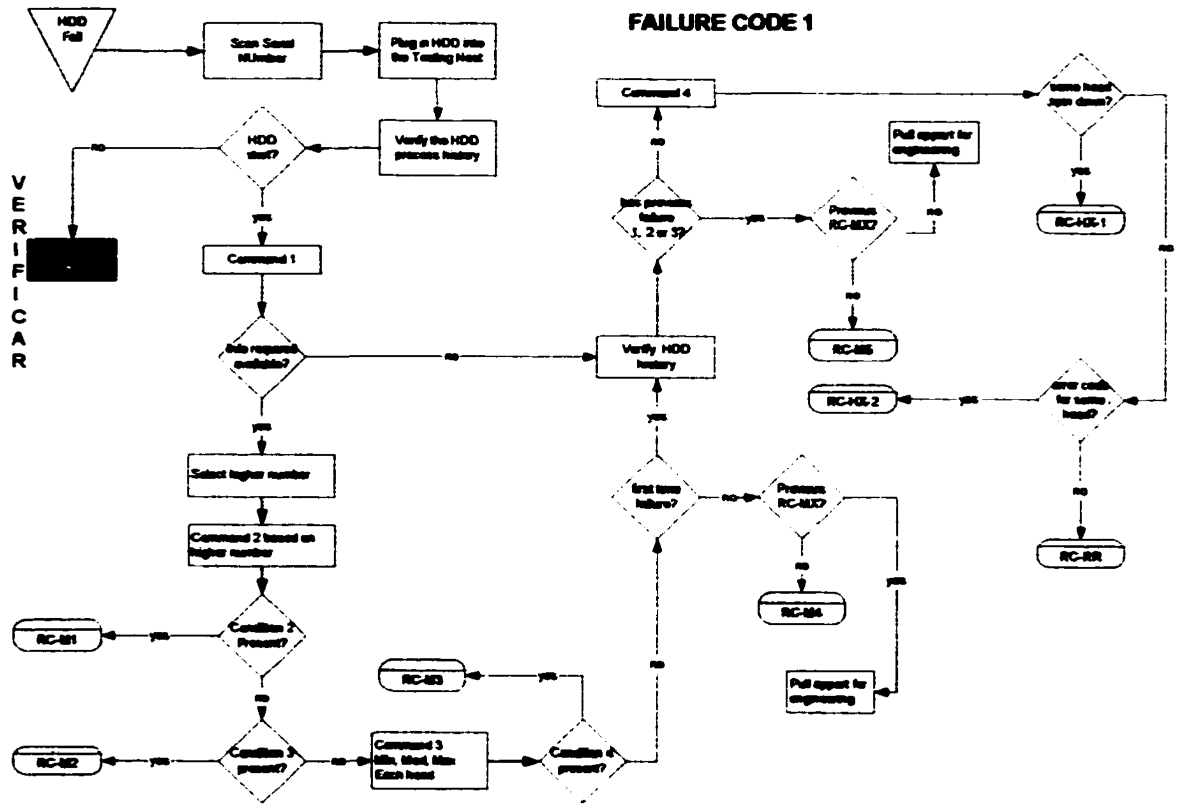

Figure 5.5 Failure Repair Process Flow for failure 1 – Experts reviewed

5.1.3 Writing the Initial Code

The initial code described for this example is the set of rules that will be the base to the Software development. Criteria and commands will be coded due to confidentiality agreements. Flow shown at figure 5.5 is the algorithm for failure 1

Table 5.1 Rule Scheme for failure 1

```
Type 1
Start Rule : Turn on the power supply
Rule 1:
IF      The drive turn on
THEN    Type Command 1
ELSE    Replace PCB with a master
Rule 2:
IF      The drive starts with PCB Master
THEN    Type Command 1
ELSE    Pull apart for engineering
Rule 3
IF      Data request with command 1 appears
THEN    Select the higher number and type command 2 based on higher number
ELSE
Rule 4
IF      Condition 2 Present on Head "i"
THEN    Repair code RC-H1
ELSE    Type command 3
Rule 5
IF      Condition 3 present on Head "i"
THEN    Repair code RC-H2
ELSE    Go to rule 6
Rule 6
IF      All heads verified for Condition 2 and 3
THEN    Type Command 3 for Min, Med and Max
ELSE    Go to rule 4 at Head "i" + 1
Rule 7
IF      Condition 4 present at Min, Med or Max
THEN    Repair code RC-H3
ELSE    Verify HDD history
Rule 8
IF      There is a failure code 1,2 or 3
THEN    Rule 101
ELSE    Type Command 4
Rule 9
IF      Some Head spin down
THEN    Repair code RC-HX-1
ELSE    Rule 102
Rule 101
IF      Previous RC-HX
THEN    Pull apart for engineering
ELSE    Repair code RC-H5
Rule 102
IF      Error code for some Head
THEN    Repair Code RC-HX-2
ELSE    Repair Code RC-RR
```

All these rules represent the repair flow (Table 5.1) for code 1. As it was mentioned earlier, the failure analysis flow used to define the rules has been verified and modified by the experts. Some modifications were done to the flow and others were done to the commands, the modifications on commands will be explained forward.

5.1.3.1 Writing the program Type I (ES Shell)

Expert system shells are programmed as a decision tree, some rules are repeated regard to the branch of the tree. In the shell type of programs the loops are broken and converted in longer branches. Expert System shell summarizes the expert knowledge and heuristics knowledge in a set of rules to allow the computer to work. Rules will be defined in IF/THEN format [Corvid Manual, 2002]. This shells have the experts knowledge in the decisions available for the user, the decision is shown at the screen and the possible choices are show below as a multiple choice test (Figure 5.6). These options are the summarized expert knowledge; when a possible answer is chosen a prompt is shown on the next screen, and the next set of possible answers will be displayed on the screen. The following example represents the ES shell program for the failure code 1.

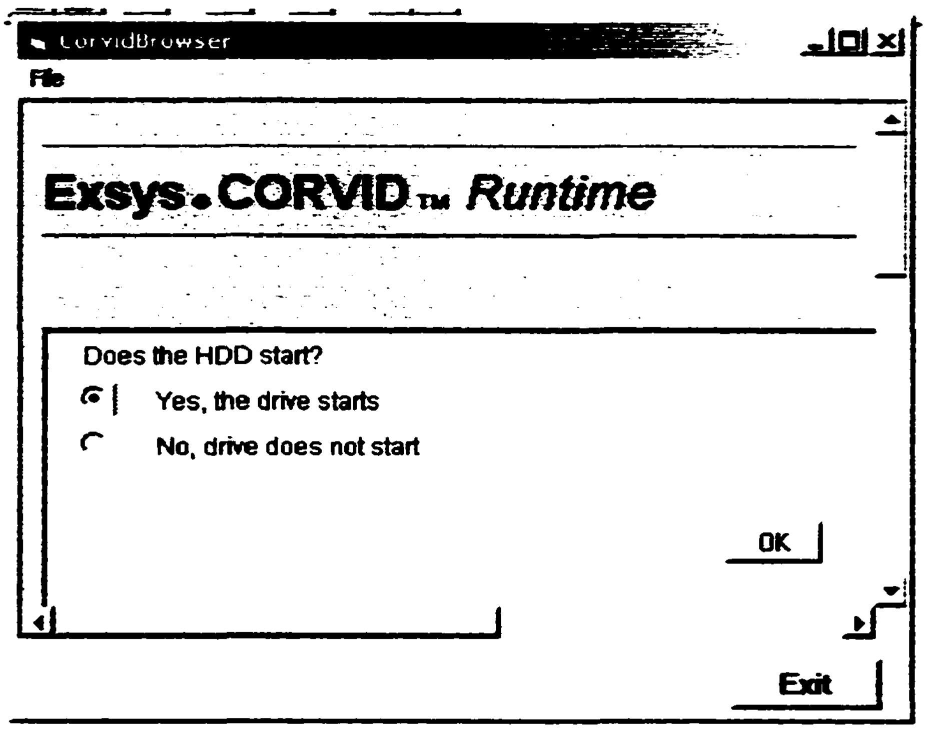

Figure 5.6 The User Interface for the user. The rules are multiple-choice options.

The first step in the shell programming is to have the algorithm with the knowledge of the experts included. For this example the flow used is the shown in figure 4.14 for failure 1. The first step in this shell is to open a new program, the second stage is to define the nodes or decision points. Nodes definition is done in a special screen, this screen defines different types of variables. Each decision node has a name and a question that will be shown to the user when the program is running, with the question also will be displayed on the screen the options, those options are also defined in this variable definition phase (Figure 5.7). After programming, all the decision nodes and the repair diagnosis are loaded in the system. Once all nodes and repair codes or "answers" are set up into the system the rules should be linked in IF-THEN rule format. The nodes are linked between them and with the diagnosis or "answers" to provide routes to make a decision.

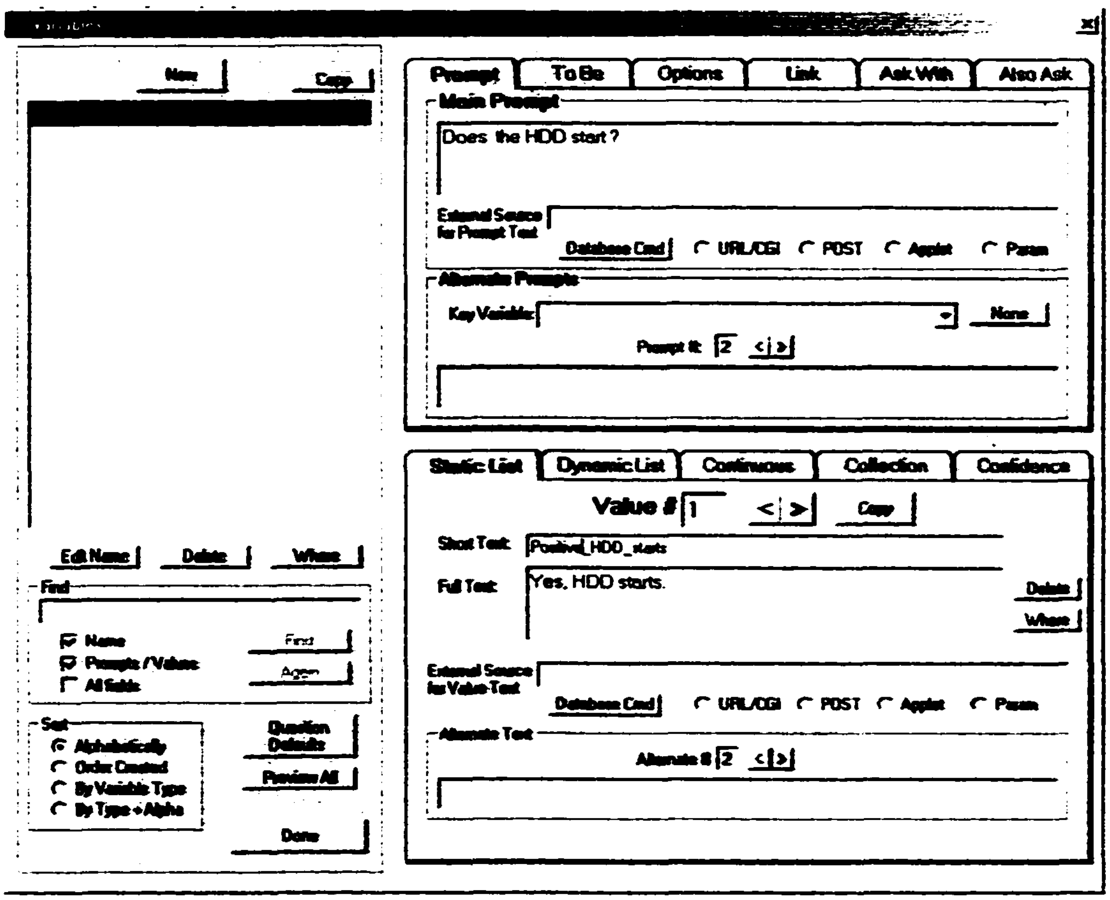

Figure 5.7 Variable Definition Window.

The expert system shell has a window session to make the program in easy steps, the IF-THEN rules are linked in "Logic Blocks". These blocks will be the program structure. After the logic block is finished the EXSYS shell compiles the rules and defines a functional structure for the program (Figure 5.8). This structure will be the base for the rules that are displayed on the screen to the end user (Figure 5.9).

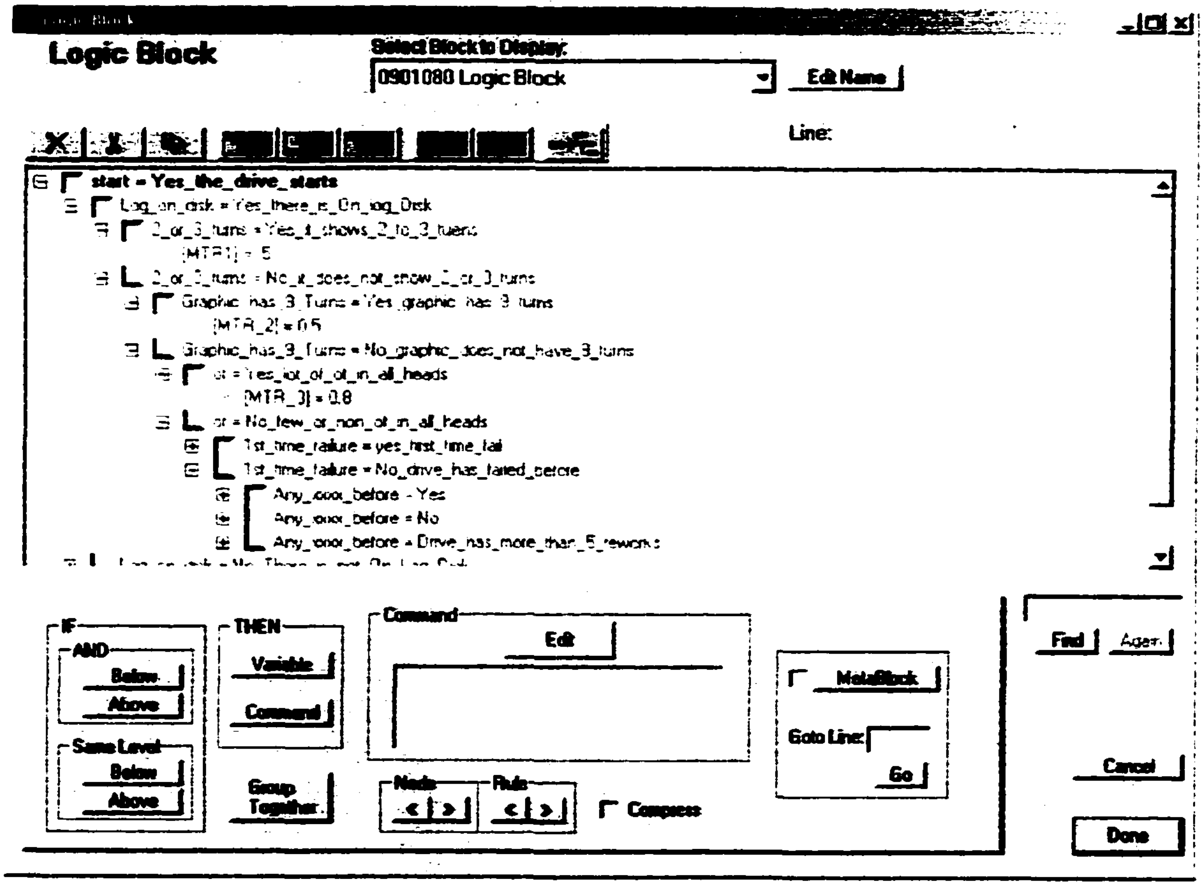

Figure 5.8 Logic Block Window of EXSYS

The complete set of rules for the programs for the top five failures could be addressed in appendix B, the complete set of rules with the diagnosis for each program is attached. It should be observed that the shell has the ability to detect the open nodes avoiding programmer constraints in the setting rules process. The design of the Expert

System Program in this shells are not the most critical part, the harder part is to collect the right information from the experts.

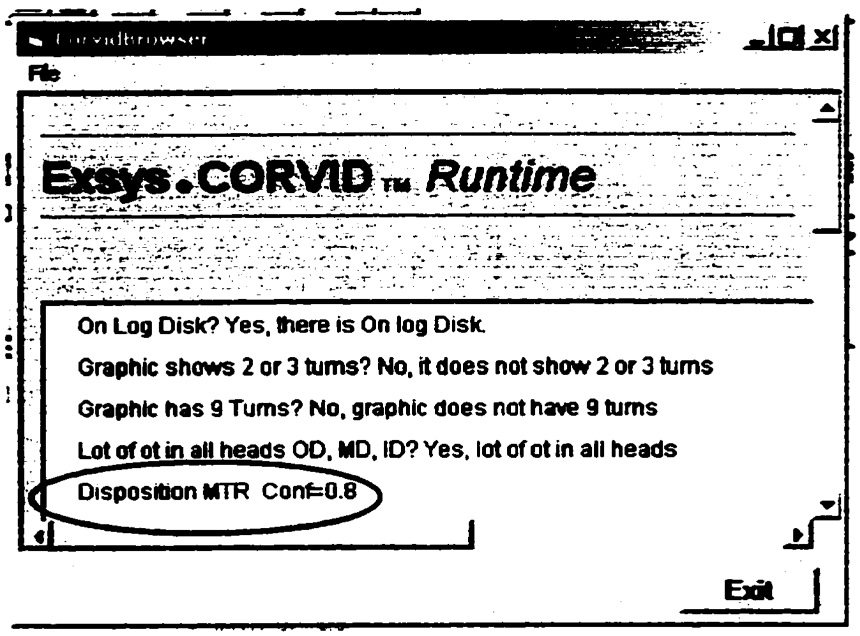

Figure 5.9 Expert System assign repair disposition

5.1.3.2 Lab View Program

The second alternative tested in this project was a program that has the ability of communicate with the HDD and sent commands and receive and interpret information with the HDD. The program selected was Lab View, this software uses graphic icons to make the program but it is a programming language as C, Visual Basic or others. Lab View has an advantage for this application because is a programming language oriented to electronic signals interpretations, and electronic analyzers. It has been designed for people that are not experts in software programming, this software is oriented to Mechanical Engineers, Electronic technicians and many others that have the need of make programs with inputs from electronic devices such as HDD in this case. As this ES development requires a communication feature with the HDD in an understandable and simple base, this program fits that requirement. If the HDD can be managed by software, the problems due to human factor will be reduced drastically. In the Cause and Effect diagram many causes of the diagnosis accuracy problem were related with the ability to interpret the data that the HDD display on the screen.

A significant advantage of this type of ES is that the test could be more extend, with ES based on a program the times are reduced drastically (see test and evaluation section), due to the lost on time caused by interpretation of data and command input. The time advantage will provide the opportunity to do a more extended test providing a better diagnosis, it means that in the previous analysis method the technician test the HDD in three tracks per head. Now the software can test in fifty or more tracks or perform extra commands as continuous track seek or other useful test.

The failure 1 was selected to develop the Expert System Program based on Lab View programming language, the flow was previously described in figure 5.5. The Lab View program development generated new questions over the way that the failure analysis was been done, and experts gave their feedback over specific questions that came on the programming process.

The first step was to make the communication between HDD and Lab View trough serial port, some issues were solved regarding the physical configuration of some cables. Once the configuration was ready the next step was to send commands to the HDD and got the correct response. The responses that are received need to interpret the data and compare them with reference values, and a decision should be made. This process is been doing by operators and is one of the main sources of variation due to several human factors and ergonomic issues. In the expert system shells this step of processing and in interpreting the HDD information still be doing by the FAA technician.

The second step on the Lab View program development was to develop the testing modules to make the correct representation of the test algorithm. The data arrives to the system by the serial port and it is processed based on the rules that correspond for each step of the test. In the other system the probability of mix rules in different steps were high, as it can be observed in the R&R studies. Is important to remark that some information should be input by the technician like the previous failure code, previous repair code, and the time that the HDD has passed through FAA. This step could be a noise factor, this characteristic was leave open due to the difficulty to make the link with the current tracking system for the HDD through the process. At the end the Lab View routine, it provides a diagnosis and assign a repair code for that specific failure code.

5.2 Testing

In order to evaluate an Expert System many methods can be used, commonly the authors do not provide enough information regarding evaluation and testing methods for Expert Systems.

Adelman [1992] describes three methods for Expert System evaluation: The subjective, the technical and the empirical testing. For the subjective evaluation methods Adel man propose five types: multi-attribute utility technology, the dollar equivalent technique, cost-benefit analysis, decision analysis and a multi-attribute utility technology based cost-benefit analysis.

The technical evaluation methods are divided in four: the evaluation methods for evaluating the appropriateness of the analytical methods used on the decision support system and expert system, those for estimating the software development cost, those for formal software testing and verification methods, and those for evaluating the logical adequacy and predictive accuracy of a knowledge base. For empirical evaluation methods are oriented to decision makers performance in a before-after comparison regarding to the system. Adelman [1992] classify the empirical methods in three: the experiment, the quasi-experiments and the case studies.

Ignizio [1991] proposes three stages for validation process:

- Phase one: the justification of the expert system, why it is been applied
- Phase two: the validation of the consistency and the coverage of the expert system
- Phase three: the performance of the expert system

The first point will not be used because is based on a several questions that are not very specific and will not provide objective evaluation criteria; the second point will be used to verify the consistency of the rules that is a key point that many authors not mention. The performance will be evaluated based in the results of previous methods used as the R&R study and cost-benefit analysis as is call by many authors.

The parameters used to measure the efficiency of the Failure Analysis process were used to evaluate the new Expert Systems, these parameters are the R&R score that is used. Another concept that was used to qualify the performance of FA was the effectiveness of diagnosis that was focused to rate the quality of the Failure Analysis Process Flow. A third parameter was tracked to avoid disturbances on the process and it was the capacity of each FAA station, that measurement was selected as a key parameter to avoid the creation a solution that brings more problems for failure processing.

5.2.1 Expert System Shell Evaluation

Multi-attribute Utility Technology and also cost-benefit analysis was done for the ES Shell Evaluation, but not exactly as Andriole [1986] refers as a subjective evaluation method. Besides the Ignizio [1991] point for consistency of the rules, it was also a key point in system evaluation. The first step was to define the key organizational requirement that the Expert System needs to satisfy, these points are the "customer requirements", both systems will be analyzed and scored based on these organizational requirements.

Since the beginning of the project the top managers setup key requirements to develop a expert system, while the project was been developed the team added some concept as well. The evaluating factors were the following:

- Increasing the accuracy of diagnosis
- Reduce the HDD loops level
- Reduce Inventory in Process
- Reduce time to repair
- Expert System robustness
- Rules consistency
- Current systems compatibility
- Ease of use

The Expert System shell provides the multiple choice format with the reasoning route that an expert would follow to analyze and decide which was the failure cause of the HDD. Nevertheless, the main characteristic of HDD testing data interpretation still been doing by the technician and as it was previously described this step of the process has deficiencies due to human factors and ergonomic issues.

Based on the results of the Repeatability and Reproducibility study the EXSYS development (Table 5.2), the percentage of matched diagnosis within the appraisal improved when it was compared with the previous R&R study that had been performed to the FAA technicians at the beginning of the project. The results of the ANOVA test (Table 5.3) shows a raise in the percentage of diagnosis matched between technicians, the mean increases from 81.28 percent with the current FAA system to 88.45 percent with EXSYS, besides the Standard Deviation showed a significant decrease, from 15.73 to 8.78.

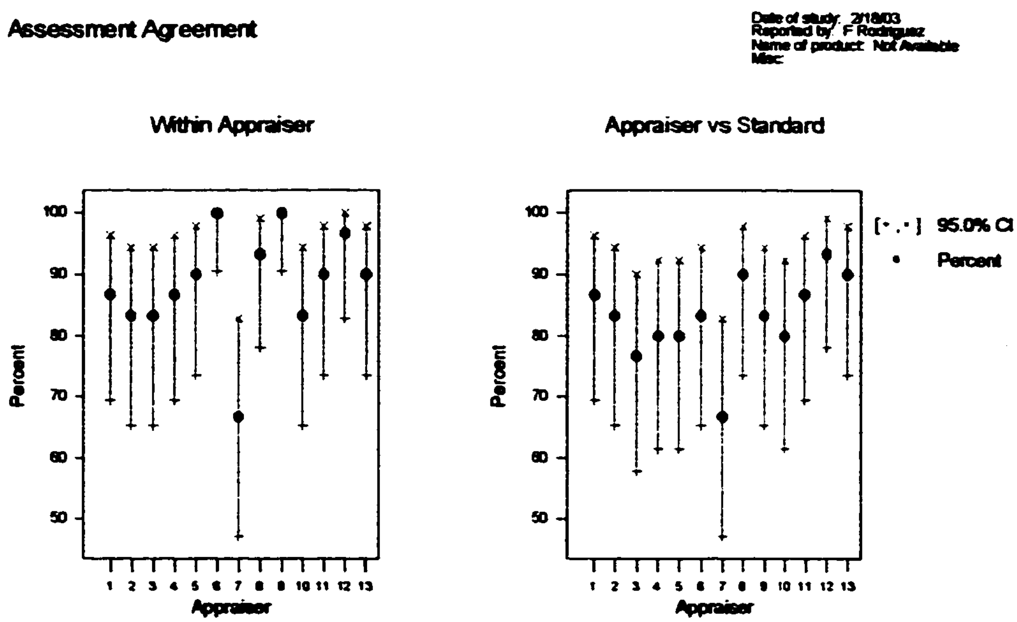

Figure 5.10 EXSYS R&R score within appraiser and Appraiser vs. Master Value.

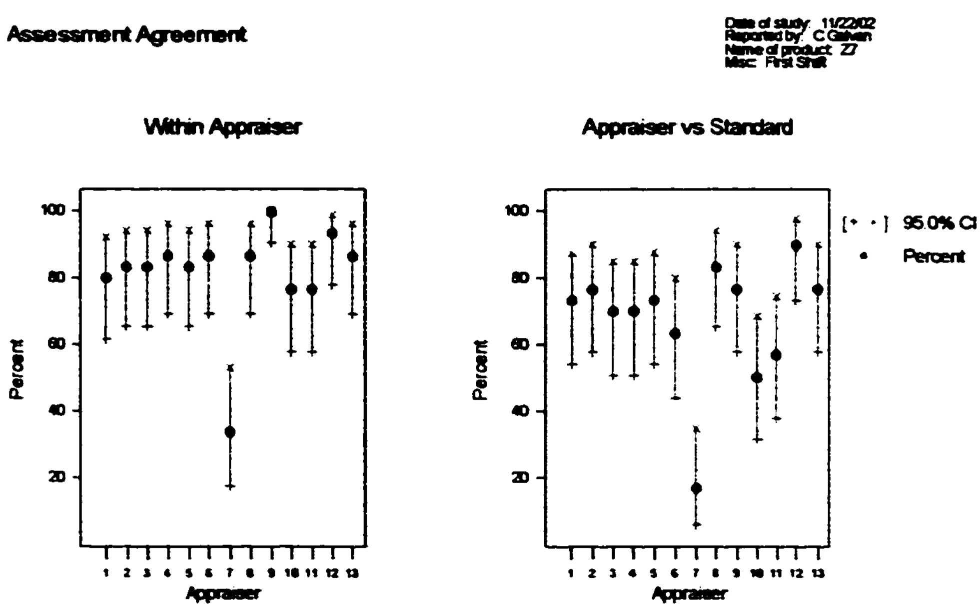

Figure 5.11 FAA standard method of diagnosis evaluation for first shift before ES project

Table 5.2 Repeatability and Reproducibility test results for Easy

Assessment Agreement

Appraiser	# Inspected	# Matched	Percent (%)	95.0% CI
1	30	26	86.7	(69.3, 96.2)
2	30	25	83.3	(65.3, 94.4)
3	30	23	76.7	(57.7, 90.1)
4	30	24	80.0	(61.4, 92.3)
5	30	24	80.0	(61.4, 92.3)
6	30	25	83.3	(65.3, 94.4)
7	30	20	66.7	(47.2, 82.7)
8	30	27	90.0	(73.5, 97.9)
9	30	25	83.3	(65.3, 94.4)
10	30	24	80.0	(61.4, 92.3)
11	30	26	86.7	(69.3, 96.2)
12	30	28	93.3	(77.9, 99.2)
13	30	27	90.0	(73.5, 97.9)

Matched: Appraiser's assessment across trials agrees with standard.

Assessment Disagreement

Appraiser	# 1/0	Percent (%)	# 0/1	Percent (%)	# Mixed	Percent (%)
1	0	*	0	0.0	4	13.3
2	0	*	0	0.0	5	16.7
3	0	*	2	6.7	5	16.7
4	0	*	2	6.7	4	13.3
5	0	*	3	10.0	3	10.0
6	0	*	5	16.7	0	0.0
7	0	*	0	0.0	10	33.3
8	0	*	1	3.3	2	6.7
9	0	*	5	16.7	0	0.0
10	0	*	1	3.3	5	16.7
11	0	*	1	3.3	3	10.0
12	0	*	1	3.3	1	3.3
13	0	*	0	0.0	3	10.0

Table 5.3 ANOVA table for EXSYS vs. FAA current system (Within Appraisal)

```
Analysis of Variance
Source     DF        SS        MS        F        P
Factor      1       335       335     2.06    0.164
Error      24      3895       162
Total      25      4229
                                   Individual 95% CIs For Mean
                                   Based on Pooled StDev
Level       N      Mean     StDev  -------+----------+----------+---------
Exys per   13     86.46      8.78               (-----------*-----------)
FAA perc   13     81.28     15.73  (-----------*-----------)
                                   -------+----------+----------+---------
Pooled StDev =    12.74                  78.0       84.0       90.0
```

The ANOVA test done to compare the differences between the previous system that has been used to analyze the HDD failures, the test showed significant improves using the EXSYS system, the technician scored a 67.44 % matching the master diagnosis, with the EXSYS program the technician raise this score up to a mean of 83.8%. Besides this significant improvement, the Standard deviation showed a significant decrease, it get down from 18.51 to 6.86.

It can be observed in figure 5.11 that there still a score of 60% of Reproducibility of diagnosis, this could be caused by the fact that the human still having the ability to determine and interpret the results that the program showed in the screen and that interpretation was often wrong and for appraiser 7 the concept for decision taking process still being "fuzzy."

Table 5.4 ANOVA table for EXSYS vs. FAA current System (Appraisal vs. Master)

One-way ANOVA: EXSYS %, FAA %

```
Analysis of Variance
Source     DF        SS        MS        F        P
Factor      1      1590      1590     8.16    0.009
Error      24      4675       195
Total      25      6264
                                   Individual 95% CIs For Mean
                                   Based on Pooled StDev
Level       N      Mean     StDev  ----------+---------+---------+------
EXSYS %    13     83.08      6.86                     (-------*-------)
FAA %      13     67.44     18.51  (-------*-------)
                                   -+---------+---------+---------+-----
Pooled StDev =    13.96             60        70        80        90
```

Regardless the improvement reached with the implementation of the expert system shell (table 5.4), the system cannot be rated as an effective failure analysis and diagnosis system. The average of 83% matches between appraisal against the master still far away of a satisfactory performance for an expert system. This barrier to reach the objective is related to the information flow in the system. Some links still been weak, the human interpretation still been a source of variance. In the other hand there is the fact that the HDD works with electronic and electromechanical principles and the measurements of some characteristics of the HDD has a natural variability that always be present and should be addressed in the analysis process and considered as a noise factor.

Table 5.5 Main characteristic matrix for expert system evaluation

	Evaluation Criteria	Accuracy of Diagnosis	Ease of use	Time per HDD analyzed	Robustness	Hardware Requirement	Software cost	User acceptance	System data input/output	Data management	WIP level	Rules Consistency	
	Importance	10	4	8	8	4	6	3	8	7	9	9	
		1	2	3	4	5	6	7	8	9	10	11	
1	EXSYS	4	9	3	6	9	9	9	4	2	5	8	428
2	LAB VIEW	9	9	9	9	3	1	9	9	8	8	8	587
3	CURRENT	3	7	6	3	9	9	8	3	4	3	5	368

Besides the increase on R&R score, other main criteria that was evaluated at the beginning was the accuracy of diagnosis, as it was described at the beginning of this chapter, the evaluation of accuracy is extremely time consuming. For the drives evaluated with EXSYS tool, the results shown where better as it can be observed in table 5.5 the accuracy of diagnosis improve for the failure codes that were tested. The yield for the repaired HDD that had been analyzed with the previous method was from 59.7 % to 64.3 %. With the Expert System shell, five programs were evaluated and the results can be observed in table 5.6.

Table 5.6 Proportion Hypotesis Testing for HDD analyzed and repaired with Exsys Shell

			Test			
Failure	EXSYS	Old Yield	Success	Trials	P Value	Acept Ha
Type 1	ok	64.3%	35	50	0.35	No
Type 2	ok	62.5%	46	60	0.014	Yes
Type 3	ok	61.2%	37	45	0.002	Yes
Type 4	ok	63.4%	28	39	0.179	No
Type A	ok	59.7%	48	70	0.081	No

It can be observed that only for Failure type 2 and type 3 there is a significant difference on acceptance yield for HDD analyzed with the Expert System Shell program. It is observed also that all of them show a positive acceptance yield change but it can be assume as a real difference based on the fact that we cannot accept the null hypothesis and determine that there is a significant difference for some of them.

The amount of HDD tested were based on several factors, first as it was explained before the HDD following through the repair process is very difficult and should be run in small batches to avoid the components mix. Therefore, the use of large sample sizes was not possible, also some failures do not come out so often and that was a constraint as well.

There is another key factor that was also measured to determine if the expert system shell was an option to implement into the HDD failure analysis and it was the time that the HDD takes to be analyzed, this key point was evaluated an the results (Figure 5.12) shows a significant increase in the time that the technician uses to analyze an HDD. The time distribution for time used during the analysis has lower variation because the ES Shell program provides a guide for the technician while he/she is doing the analysis. The ES avoid confusion on the steps to follow or avoid the waste on time when technician is looking for some guides to complete the analysis.

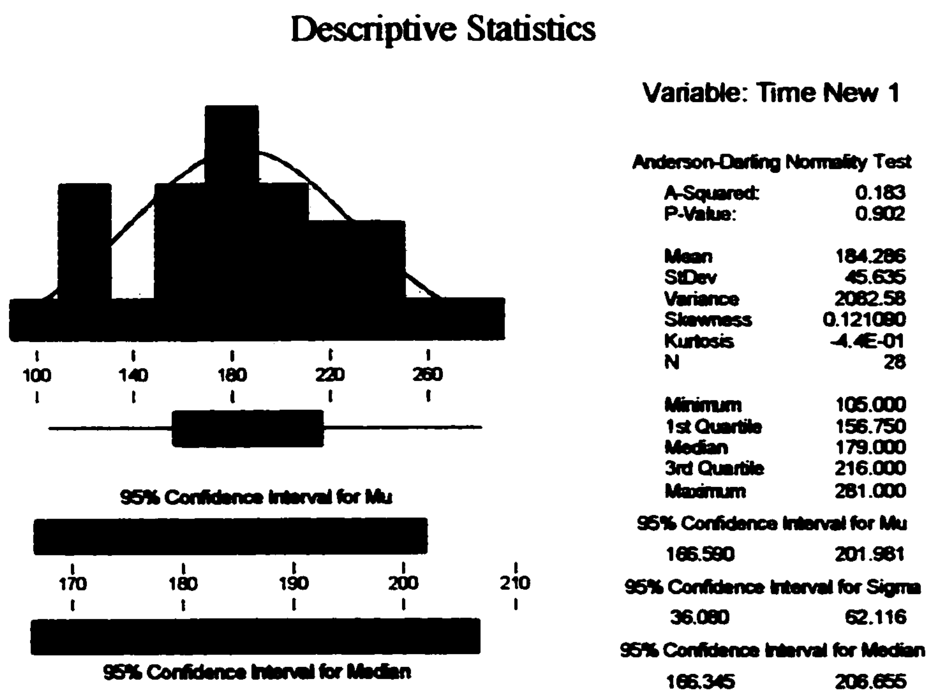

Figure 5.12 Time distribution for HDD FA using Expert System Shell Program Failure 1

The testing time of ES is longer in average than the time that it was required before to analyze the same type of failure, that is caused by the fact that the ES shell does not have the ability to interpret the data, that step of the Analysis Process still been doing by the operator. Consequently, the analysis time in this step still the same, but the increase of the testing time could be caused by the resistance of change, the novice regarding the use of the system, or due to it is required to switch windows to be able to use the ES. As it can be observed the mean for the time distribution for ES Shell is higher and the ANOVA table (Table 5.7) proves that there are a significant difference between the Standard FA process and ES FA process.

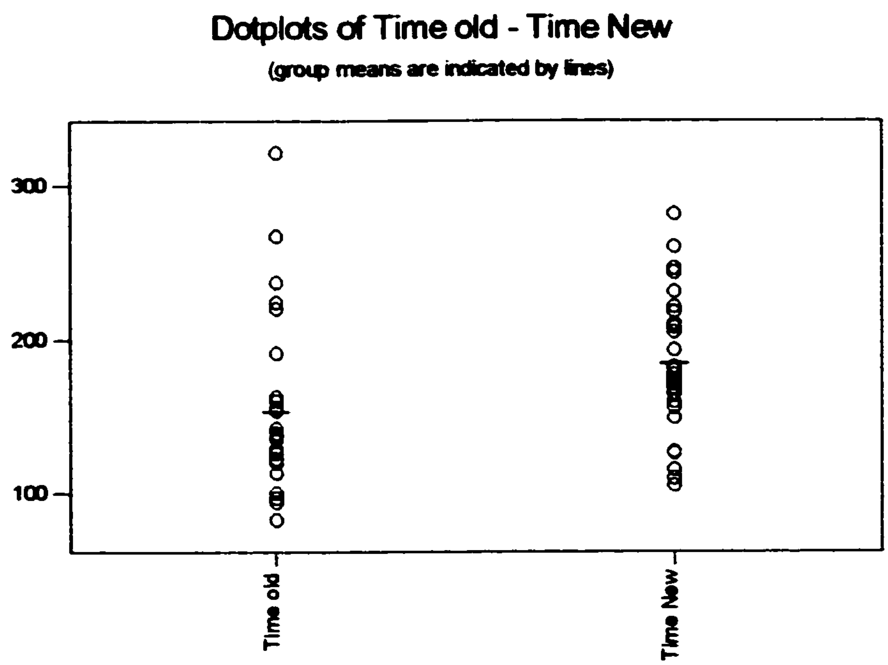

Figure 5.13 Dot plot for time compare between Standard Method and ES Shell for failure1

Table 5.7 ANOVA for FA process time between Standard Vs. ES Shell

One-way ANOVA: Time old 1, Time New 1

```
Analysis of Variance
Source      DF        SS        MS        F        P
Factor       1     13330     13330     5.20    0.027
Error       54    138445      2564
Total       55    151775
                                   Individual 95% CIs For Mean
                                   Based on Pooled StDev
Level        N      Mean     StDev  ---+---------+---------+---------+---
Time old    28    153.43     55.18  (---------*--------)
Time New    28    184.29     45.64                 (--------*---------)
                                   ---+---------+---------+---------+---
Pooled StDev =     50.63               140       160       180       200
```

5.2.2 Test Results of the Expert System Type II

The evaluation of the expert system for the Expert System Type II was based on the same criteria used for evaluation of expert system shell, as it can be observed in table 4.10 the expert system type II has better score than the other two system. That happened because the main characteristic or advantage of the Type II program was the information processing method. The other two Systems the technician makes the information processing, and for Type II system the information is processed by the program; consequently, the chances of human error as well as the time required is reduced significantly.

The first evaluation criteria was the R&R study, it is important to remember that two versions were developed for this ES, the first version was done based on the same flow diagram that was used for expert system shell, the second version has changes on its information flow and on decision criteria.

5.2.2.1 Test Evaluation for ES Type II Version 1.0

The R&R score for the ES developed in Lab View was not as good as it was expected, the result was even worst than the standard method of FA, that has several reasons to happened, the problem was analyzed and the second version was developed in base of the analysis of the low R&R score for this program for the first release. The performance between appraisal is much better than the appraisal vs. master value, the overall performance compared against the standard method is lower.

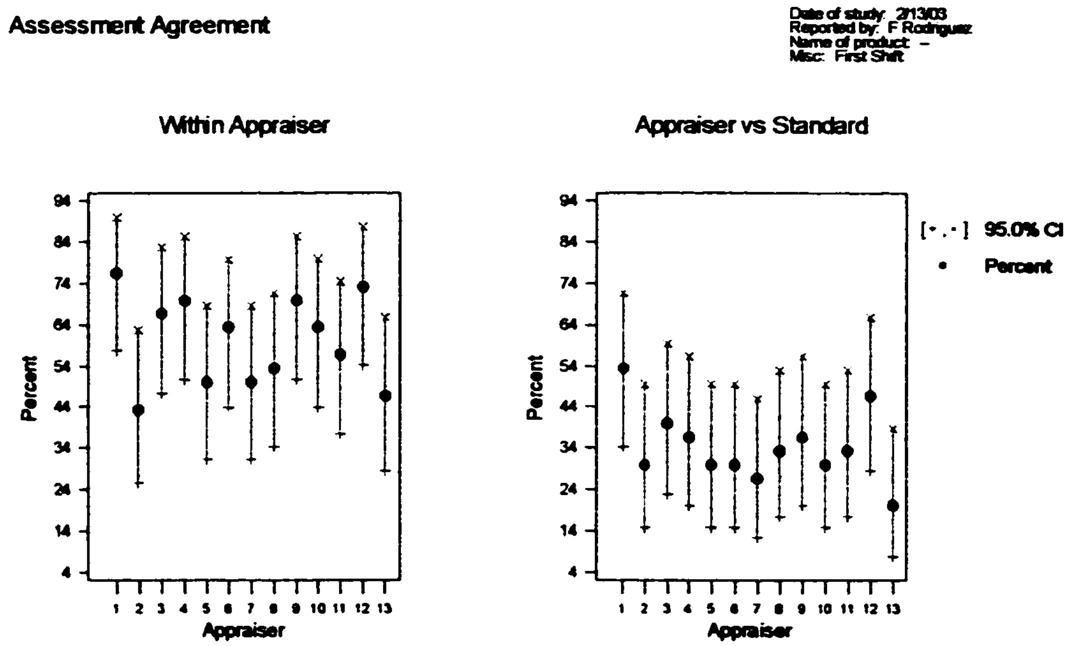

Figure 5.14 R&R Study for Expert System Type II Version 1.0

The mean of 60.25% for the concept of agreement between appraisers is under the minimum of 85% for release a system, the Standard Deviation goes worst the situation. Because the result of 10.93 it is not acceptable for a system that makes the decisions based on a computer program. The appraisal versus the master value goes worst with a mean of 34.36% is simply unacceptable. This program can be used on the regular production.

Table 5.8 Basic Statistic for Type II version 1.0 R&R Results

Variable	N	Mean	Median	TrMean	StDev	SE Mean
% within Ver 1.0	13	60.25	63.30	60.30	10.93	3.03
% app vs mtr 1.0	13	34.36	33.30	33.95	8.65	2.40

Variable	Minimum	Maximum	Q1	Q3
% within Ver 1.0	43.30	76.70	50.00	70.00
% app vs mtr 1.0	20.00	53.30	30.00	38.35

ANOVA test was done to the results of the R&R study to determine if it is a difference or not between the standard FA system and the Type II version 1.0 system. As it can be observed in table 5.9 there is a significant difference between the two system compared, also this difference can be observed in figure 5.15, the percentage of accuracy of the different stations compared with the standard performance is lower. Even with the reduction on the standard deviation is not an improve process variation because the expectation for an automatic system is to get a standard deviation score near to cero.

Table 5.9 ANOVA for Std System and Type II Version 1.0

One-way ANOVA: Within technicians between Std System and Type II V 1.0

```
Analysis of Variance
Source      DF        SS        MS        F        P
Factor       1      2875      2875    15.67    0.001
Error       24      4404       183
Total       25      7278
                                   Individual 95% CIs For Mean
                                   Based on Pooled StDev
Level          N      Mean     StDev  --------+---------+---------+--------
Std FA        13     81.28     15.73                        (------*-------)
Type II 1.0   13     60.25     10.93   (------*-------)
                                      --------+---------+---------+--------
Pooled StDev =     13.55                     60        70        80
```

The R&R study was done in the first shift and the Lab View program was installed in all machines, the technician input was only to provide the system if the HDD has previously failed or if it was the first time and if it has failed before what had been the previous diagnosis. That step was very easy then the probability of error from the technician was minimum.

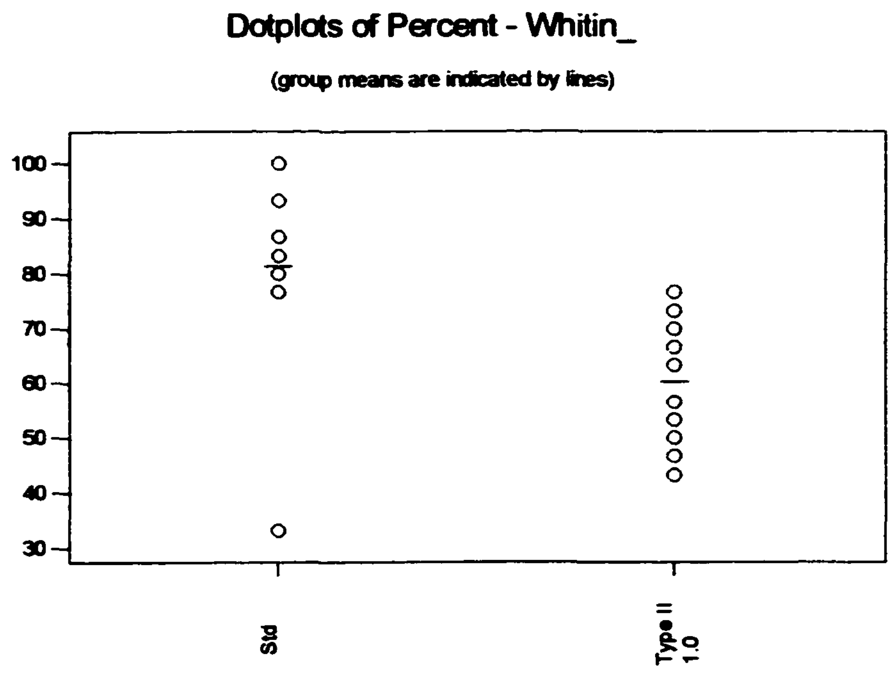

Figure 5.15 Dot plots for Std FA process vs. Type II Version 1.0

The Type II System showed a significant reduction on testing time that is due to the fact that the decisions and the interpretation of the information from the screen now is done by the Lab View program, the figure 5.15 shows the difference on the cycle time improvement. Besides the significant time reduction also the variation on time has a significant decrease, that reduction in cycle time has a direct effect on the capacity of the station and it will cause a reduction in WIP because these concept has a direct relation, as faster the HDD is analyzed the waiting time will be reduced.

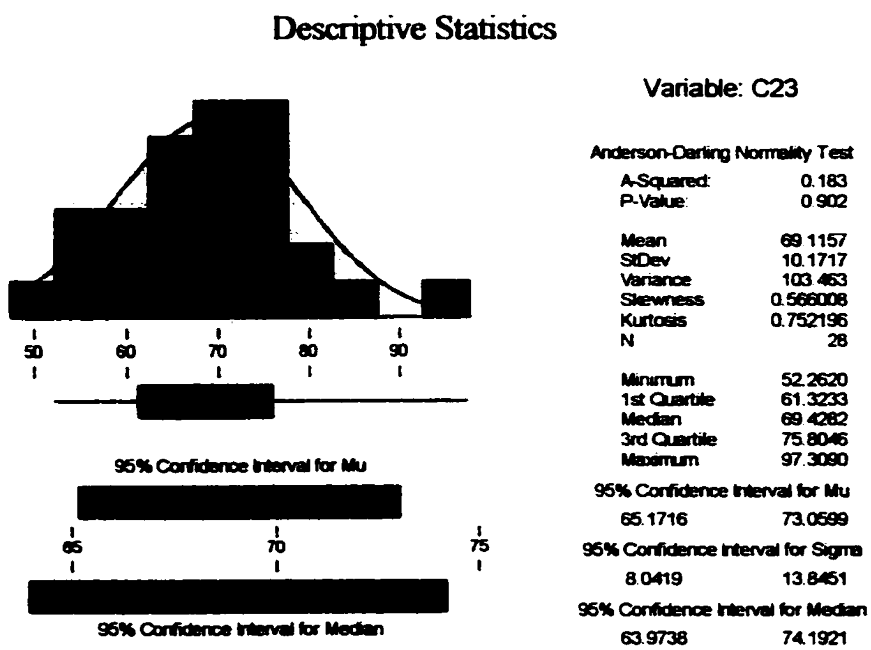

Figure 5.16 Basic Statistic study for cycle time of FA using Type II ES Version 1.0

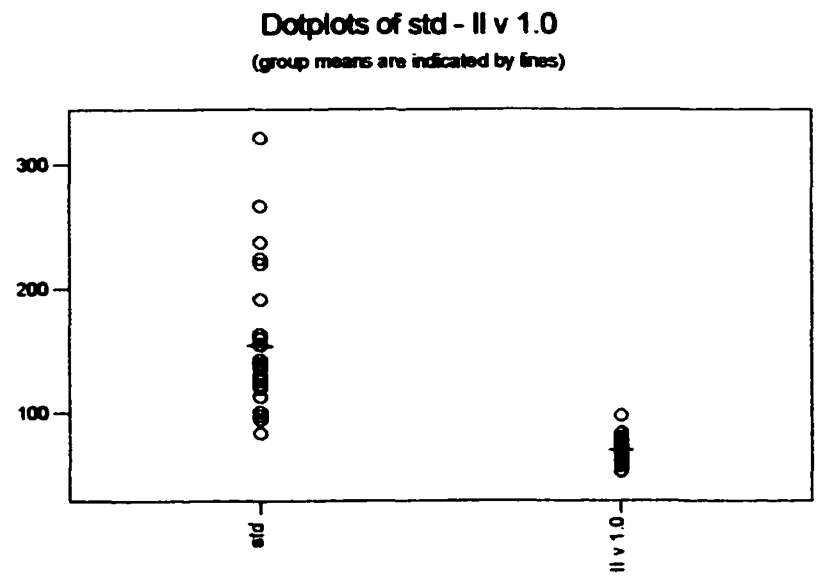

Figure 5.17 Dot plots for time cycle comparison between Std vs. Type II 1.0

The study for testing for accuracy of diagnosis was cancelled due to the low R&R score it was considered that it was a unnecessary waste of resources due to the high variation of the results provided by this system.

5.2.2.2 Expert System Type II Version 2.0 Evaluation

The Expert System was modified several times but mainly were release two versions, the version 1.0 that was previously analyzed and the version 2.0 that after several modifications. In this section the version 2.0 will be analyzed and compared with the standard FA process.

As it was done with the Expert System shell the basic metric to evaluate the FAA performance is the R&R study, it can be observed that the performance within appraisal where above 85% matched when 1st and 2nd trial are compared, also the appraisal against the attribute were higher than any other system used for HDD FA. This is a direct consequence of the fact that the human factor in the data interpretation from the screen and the decision making process was eliminated and it was a main source of variation in diagnosis. Even the good results it still a percentage that should be improved, because the R&R scores should be above 95% or near to 100% for a ES based on automated decision taking process, but in this case there are some factors that are external to the system and are external sources of variation.

The increase is statistically significant based on the results of the ANOVA when we are comparing the Within Appraiser metric, the increase goes from matching percent of 81.28% for standard FA process against the 91.55% that was gotten using the ES Type II Version 2.0.

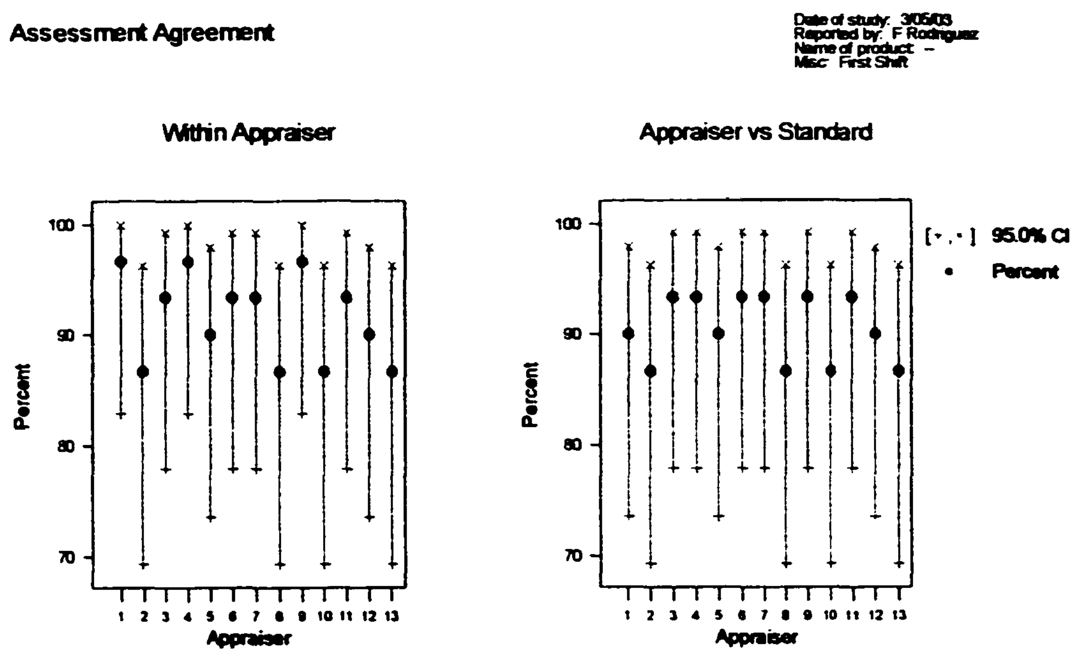

Figure 5.18 R&R Charts for ES Type II Version 2.0

The standard deviation also was reduced 4 times from 15.73 for Std FA to 3.99 with the ES Type II, that is also significant because not only a increase on the mean of percentage matched mean was obtained, also a more accurate process in different trials that is a measure of robustness of the system.

Table 5.10 ANOVA Within Appraiser Std FA process vs. ES Type II V 2.0

One-way ANOVA: Within Appraiser Std vs. Type II V2.0

```
Analysis of Variance
Source      DF        SS        MS        F        P
Factor       1       684       684     5.20    0.032
Error       24      3161       132
Total       25      3845
                                    Individual 95% CIs For Mean
                                    Based on Pooled StDev
Level        N      Mean     StDev  ----+---------+---------+---------+--
Std FA      13     81.28     15.73   (--------*---------)
Type II 2.0 13     91.55      3.99             (---------*--------)
                                    ----+---------+---------+---------+--
Pooled StDev =     11.48             77.0      84.0      91.0      98.0
```

The ES Type II Version 2.0 got also a significant improve in the appraisal vs. master score, that result was expected in the version 1.0 due to the program was developed with the knowledge of the experts. The ES should be able to make the diagnosis following the same rules each time, the results observed on table 5.11 shows a significant increase on this metric, the mean of matched percentage between appraiser vs. master increase from a 67.44% of the Standard FA method to a 90.51% with the ES Type II, besides the standard deviation was reduced from 18.51 to 2.97 that shows a more accurate diagnosis system.

Table 5.11 ANOVA Appraiser vs. Master. Std FA process vs. ES Type II V 2.0

One-way ANOVA: Appraiser vs. Master Std FA process Vs. ES Type II V 2.0

```
Analysis of Variance
Source      DF        SS          MS         F        P
Factor       1      3459        3459     19.69    0.000
Error       24      4216         176
Total       25      7675
                                         Individual 95% CIs For Mean
                                         Based on Pooled StDev
        Level        N      Mean        StDev  -+---------+---------+---------+-----
Std     Percent_    13     67.44        18.51    (-----*------)
TypeII  Percent_    13     90.51         2.97                        (-----*------)
                                                -+---------+---------+---------+-----
Pooled StDev =     13.25                60         72        84        96
```

The time reduction was similar to the version 1.0 but it takes longer because other test are performed but it still been lower cycle time than the Standard FA Process or Expert System Shell. With a mean of 81.89 second per cycle it takes longer than the 69 seconds that version 1.0 was doing, the standard deviation has small reduction it goes from 10 sec. to 7.2 sec., the increase is significant between the two versions;

nevertheless, the version 2.0 provides a smaller cycle time than the Standard FA process (Figure 5.19).

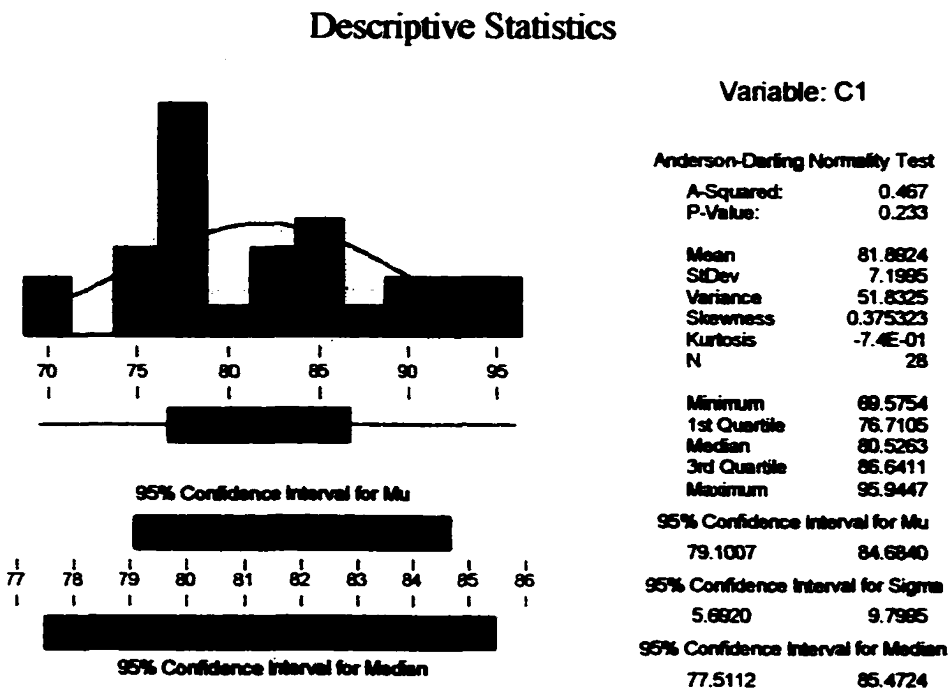

Figure 5.19 Cycle Time distribution for Type II version 2.0

Table 5.12 ANOVA Table for cycle time ES Type II Version 1.0 vs. 2.0

One-way ANOVA: II v 1.0, II v 2.0

```
Analysis of Variance
Source     DF        SS          MS         F          P
Factor      1     2286.1      2286.1     29.46      0.000
klError      54     4189.7        77.6
Total      55     6475.8
                                        Individual 95% CIs For Mean
                                        Based on Pooled StDev
Level       N      Mean       StDev    -+---------+---------+---------+-----
II v 1.0   28    69.114      10.168     (----*-----)
II v 2.0   28    81.893       7.196                          (----*-----)
                                        -+---------+---------+---------+-----
Pooled StDev =    8.808             66.0      72.0      78.0      84.0
```

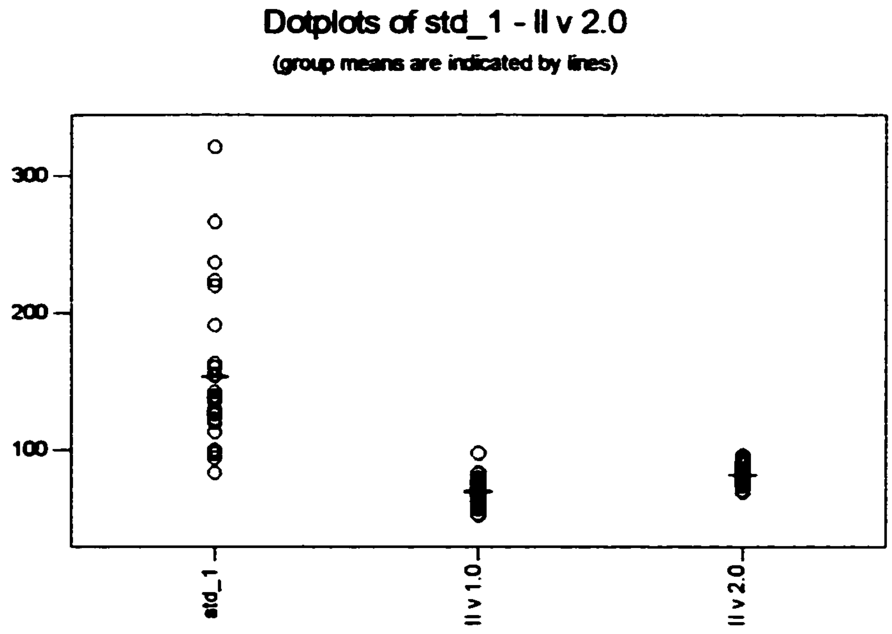

Figure 5.20 Dot plot for cycle time Std FA process vs. ES Type II V 1.0 and 2.0

The last test to prove if the new system is doing the things properly was the evaluation of the diagnosis of the HDD provided by the system is correct, the technique used was the same that the one used for the evaluation of Expert System Shell but with for the Expert System Type II the top failure code was developed and tested. In the study 60 drives were disassembled and followed through the process in batches of 15 from failure code 1. The results were the following: From the 60 drives analyzed and repaired based on the diagnosis provided by the Expert System Type II version 2.0, 46 succeed on the testing process, that increase is significantly greater than the obtained by using the

Standard FA process. The results shown in table 5.13 there is a p-value of 0.028 that probes the difference.

Table 5.13 Proportion Hypothesis Test for Type II System

Test and CI for One Proportion

Test of p = 0.643 vs p > 0.643

Sample	X	N	Sample p	95.0% Lower Bound	Exact P-Value
1	46	60	0.766667	0.659518	0.028

5.3 Modifications

Testing phase is not the end of the expert system development, the testing phase will show the errors that the system has, and if the performance in the test is satisfactory the product can be released. In the development of Expert System the experts that are working on the System design still generating new knowledge, in the process of "download" their knowledge in a understandable and formal way many times new knowledge is generated, this new knowledge can be useful for a ES development.

5.3.1 Expert System Shell Modification

The Expert System Shell development generates several modifications to the process flows and the information management to the technicians. In the codes were the system was developed, besides some missing steps were added to the FA process flow because some tests was not considered and was required. The five codes that were used to develop the Expert System Shell Programs were modified in their flow diagrams, besides some others flows from other failures were also modified.

The main modification to the Expert System Shell was the replace of the ES Shell for a more effective Systems, the problem was that the nature of the process was not the field where ES are effective, the data interpretation from the screen and the human factor make a complex scenario. Besides, the high volume rate of failures that need to be analyzed complicated the situation, the ES Shell had a larger cycle time for HDD analysis and improve in the accuracy was not significant for all failure codes. Therefore, the idea of use a system that could manage the data from the HDD and provide command to the HDD during the test come up and the Lab View Software was an alternative.

5.3.2 Lab View Modifications

Lab View program has two versions the 1.0 and the 2.0 that significant change happened due to the bad results that the version 1.0 got in testing phase. The main changes were due to some concepts present high variability rate and in the other systems as the technician got a signal (Figure 5.21). Under one command and the ranges were too wide that at that point the test showed an acceptable repeatability, and in the interpretation procedure the technicians force it to match.

That signal (Figure 5.21) provides information about the head position error or position error signal (PES). The problem with using this PES as a decision criteria is that each time that is taken it is different even if the signal is taken in the same head and track. That was a extreme variability on the process. Other issue was the fact that the same signal could be interpreted different by the same technician in different opportunities, the technicians need to count the "cycles" and if the number of "cycles" match with the criteria. They take a decision and provide a repair diagnosis if the number of "cycles" not match they continue the analysis.

Technicians were evaluated for this metric and they did not show a strong criteria on determining the number of cycles. The variation from technician to technician was high and they tent to match the cycles to 3 and 9 to match the decision criteria. The worst thing was even if they try to set up standard criteria, there is not any criteria about the counting "cycles" rules, then we were not able to determine the criteria.

Figure 5.21 Position Error Signal

5.3.2.1 Commands Modifications

In the ES review for failure code 1, 2 and 3 the Position Error Signal (PES) is a parameter that is verified. It is analyzed to make a decision and to assign a repair code, the decision rule is: "If the number of cycles or turns in the PES taken from specific Head on specific track has certain number of turns, then the repair code is motor replace. Else the analysis continues". In the testing phase of Expert System Type II Version 1.0 it was found that the turns criteria has variability, in HDD failures the number of turns vary from two to eight measuring the same head and the same track in the same HDD. The variation can be observed in figure 5.22, the same study was done to 35 failure drives for the failure code 1 and all of them showed similar variation level, that is critical due to the number of turns is a decision criteria in all type of systems. Besides, a pass HDD was tested for this concept, and it was found that it sometimes meet the criteria to be repaired.

The HDD that passed all the tests and the criteria is not reliable; consequently, all the decisions based on that turn criteria are not valid. These results concerned the experts because since the product started the criteria of turns had been used and nobody has noticed that it has variation. In the other type of Expert System and the standard system the technician makes the turn test once or two at the most and takes a decision, that is one of the causes of why they have not noticed that this criteria has that level of variation.

The requirement is to find other criteria that replace that test with similar concept. The HDD has recorded a list of error per track and head, the experts recommended in a brain storm session that making a reading of the signal for the each head to measure the behave of the head on the track using a Fast Fourier Transformed (FFT) to understand if the head or the motor is the cause of the variation.

A second option was to make a decision based on specific test results that provides the number of errors per head and per track during the test and making others analysis in order to determine the limit of errors allowed.

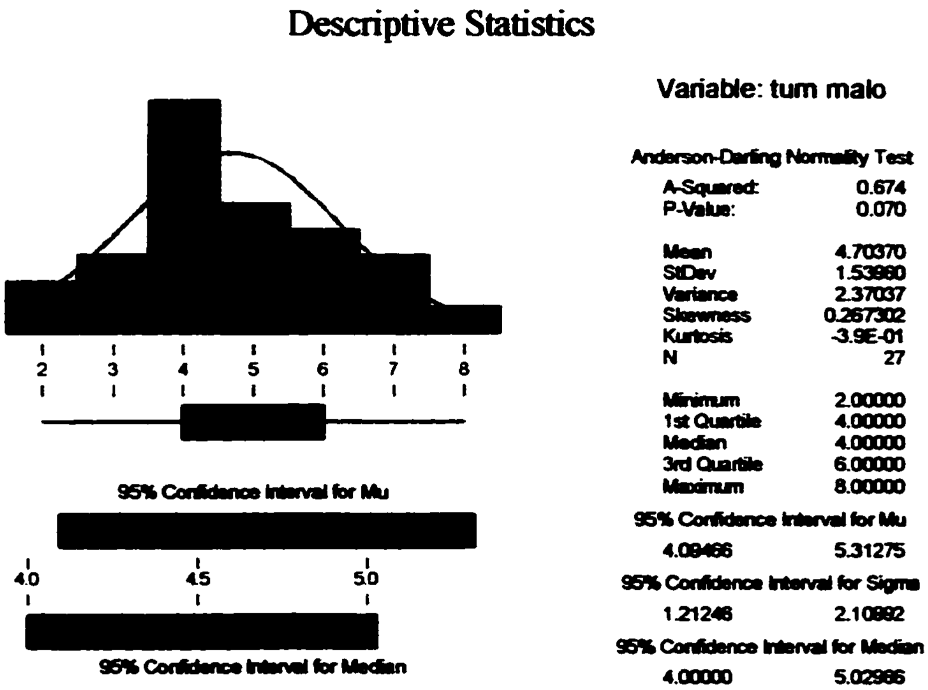

Figure 5.22 Number of turn for the same head, track and drive for a failure.

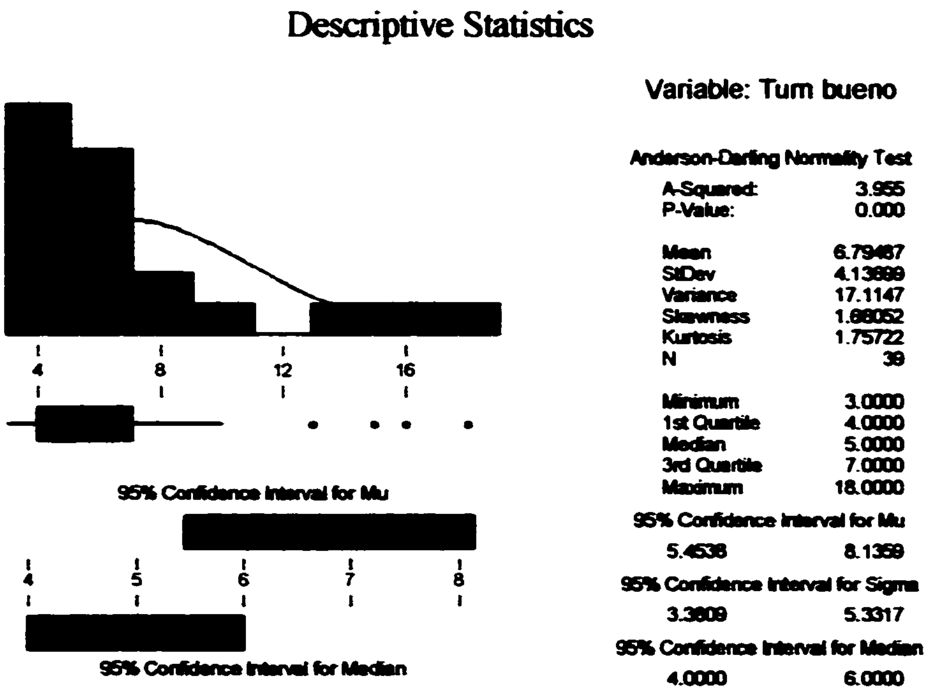

Figure 5.23 Number of turns for the same head, track and drive for a pass HDD

The first idea to replace the use of turn criteria was the FFT concept, the objective was to determine frequency levels to determine the type of damaged component of the HDD. In the figure 5.24 it is shown a FFT chart, the axis are mV and Hertz, by the analysis of 35 HDD from the same failure code the technicians tried to identify a pattern of the wave but it was not possible. The wave or spectrum showed similar patterns but it has variation each time that it is analyzed even if the same head and same track is been tested. The behavior of the wave is the same deficiencies that the turn concept used in the standard FA system. This chart is like a picture taken to a track runner, even if the picture is taken to the same runner (head) in the same track in the same point of the stadium, each time the picture will be different; consequently, the repeatability and reproducibility will continue been a issue.

Even range of values could not been determined for the diagnosis of failures. This concept is used in similar HDD models but it is not reliable measure to make a decision about the root cause of the failure.

The second idea selected to replace the turn test was the sum of errors, the sum of errors is a set of data that is recorded in the HDD and represents the sum of errors per track that are founded in the testing process (Table 5.14). An error is generated when the Head con not read the information from specific sector. Expert System need to extract this data from the drive and use the rules determined for the experts to reach the conclusions. The R&R study will not be feasible but the effectiveness study and rules consistency will determine if there is a significant improve or not.

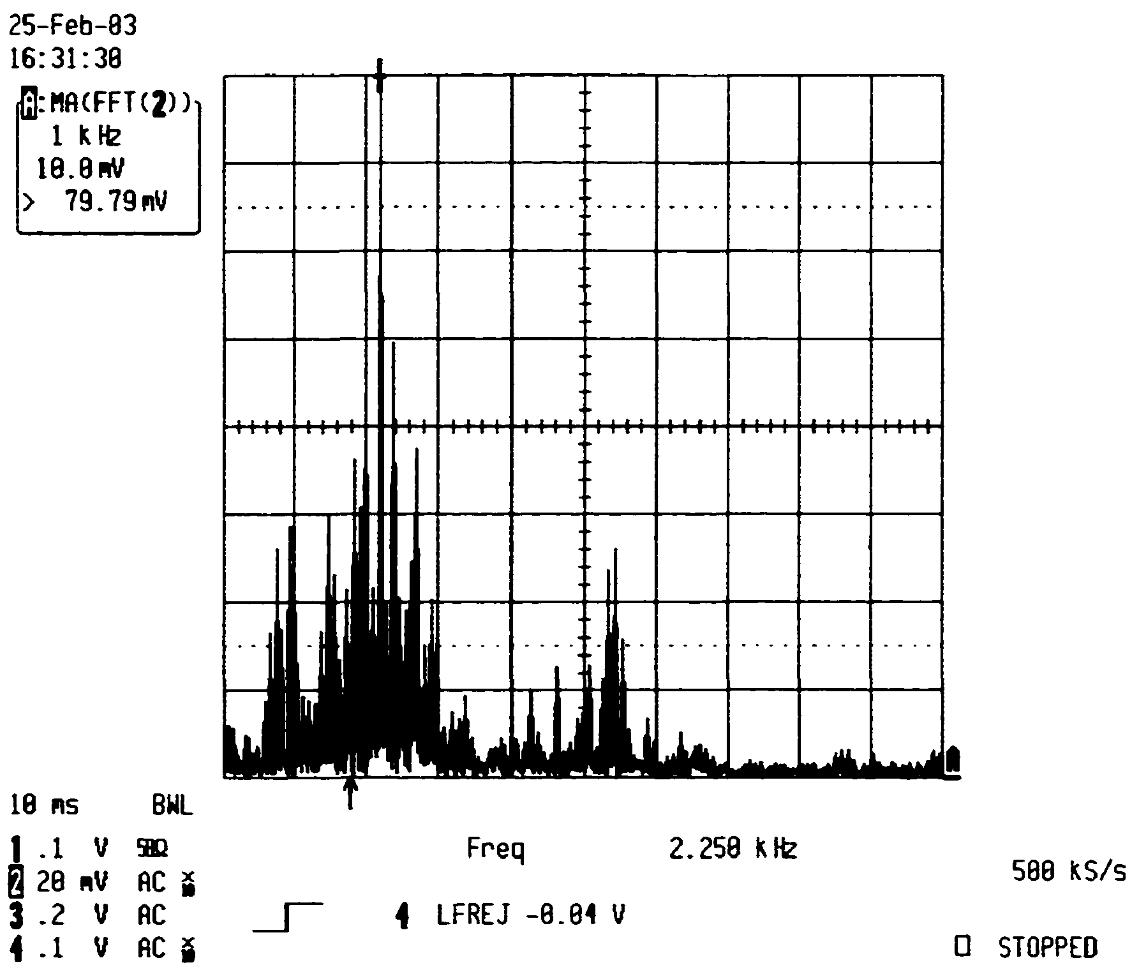

Figure 5.24 Fast Fourier Transform for Failure Type 1

Table 5.14 Sum of error per track and head.

```
0006.00 Sum = 00005169
0007.00 Sum = 00004D47
0008.00 Sum = 00004BB2
0009.00 Sum = 00005516
000A.00 Sum = 00005A98
000B.00 Sum = 00004C8A
000C.01 Sum = 00005CDA
000D.00 Sum = 000144EE
000E.00 Sum = 0000465C
000F.00 Sum = 00004C22
0010.00 Sum = 00005199
0011.00 Sum = 00004D77
0014.00 Sum = 0000480B
0015.00 Sum = 00004B60
```

There was any documents or references in similar products about the use of this information and the parameters; therefore all the rules and the decision criteria were developed and tested, all the information come from experiments.

The strategy used to develop the rules for the expert system were the following:

1. The data of sum of errors should be classified by head, media (disc) and media sector
2. Each HDD analyzed should be des assembled and all its parts should be tested, fixed and reassembled.

3. After testing components are completed then a comparison is done between the sum of errors data and the test components results.
4. Rules are developed.

Then for the experiment the data was taken from the sum of error were classified and recorded. The classification was done in categories (Table 5.15), the HDD can have different number of heads, then each head has a media to write and read information. Tracks were classified in five groups starting from the inside of the media to the outside, that was done for the first approach and for the first set of rules definition. For next developments this number of sections can be increased to have a better resolution and develop new decision criteria. If the section has a number of continuous tracks with a significant amount of errors then it is assume the probability of having a scratch on the media. Based on this table the Lab View program reads and classify the errors in the categories defined in the table, each HDD was analyzed and classified. Then the second step started.

The second phase of experiment show that the heads and the medias had problems, and it can be recall that the Motor was the first disposition for replace as the failure diagnosis, and also is important to recall that if the head or media do not get disposition. They pass to the repair process without been verified, and not all the material that is des assembled can be tested because of capacity issues besides if it is not required then there is a over processing kind of waste.

Table 5.15 Sum of errors codification table

HDD	Head	Errors	Track	Scratch
1	1	A	1	No
		A	2	No
		B	3	No
		C	4	No
		C	5	Yes
	2	A	1	No
		B	2	No
		A	3	No
		C	4	Yes
		D	5	Yes
	3	None	1	---
			2	---
			3	---
			4	---
			5	---
	4	None	1	---
			2	---
			3	---
			4	---
			5	---

After the repair process it was observed that 31.43 % of the HDD analyzed had problems with their heads, 17.14 % had media rejects and the HDD that from the remaining HDD that did not have head or media rejects were reassembled without replacing the motor. The acceptance yield in final test increase up to 81.82% that is not a significantly difference from the current effectiveness of the standard FA system that can be caused due to the small sample size of the second sample.

Table 4.16 Hypothesis test to determine if there is a difference between standard FA process and Type II V 2.0 effectiveness.

Test and CI for Two Proportions

```
Sample                    X     N    Sample p
Std FA                   48    76    0.631579
ES Type II V2.0          18    22    0.818182

Estimate for p(1) - p(2):  -0.186603
95% CI for p(1) - p(2):  (-0.380862, 0.00765620)
Test for p(1) - p(2) = 0 (vs not = 0):  Z = -1.88  P-Value = 0.060

* NOTE * The normal approximation may be inaccurate for small samples.
```

Table 5.17 Effectiveness Test Table

Number	VI	VI-2	Head Test	Media Test	Write Test	W&R Test
1	Fail	NA	NA	ok	NA	NA
2	Pass	Pass	Pass	ok	Pass	pass
3	Pass	Pass	Pass	ok	Pass	pass
4	Pass	Pass	Pass	ok	Pass	pass
5	Pass	Pass	Pass	ok	Pass	pass
6	Pass	Pass	Pass	ok	Pass	fail
7	Fail	NA	NA	ok	NA	NA
8	Pass	Pass	Pass	ok	Pass	pass
9	Fail	NA	NA	ok	NA	NA
10	Pass	Pass	Pass	Scrap	Pass	pass
11	Fail	NA	NA	Scrap	NA	NA
12	Pass	Pass	Pass	ok	Pass	pass
13	Pass	Fail	NA	ok	NA	NA
14	Pass	Pass	Pass	ok	Pass	pass
15	Pass	Pass	Pass	ok	Pass	fail
16	Pass	Pass	Pass	ok	Pass	pass
17	Pass	Pass	Pass	ok	Pass	pass
18	Pass	Pass	Pass	ok	Pass	pass
19	Fail	NA	NA	ok	NA	NA
20	Pass	Pass	Pass	Scrap	NA	NA
21	Pass	Pass	Pass	ok	Pass	pass
22	Pass	Pass	Pass	ok	Pass	pass
23	Pass	Fail	NA	ok	NA	NA
24	Pass	Pass	Pass	ok	Pass	pass
25	Fail	NA	NA	ok	NA	NA
26	Pass	Pass	Pass	ok	Pass	pass
27	Pass	Pass	Pass	ok	Pass	pass
28	Pass	Pass	Pass	ok	Pass	pass
29	Pass	Pass	Pass	ok	Pass	fail
30	Pass	Pass	Pass	ok	Pass	pass
31	Fail	NA	NA	Scrap	NA	NA
32	Fail	NA	NA	Scrap	NA	NA
33	Pass	Pass	Pass	Scrap	NA	NA
34	Pass	Pass	Pass	ok	Pass	fail
35	Pass	Fail	NA	ok	NA	NA

5.4 System Documentation

The final Expert System that was selected was the Lab View based, the ES Type II V 2.0 prove to be effective and also provides a better cycle time. The improving and testing process include baseline, benchmarking, brainstorming and R&R studies. All tests done to each alternative of ES were documented in a Six Sigma project that is a formal documentation procedure that the company has.

For the Expert System implementation a Standard Operation Procedure (SOP) was developed, in this procedure the responsibilities and the modification procedures of the software are specified. Besides, the restrictions and requirements for the updates and the release of new programs for new failure codes.

The programs will be located in a server to be able to be used in the stations that are required, besides it is easier to update the program and avoid modifications that can be done when the program is local. The procedure documentation also calls for statistical justification for improves or changes to documented as a probe of improvement done.

5.5 Maintenance and Feedback

The top management of the site developed a weekly meeting for process improvements review. Then if the ES has any issues the responsible of FAA will elevate the issue in this meeting and corrective actions will be opened for the people involved in solve the problem, besides any improve project that has as conclusion the modification of FA flow for specific failure code will require to update the ES. It is a closed loop for improving and ES is a tool for making sure that everybody follows the new release of FA process. In the pass the technician has the ability to skip the steps, it happened very often. If they were not convinced of the change they just ignore the change done, and always the 2nd and 3rd shifts have complains about they were not notified and trained regarding the changes.

There is a plan for train the people in charge of making the updates and develop new programs to be trained in Lab View software, because currently just some people knows the software but they are not able to develop complex application as are required. The expert system will be integrated to the general system, this new system needs to exchange information with the general information system. Some additional tests are planned to be included as a standard feature of the system, the most significant is the R&R mode that is an application to "calibrate" the system. This R&R mode feature will automatically ask the operator to retest specific amount of drives in that station, and it will be done also in other stations to make sure that the system is working properly.

CHAPTER 6

CONCLUSIONS

The complexity of today's systems and processes has created the need for more effective analysis tools. Expert System is an effective tool for failure analysis and problem solving. The computer and software development in recent years is a solid support for Expert System Development.

Due to the deficiencies found in the Failure Analysis Area in the Hard Disk Drive warranties repair process, there is a need for process improvement. Expert System development is a feasible option that provides a robust and effective failure analysis method.

Based on the Expert System definition, ES is a model that utilizes expert's knowledge for effective problem solving. The software helps to organize the expert's knowledge and makes it accessible to more people in the organization. Expert Systems could be classified in two main groups: The Expert System Shells and The Software Developed Systems.

The first type of Expert System (ES Shells) has advantages compared with the Software Development Systems. The Shell is easier to apply because ES shells are designed for providing a friendly programming environment with a low software knowledge requirement. This feature gives the shell the ability to be widely utilized because a software expert is not required. Besides the friendly environment, the ES Shells have been developed considering the Expert System developer requirements. ES Shells have been updated lately to fulfill the new Internet application requirements. On the other hand, the ES Shells have some disadvantages. The system is not able to make all decisions by itself; someone is required to load information into the system. Consequently, a certain knowledge level is required for this system.

Based on the results of the Repeatability and Reproducibility study, the EXSYS Expert System obtained an improvement in the percentage of matched diagnosis "within the appraisal" when it was compared with the previous R&R study that had been performed to the FAA technicians at the beginning of the project. The mean increases from 81.28 percent with the current FAA system to 88.45 percent with EXSYS. Besides, the Standard Deviation showed a significant decrease from 15.73 to 8.78.

EXSYS showed a partial improvement regarding the Diagnosis Effectiveness metric. Five failure codes were evaluated and only two out of five showed a significant improvement by utilizing EXSYS program. Results could be observed in table 5.6.

The third metric for evaluation was the cycle time for HDD failure analysis. The testing time for EXSYS system is longer than the standard method because the ES shell does not have the ability to interpret the data. The technician was still doing the data interpretation step; consequently, the analysis time increased because the technician needed to be switching windows to be able to use the ES. Nevertheless, the main disadvantage of EXSYS is that the decision making process still being done by humans.

The second type of system's main objective is to make the failure analysis without human involvement since the human factor was found to be the major cause of FAA problems. The HDD has recorded inside the results of the testing process. These results can be consulted and interpreted automatically by the computer program. The program that best fits this application was Lab View from National Instruments. This programming tool is utilized to get information from sensors and these results are interpreted based on program rules set by the experts.

The increase in repeatability and reproducibility studies is statistically significant. In the Within Appraiser metric, the increase goes from matching percent of 81.28% for standard FA process to 91.55% for ES Type II Version 2.0. The variation (standard deviation) in this metric was reduced from 15.73 of Standard FA to 3.99 of Lab View program.

Expert System developed in Lab View got better results for Diagnosis Effectiveness, the HDD analyzed with this system got a significantly better acceptance yield, the increase was above 10% of acceptance yield, and it was proved to be statistically significant.

The cycle time was reduced in average and in variation; the average cycle time for standard FA was around 150 seconds, the Lab View program decreases it to 82 seconds. The variation also was reduced more than 3 times with the Lab View program because the decision making process is being done by the system.

Nevertheless there is the probability that a bad component is assembled into an HDD. The increase in accuracy of diagnostic will purge the system from defective undetected components.

The improvements done by the two types of systems give advantages to the FA process but the Type II system (Lab View) eliminates the points were human error could cause an incorrect decision. Nevertheless, the Lab View is an option that requires higher resources and higher software knowledge. It was proven that it is a better option based on the three critical performance metrics of Failure Analysis Area: Diagnosis Effectiveness, Repeatability and Reproducibility, and Cycle Time.

REFERENCES

1. Ignizio, J., Introduction to expert systems Mc Graw Hill, 1991
2. Tuthill, S. Levy,S. Knowledge Based Systems TAB, 1991
3. Steels Luc, McDermott John; The Knowledge Level In Expert Systems Academic Press Inc, 1994
4. Krishnamoorthy C.S., Rajeev S. Artificial Intelligence and expert systems for engineers. CRC Press, Inc., 1996
5. Clarke, Dana. "Inventive Troubleshooting", Machine design 72 No 12 Je 15 2000
6. J.P. Barthélemy, R. Bisdorff and Ph. Lenca (Guest editors) (2002), Human Centered Processes. Feature Issue, *European Journal of Operational Research* EJOR, Volume 136, Number 2, January 16, 2002, pp. 231-352
6. Barthelemy, Bisdorff, Coppin, "Human centered process and decision support systems". European Journal of Operational Research".
7. Schaafstal, Maarten Schraageen and Van Berlo. "Cognitive Task Analysis and Innovation of Training: The Case of Structured Troubleshooting" Human Factors 42 No 1 Spr 2000
8. Adelman, Leonard. Evaluating Decisil. Supporrt and Expert Systems, John Wiley and Sons, 1992
9. Durkin, John. Expert Systems Design and Development. Mavmillan, 1994
10. Beerel, Annabel. Expert Systems, Strategic Implications and Applications. Ellis Horwood Limited, 1987.
11. Payne, Edmund; Mc Arthur, Robert. Developing Expert Systems. John Wiley and Sons, 1990.
12. Liebowitz, Jay. Knowledge Management, Learning from Knowledge Engineering. CRC 2001.
13. Berry, Diana, Hart Anna, Expert Systems Human Issues. MIT Press 1990

14. Brown David, Chandrasekaran B, Design Problem Solving, Knowledge structure and Control Strategies. Pitman Publishing, 1989
15. http://www.autonomy.com/Content/IDOL/
16. Torsun, I.S. Foundations of Intelligent Knowledge-Basecd Systems, Acdemic Press 1995
17. Tourbaim, Efrain; Liebowitz Jay, Managing Expert Systems. Idea Group Publishing, 1992.
18. Andriole, Stephen. Software validation, verification, testing and documentation. Petrocelli Books, 1986.
19. Medsker,Larry; Liebowitz,Jay. Design and Develop of Expert Systems and Neural Networks. Mc Millan, 1994.
20. Mc Graw, Karen. Harbison-Brigss, Karan. Knowledge Acquisition, principles and guidelines. Prentice Hall, 1989.
21. EXSYS Corvid Manual, Corvid Systems 2002.
22. Computing Magazine, Cost of Hard Disk Storage Space, December 1981, p 6.
23. Efstathiou, J, Calinesu, A. An Expert Sytem For Assesing the Effectivenes of Manufacturing Information Systems. University of Oxford 1992.
24. Slap, Albert., Hillman, Daniel., Moore, David. Expert System in Emergency Response. Acu Tech Consulting. San Francisco CA. March 1998
25. Quaddus,Lu., Poh, K.L. Williams, R. The Design of a Knowledge Based Guidance System for an Intelligent Multiple Objective Decision Support System. National University of Singapore. 1999
26. Quing Shou Wang, Expert System Integrating Construction Scheduling Cad Drawing. National University of Singapore. 1994
27. Preston,P., Comptom,P., Litkouhi, D. An Expert System Interpreter for Time Course Data With Refinement in Context. Chemical Pathology Department, Sidney, Australia. 1993
28. Porter, Jim., Disk Drive Evolution. Disk Trend. Santa Clara University CA, 1999

APPENDIX A

Variables:

[1st_time_failure]

Static List Variable
Prompt: 1st time fail?
Static List Values:

yes_first_time_fail
yes, first time fail

No_drive_has_failed_before
No, drive has failed before

Flags:

Always obtain a value: False
Display with results: False
Never Ask User: False
Display with results: False
Initialize: False
Check for PARAM data passed in Applet call: False
In backward chaining, stop after first value is set: False
In backward chaining, skip redundant rules: False
Use backward chaining to derive value: True
Use External Source to get value: False
Only a single value can be assigned

Display:

Ask with: Radio Buttons
Arrange: One item per line

[2_or_3_turns]

Static List Variable
Prompt: Graphic shows 2 or 3 turns?
Static List Values:

Yes_it_shows_2_to_3_tuens
Yes, it shows 2 to 3 tuens

No_it_does_not_show_2_or_3_turns
No, it does not show 2 or 3 turns

Flags:

Always obtain a value: False
Display with results: False
Never Ask User: False
Display with results: False
Initialize: False
Check for PARAM data passed in Applet call: False
In backward chaining, stop after first value is set: False
In backward chaining, skip redundant rules: False
Use backward chaining to derive value: True
Use External Source to get value: False
Only a single value can be assigned

Display:

Ask with: Radio Buttons
Arrange: One item per line

[7ffff]

Static List Variable
Prompt: Value =7ffff in a single head?
Static List Values:

Yes_7ffff_value_was_founf_in_some_head
Yes, 7ffff value was founf in some head

No_any_7ffff_value_was_found_in_a_single_head
No, any 7ffff value was found in a single head

Flags:
Always obtain a value: False
Display with results: False
Never Ask User: False

Display with results: False
Initialize: False
Check for PARAM data passed in Applet call: False
In backward chaining, stop after first value is set: False
In backward chaining, skip redundant rules: False
Use backward chaining to derive value: True
Use External Source to get value: False
Only a single value can be assigned

Display:
Ask with: Radio Buttons
Arrange: One item per line

[AFx_1]

Confidence Variable
Prompt: Disposition AFx
Calculation Mode: Sum

Flags:
Always obtain a value: False
Display with results: False
Never Ask User: False
Display with results: False
Initialize: False
Check for PARAM data passed in Applet call: False
In backward chaining, stop after first value is set: False
In backward chaining, skip redundant rules: False
Use backward chaining to derive value: True
Use External Source to get value: False

Display:
Ask with: Edit Box
Arrange: One item per line

[AFx_2]

Confidence Variable
Prompt: Disposition AFx
Calculation Mode: Sum

Flags:
Always obtain a value: False
Display with results: False
Never Ask User: False
Display with results: False
Initialize: False
Check for PARAM data passed in Applet call: False
In backward chaining, stop after first value is set: False
In backward chaining, skip redundant rules: False
Use backward chaining to derive value: True
Use External Source to get value: False

[Graphic_has_9_Turns]

Static List Variable
Prompt: Graphic has 9 Turns?
Static List Values:

Yes_graphic_has_9_turns
Yes, graphic has 9 turns

No_graphic_does_not_have_9_turns
No, graphic does not have 9 turns

Flags:

Always obtain a value: False
Display with results: False
Never Ask User: False
Display with results: False
Initialize: False
Check for PARAM data passed in Applet call: False
In backward chaining, stop after first value is set: False
In backward chaining, skip redundant rules: False
Use backward chaining to derive value: True
Use External Source to get value: False
Only a single value can be assigned

Display:

Ask with: Radio Buttons
Arrange: One item per line

[Head_spin_down]

Static List Variable
Prompt: Any Head spin down?
Static List Values:

Yes_head_spin_down
Yes, head spin down

No_any_head_spin_down
No, any head spin down

Flags:

Always obtain a value: False
Display with results: False
Never Ask User: False
Display with results: False
Initialize: False
Check for PARAM data passed in Applet call: False
In backward chaining, stop after first value is set: False
In backward chaining, skip redundant rules: False
Use backward chaining to derive value: True
Use External Source to get value: False
Only a single value can be assigned

Display:

Ask with: Radio Buttons
Arrange: One item per line

[Log_on_disk]

Static List Variable
Prompt: On Log Disk?
Static List Values:

Yes_there_is_On_log_Disk
Yes, there is On log Disk.

No_There_is_not_On_Log_Disk
No, There is not On Log Disk

Never Ask User: False
Display with results: False
Initialize: False
Check for PARAM data passed in Applet call: False
In backward chaining, stop after first value is set: False
In backward chaining, skip redundant rules: False
Use backward chaining to derive value: True
Use External Source to get value: False
Only a single value can be assigned

Display:
Ask with: Radio Buttons
Arrange: One item per line

[LPR]
Confidence Variable
Prompt: Disposition LPR
Calculation Mode: Sum

Flags:
Always obtain a value: False
Display with results: False
Never Ask User: False
Display with results: False
Initialize: False
Check for PARAM data passed in Applet call: False
In backward chaining, stop after first value is set: False
In backward chaining, skip redundant rules: False
Use backward chaining to derive value: True
Use External Source to get value: False

Display:
Ask with: Edit Box
Arrange: One item per line

[MTR_2]
Confidence Variable
Prompt: Disposition MTR
Calculation Mode: Sum

Flags:
Always obtain a value: False
Display with results: False
Never Ask User: False
Display with results: False
Initialize: False
Check for PARAM data passed in Applet call: False
In backward chaining, stop after first value is set: False
In backward chaining, skip redundant rules: False
Use backward chaining to derive value: True
Use External Source to get value: False

Display:
Ask with: Edit Box
Arrange: One item per line

[MTR_3]

Confidence Variable
Prompt: Disposition MTR
Calculation Mode: Sum

Flags:

- Always obtain a value: False
- Display with results: False
- Never Ask User: False
- Display with results: False
- Initialize: False
- Check for PARAM data passed in Applet call: False
- In backward chaining, stop after first value is set: False
- In backward chaining, skip redundant rules: False
- Use backward chaining to derive value: True
- Use External Source to get value: False

Display:

- Ask with: Edit Box
- Arrange: One item per line

[MTR_4]

Confidence Variable
Prompt: Disposition MTR
Calculation Mode: Sum

Flags:

- Always obtain a value: False
- Display with results: False
- Never Ask User: False
- Display with results: False
- Initialize: False
- Check for PARAM data passed in Applet call: False
- In backward chaining, stop after first value is set: False
- In backward chaining, skip redundant rules: False
- Use backward chaining to derive value: True
- Use External Source to get value: False

Display:

- Ask with: Edit Box
- Arrange: One item per line

[MTR_5]

Confidence Variable
Prompt: Disposition MTR
Calculation Mode: Sum

Flags:

- Always obtain a value: False
- Display with results: False
- Never Ask User: False
- Display with results: False
- Initialize: False
- Check for PARAM data passed in Applet call: False
- In backward chaining, stop after first value is set: False
- In backward chaining, skip redundant rules: False
- Use backward chaining to derive value: True
- Use External Source to get value: False

Display:

- Ask with: Edit Box
- Arrange: One item per line

[MTR1]

Confidence Variable
Prompt: Disposition MTR
Calculation Mode: Sum

Flags:
- Always obtain a value: False
- Display with results: False
- Never Ask User: False
- Display with results: False
- Initialize: False
- Check for PARAM data passed in Applet call: False
- In backward chaining, stop after first value is set: False
- In backward chaining, skip redundant rules: False
- Use backward chaining to derive value: True
- Use External Source to get value: False

Display:
- Ask with: Edit Box
- Arrange: One item per line

[ot]

Static List Variable
Prompt: Lot of ot in all heads OD, MD, ID?
Static List Values:

Yes_lot_of_ot_in_all_heads
Yes, lot of ot in all heads

No_few_or_non_ot_in_all_heads
No, few or non ot in all heads

Flags:
- Always obtain a value: False
- Display with results: False
- Never Ask User: False
- Display with results: False
- Initialize: False
- Check for PARAM data passed in Applet call: False
- In backward chaining, stop after first value is set: False
- In backward chaining, skip redundant rules: False
- Use backward chaining to derive value: True
- Use External Source to get value: False
- Only a single value can be assigned

Display:
- Ask with: Radio Buttons
- Arrange: One item per line

[RSTW]

Confidence Variable
Prompt: Disposition RSTW
Calculation Mode: Sum

Flags:
- Always obtain a value: False
- Display with results: False
- Never Ask User: False
- Display with results: False
- Initialize: False
- Check for PARAM data passed in Applet call: False
- In backward chaining, stop after first value is set: False
- In backward chaining, skip redundant rules: False
- Use backward chaining to derive value: True
- Use External Source to get value: False

Logic Block: 0901080 Logic Block

1 Log_on_disk = Yes_there_is_On_log_Disk
2 2_or_3_turns = Yes_it_shows_2_to_3_tuens
3 --> [MTR1] = .5
4 2_or_3_turns = No_it_does_not_show_2_or_3_turns
5 Graphic_has_9_Turns = Yes_graphic_has_9_turns
6 --> [MTR_2] = 0.5
7 Graphic_has_9_Turns = No_graphic_does_not_have_9_turns
8 ot = Yes_lot_of_ot_in_all_heads
9 --> [MTR_3] = 0.8
10 ot = No_few_or_non_ot_in_all_heads
11 1st_time_failure = yes_first_time_fail
12 --> [MTR_4] = 0.7
13 1st_time_failure = No_drive_has_failed_before
14 Any_xxxx_before = Yes
15 --> [MTR_5] = 0.7
16 Any_xxxx_before = No
17 Head_spin_down = Yes_head_spin_down
18 --> [AFx_1] = 1.0
19 Head_spin_down = No_any_head_spin_down
20 7ffff = Yes_7ffff_value_was_founf_in_some_head
21 --> [AFx_2] = 1.0
22 7ffff = No_any_7ffff_value_was_found_in_a_single_head
23 --> [RSTW] = 0.75

[illegible]
AND [illegible]
AND [illegible]
AND [illegible]
AND [illegible]

24 **Any_xxxx_before = Drive_has_more_than_6_reworks**

25 --> [LPR] = 1.0

26 **Log_on_disk = No_There_is_not_On_Log_Disk**

Log_on_disk = No_There_is_not_On_Log_Disk

27 **Any_xxxx_before = Yes**

28 **--> [MTR_5] = 0.75**

29 **Any_xxxx_before = No**

Log_on_disk = No_There_is_not_On_Log_Disk
AND Any_xxxx_before = No

30 **Head_spin_down = Yes_head_spin_down**

31 **--> [AFx_1] = 1.00**

32 **Head_spin_down = No_any_head_spin_down**

Log_on_disk = No_There_is_not_On_Log_Disk
AND Any_xxxx_before = No
AND Head_spin_down = No_any_head_spin_down

33 **7ffff = Yes_7ffff_value_was_founf_in_some_head**

34 **--> [AFx_2] = 1.00**

Log_on_disk = No_There_is_not_On_Log_Disk
AND Any_xxxx_before = No
AND Head_spin_down = No_any_head_spin_down

35 **7ffff = No_any_7ffff_value_was_found_in_a_single_head**

36 **--> [RSTW] = 0.75**

Log_on_disk = No_There_is_not_On_Log_Disk

37 **Any_xxxx_before = Drive_has_more_than_6_reworks**

38 **--> [LPR] = 1.00**

Rules:

Block: 0901080 Logic Block Row:3

IF:

On Log Disk? Yes, there is On log Disk.
AND: Graphic shows 2 or 3 turns? Yes, it shows 2 to 3 tuens

THEN:

Disposition MTR: Confidence = .5

Block: 0901080 Logic Block Row:6

IF:

On Log Disk? Yes, there is On log Disk.
AND: Graphic shows 2 or 3 turns? No, it does not show 2 or 3 turns
AND: Graphic has 9 Turns? Yes, graphic has 9 turns

THEN:

Disposition MTR: Confidence = 0.5

Block: 0901080 Logic Block Row:9

IF:

On Log Disk? Yes, there is On log Disk.
AND: Graphic shows 2 or 3 turns? No, it does not show 2 or 3 turns
AND: Graphic has 9 Turns? No, graphic does not have 9 turns
AND: Lot of ot in all heads OD, MD, ID? Yes, lot of ot in all heads

THEN:

Disposition MTR: Confidence = 0.8

Block: 0901080 Logic Block Row:12

IF:

On Log Disk? Yes, there is On log Disk.
AND: Graphic shows 2 or 3 turns? No, it does not show 2 or 3 turns
AND: Graphic has 9 Turns? No, graphic does not have 9 turns
AND: Lot of ot in all heads OD, MD, ID? No, few or non ot in all heads
AND: 1st time fail? yes, first time fail

THEN:

Disposition MTR: Confidence = 0.7

Block: 0901080 Logic Block Row:15

IF:

On Log Disk? Yes, there is On log Disk.
AND: Graphic shows 2 or 3 turns? No, it does not show 2 or 3 turns
AND: Graphic has 9 Turns? No, graphic does not have 9 turns
AND: Lot of ot in all heads OD, MD, ID? No, few or non ot in all heads
AND: 1st time fail? No, drive has failed before
AND: Any 08xxxx, 09xxxx, or 08xxxx before? yes

THEN:

Disposition MTR: Confidence = 0.7

Block: 0901080 Logic Block Row:18

IF:

On Log Disk? Yes, there is On log Disk.
AND: Graphic shows 2 or 3 turns? No, it does not show 2 or 3 turns
AND: Graphic has 9 Turns? No, graphic does not have 9 turns
AND: Lot of ot in all heads OD, MD, ID? No, few or non ot in all heads
AND: 1st time fail? No, drive has failed before
AND: Any 08xxxx, 09xxxx, or 0Bxxxx before? No
AND: Any Head spin down? Yes, head spin down

THEN:

Disposition AFx: Confidence = 1.0

Block: 0901080 Logic Block Row:21

IF:

On Log Disk? Yes, there is On log Disk.
AND: Graphic shows 2 or 3 turns? No, it does not show 2 or 3 turns
AND: Graphic has 9 Turns? No, graphic does not have 9 turns
AND: Lot of ot in all heads OD, MD, ID? No, few or non ot in all heads
AND: 1st time fail? No, drive has failed before
AND: Any 08xxxx, 09xxxx, or 0Bxxxx before? No
AND: Any Head spin down? No, any head spin down
AND: Value =7ffff in a single head? Yes, 7ffff value was founf in some head

THEN:

Disposition AFx: Confidence = 1.0

Block: 0901080 Logic Block Row:23

IF:

On Log Disk? Yes, there is On log Disk.
AND: Graphic shows 2 or 3 turns? No, it does not show 2 or 3 turns
AND: Graphic has 9 Turns? No, graphic does not have 9 turns
AND: Lot of ot in all heads OD, MD, ID? No, few or non ot in all heads
AND: 1st time fail? No, drive has failed before
AND: Any 08xxxx, 09xxxx, or 0Bxxxx before? No
AND: Any Head spin down? No, any head spin down
AND: Value =7ffff in a single head? No, any 7ffff value was found in a single head

THEN:

Disposition RSTW: Confidence = 0.75

Block: 0901080 Logic Block Row:25

IF:

On Log Disk? Yes, there is On log Disk.
AND: Graphic shows 2 or 3 turns? No, it does not show 2 or 3 turns
AND: Graphic has 9 Turns? No, graphic does not have 9 turns
AND: Lot of ot in all heads OD, MD, ID? No, few or non ot in all heads
AND: 1st time fail? No, drive has failed before
AND: Any 08xxxx, 09xxxx, or 0Bxxxx before? Drive has more than 5 reworks

THEN:

Disposition LPR: Confidence = 1.0

Block: 0901080 Logic Block Row:28

IF:

On Log Disk? No, There is not On Log Disk
AND: Any 08xxxx, 09xxxx, or 0Bxxxx before? yes

THEN:

Disposition MTR: Confidence = 0.75

Block: 0901080 Logic Block Row:31

IF:

On Log Disk? No, There is not On Log Disk
AND: Any 08xxxx, 09xxxx, or 0Bxxxx before? No
AND: Any Head spin down? Yes, head spin down

THEN:

Disposition AFx: Confidence = 1.00

Block: 0901080 Logic Block Row:34

IF:

On Log Disk? No, There is not On Log Disk
AND: Any 08xxxx, 09xxxx, or 0Bxxxx before? No
AND: Any Head spin down? No, any head spin down
AND: Value =7ffff in a single head? Yes, 7ffff value was founf in some head

THEN:

Disposition AFx: Confidence = 1.00

Block: 0901080 Logic Block Row:36

IF:

On Log Disk? No, There is not On Log Disk
AND: Any 08xxxx, 09xxxx, or 0Bxxxx before? No
AND: Any Head spin down? No, any head spin down
AND: Value =7ffff in a single head? No, any 7ffff value was found in a single head

THEN:

Disposition RSTW: Confidence = 0.75

Block: 0901080 Logic Block Row:38

IF:

On Log Disk? No, There is not On Log Disk
AND: Any 08xxxx, 09xxxx, or 0Bxxxx before? Drive has more than 5 reworks

THEN:

Disposition LPR: Confidence = 1.00

APPENDIX B

Page 1

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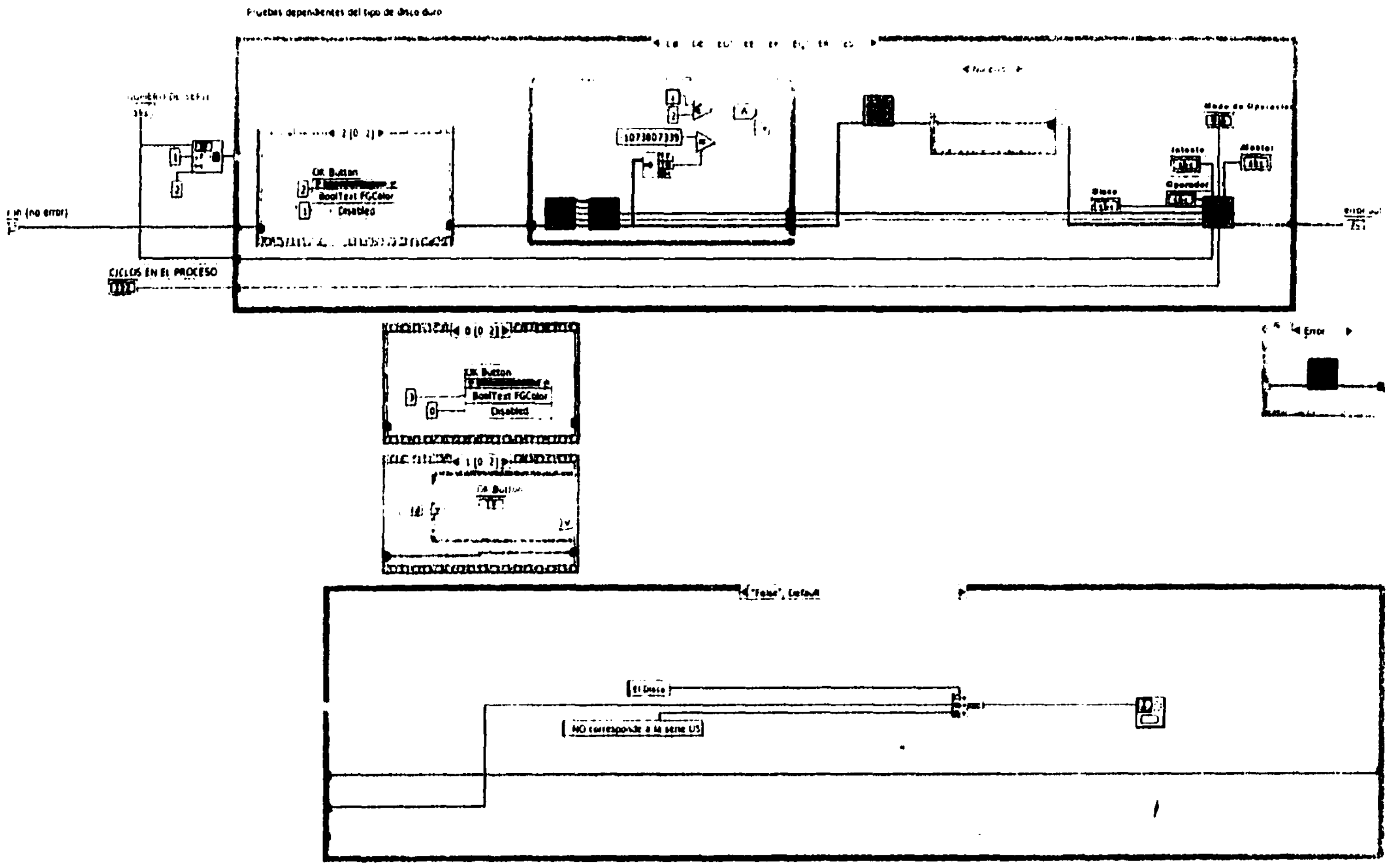

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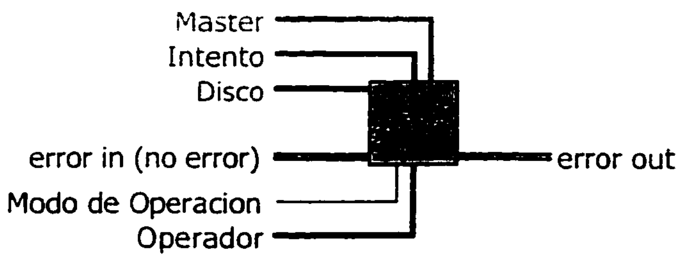

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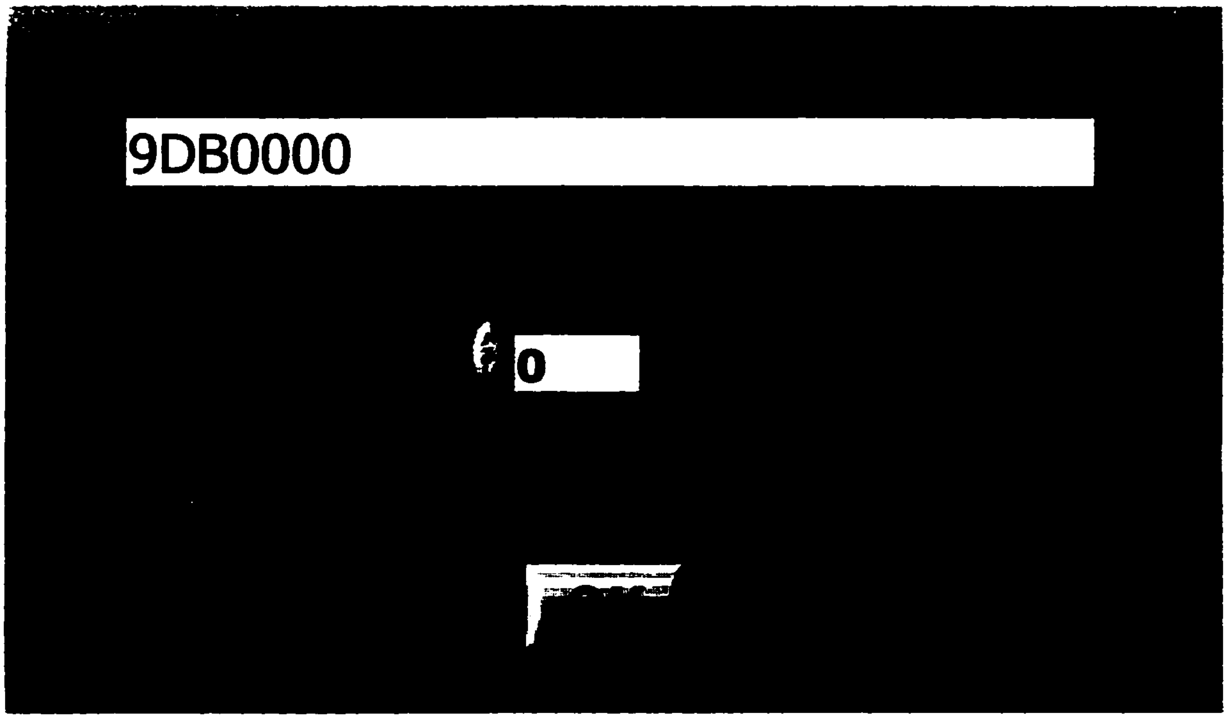

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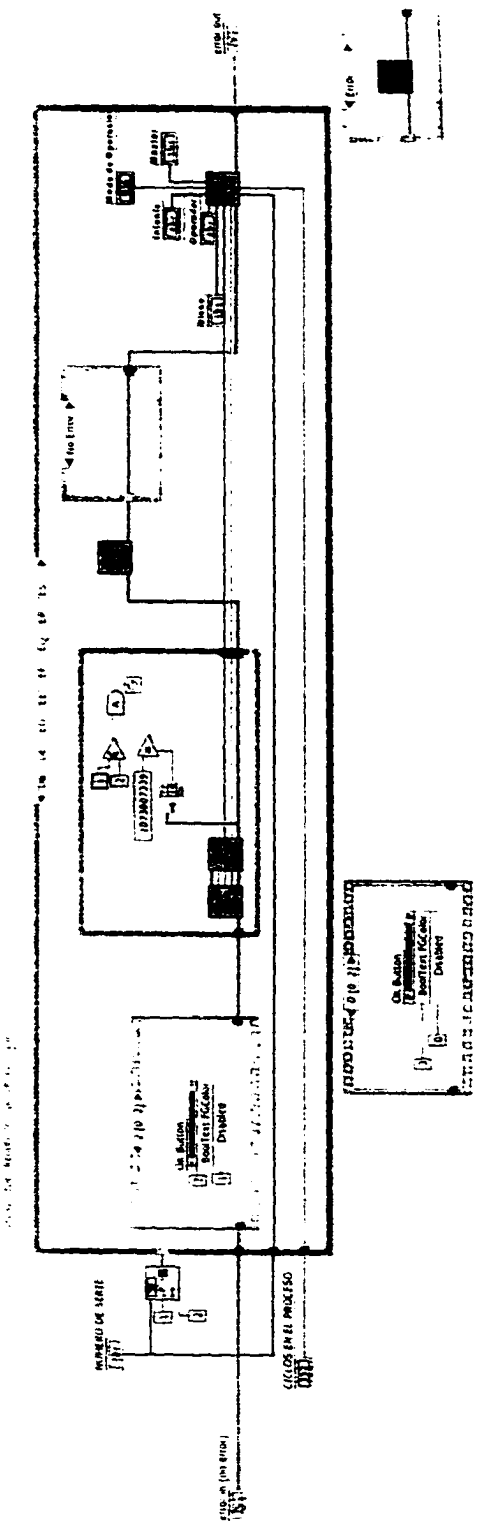

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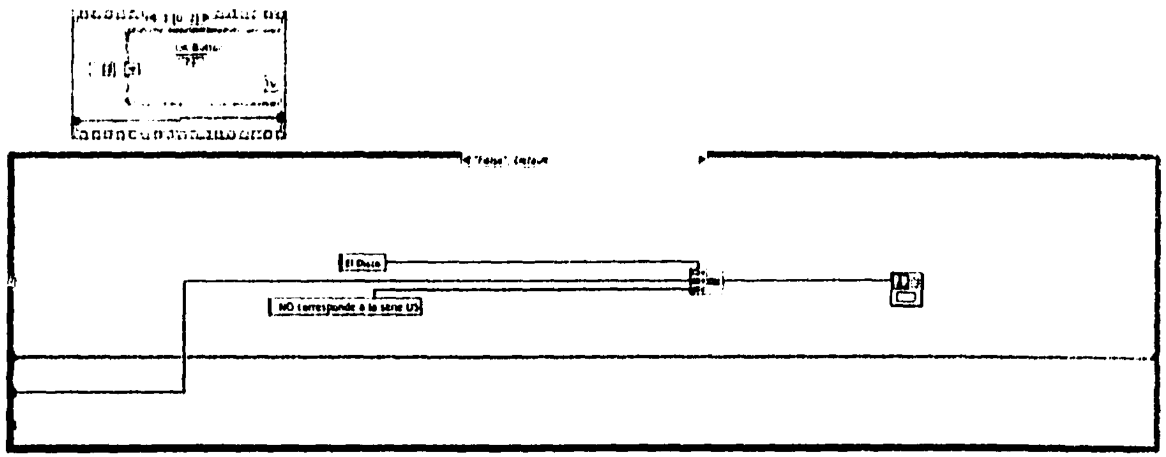

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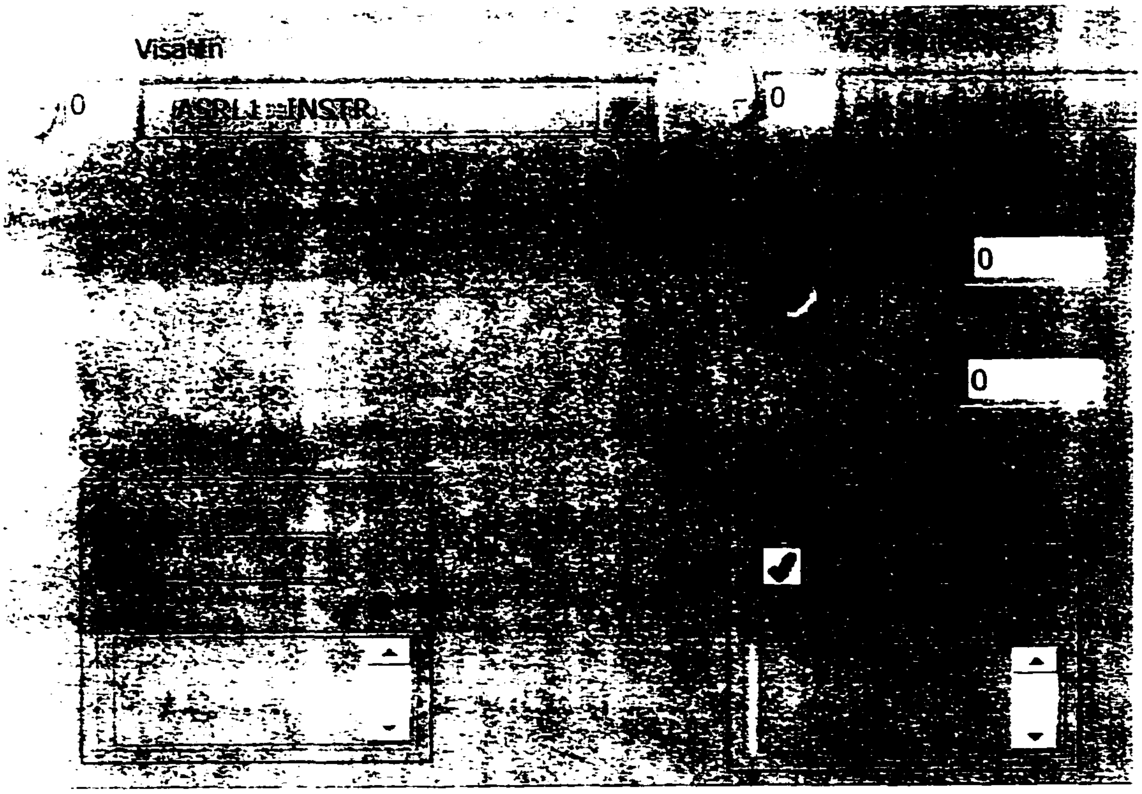

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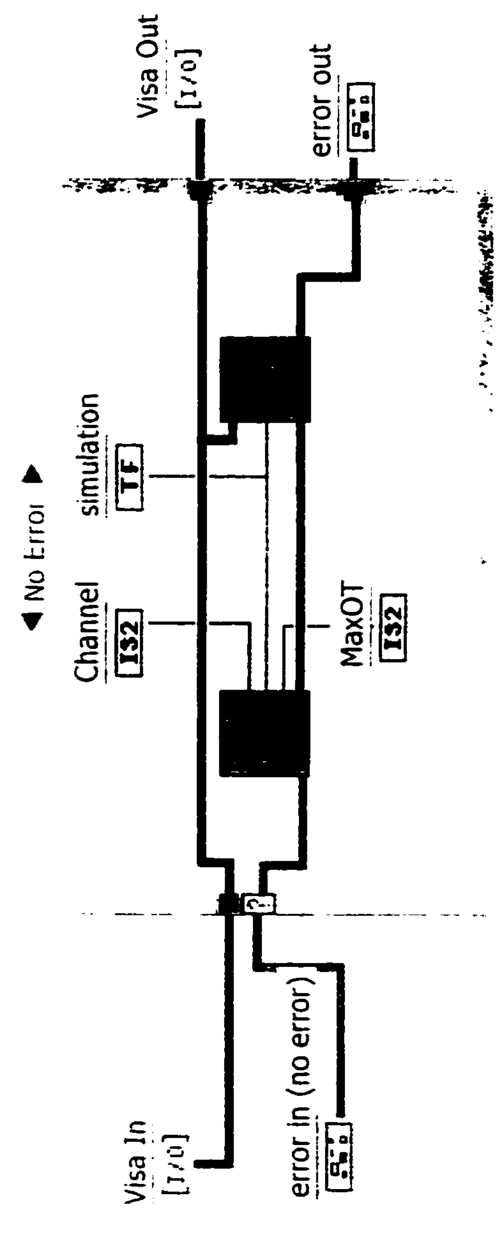

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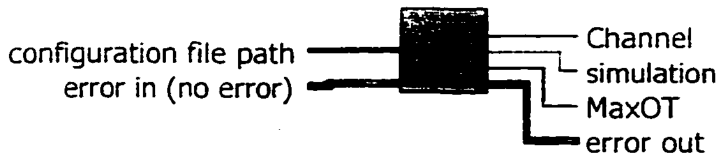

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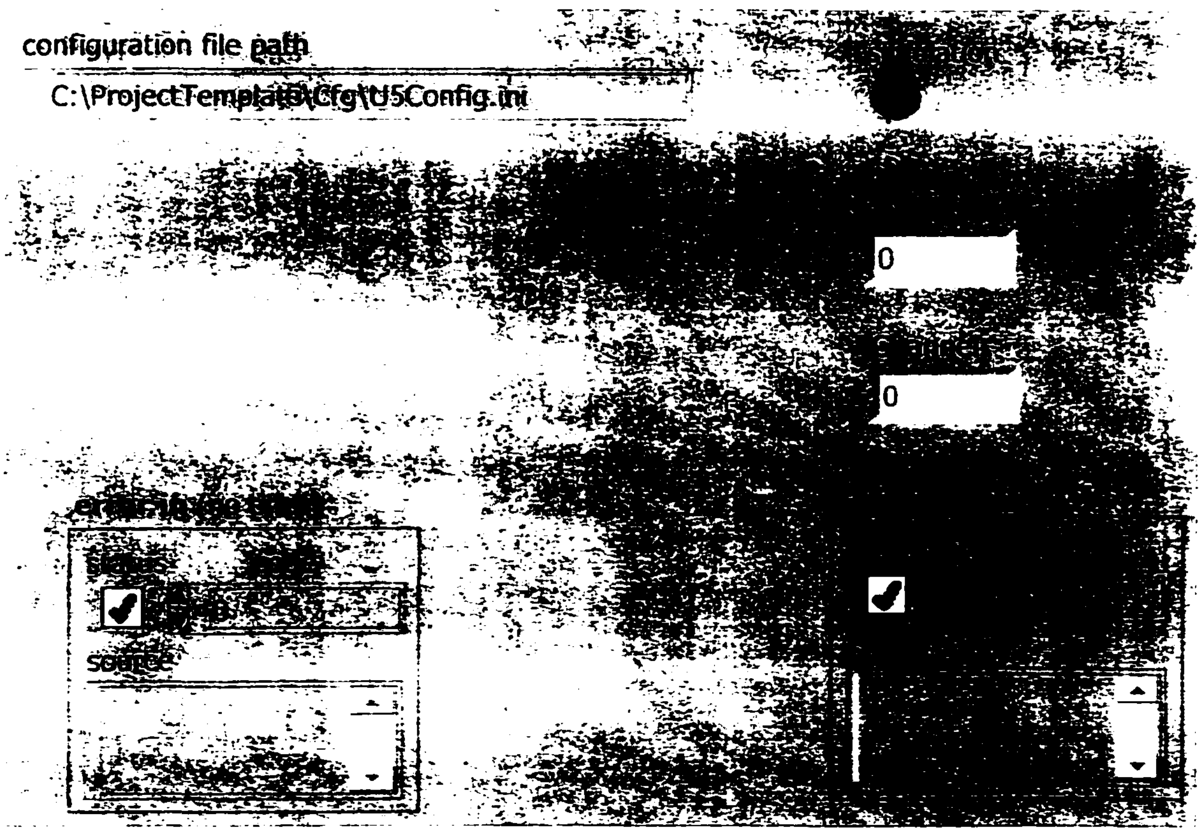

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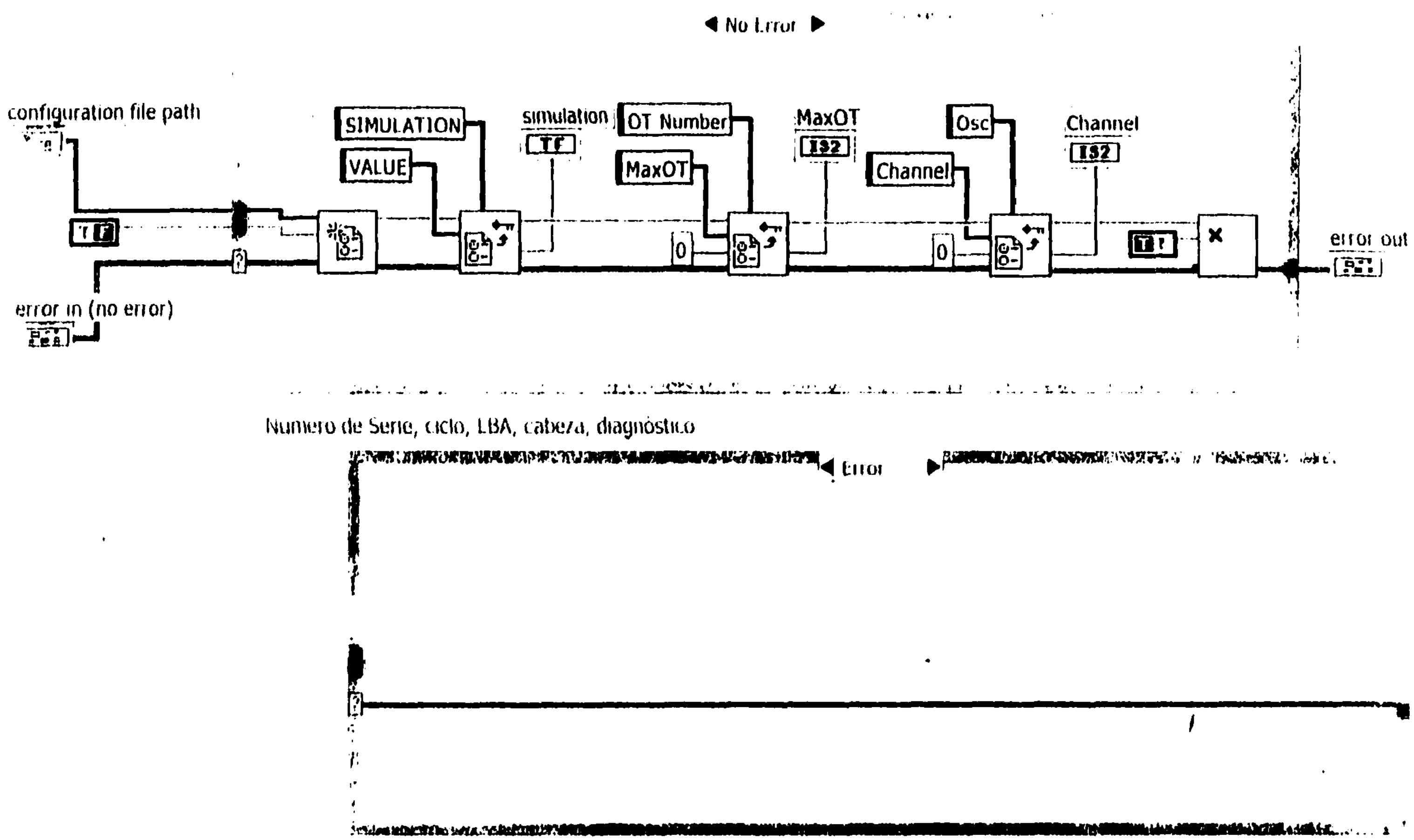

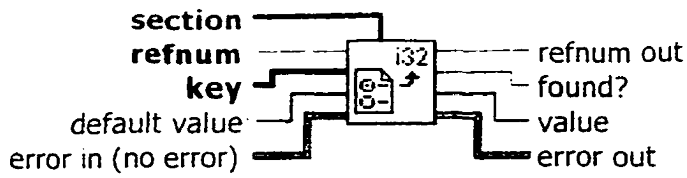

I32

Reads a value associated with a key in a specified section from the configuration data key does not exist, the VI returns the default value.

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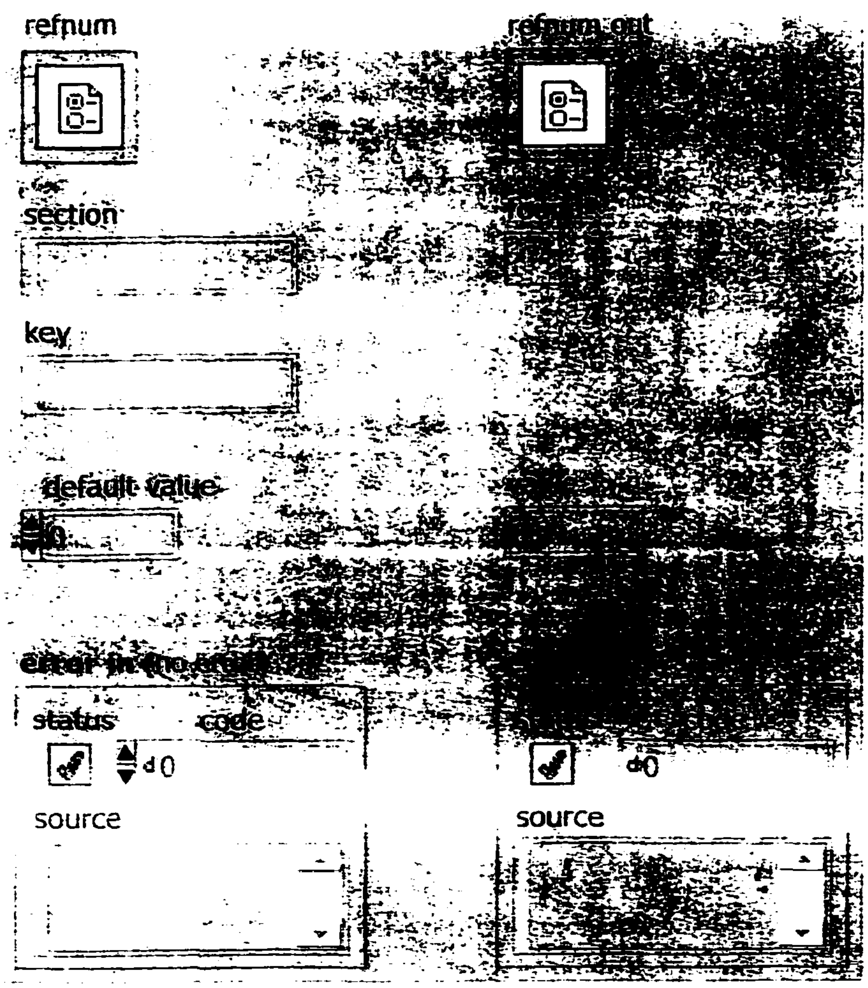
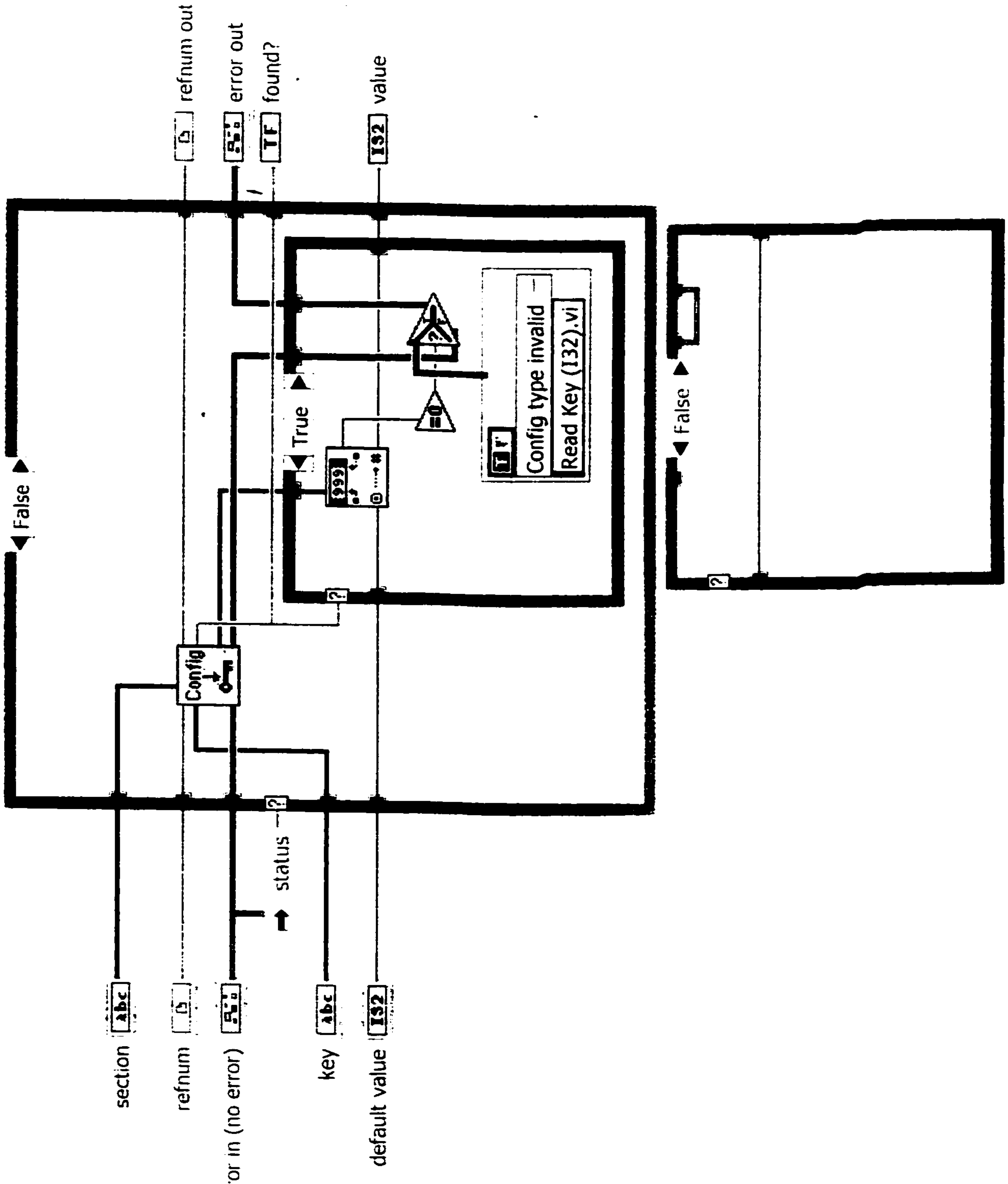
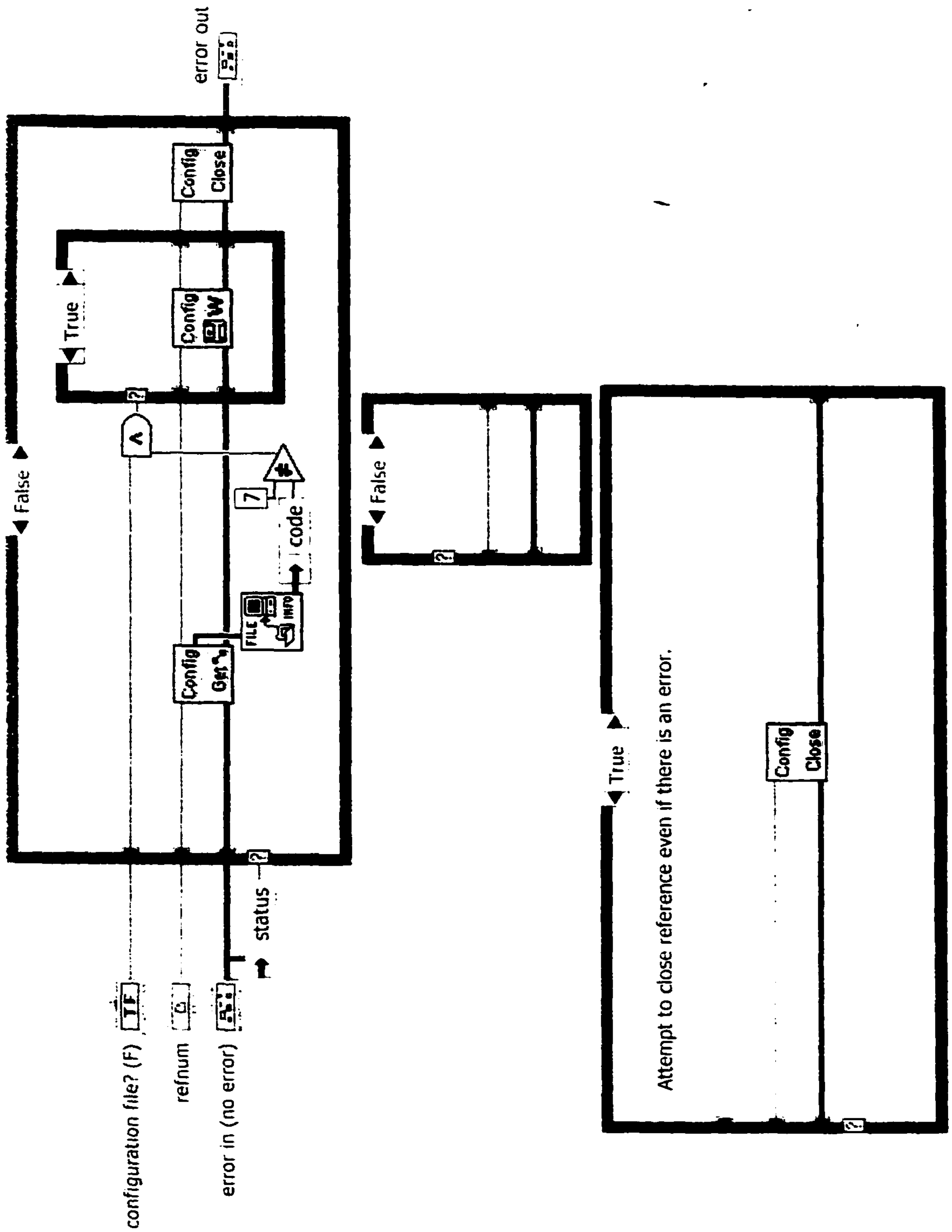



section
refnum
ror in (no error)
key
default value
status
refnum out
error out
found?
value
False
True
False
Config
999
Config type invalid
Read Key (I32).vi
abc
I32
TF



error out
False
True
Config Close
Config W
Config Get
FILE INFO
code
7
status
configuration file? (F)
refnum
error in (no error)
False
True
Attempt to close reference even if there is an error.
Config Close