NOTICE

The quality of this microform is heavily dependent upon the quality of the original thesis submitted for microfilming. Every effort has been made to ensure the highest quality of reproduction possible.

If pages are missing, contact the university which granted the degree.

Some pages may have indistinct print especially if the original pages were typed with a poor typewriter ribbon or if the university sent us an inferior photocopy.

AVIS

La qualité de cette microforme dépend grandement de la qualité de la thèse soumise au microfilmage. Nous avons tout fait pour assurer une qualité supérieure de reproduction.

S'il manque des pages, veuillez communiquer avec l'université qui a conféré le grade.

La qualité d'impression de certaines pages peut laisser à désirer, surtout si les pages originales ont été dactylographiées à l'aide d'un ruban usé ou si l'université nous a fait parvenir une photocopie de qualité inférieure.

Canada

THE ART OF LOGICAL TROUBLE-SHOOTING

by

Chaudhry Mohammad Saleem

B.Sc. in Engineering (Electrical), University of Punjab, 1961

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS

FOR THE DEGREE OF

MASTER OF SCIENCE (EDUCATION)

in the Faculty

of

Education

Simon Fraser University

November 1990

ISBN 0-315-69498-X

APPROVAL

Name: Chaudhry Mohammad Saleem

Degree: Master of Science (Education)

Title of Thesis: The Art of Logical Trouble-shooting.

Examining Committee:

Chair: Robin Barrow

A.J. (Sandy) Dawson
Senior Supervisor

Marvin F. Wideen
Professor

Dr. Lucio F. Teles
Faculty Research Associate
Faculty of Education
Simon Fraser University
External Examiner

Date Approved Dec. 11, 1990

PARTIAL COPYRIGHT LICENSE

Title of Thesis/Project/Extended Essay

The Art of Logical Trouble-shooting.

Author: ______________________
(signature)

Chaudhry Mohammad SALEEM
(name)

Dec. 11th, 1990
(date)

ABSTRACT

The question is frequently asked, what makes the difference between the competent, efficient trouble-shooter and the average repair person who spends expensive hours in vain attempts to trouble-shoot a relatively simple defect? Is the successful technician specially gifted? Does s/he have an inborn knack, or is it something that s/he learns and acquires in one's professional life? Such people are quite rare and difficult to find. There is a consensus of opinion that such people have sound knowledge of electronic circuits and the working of the system. They also have the knowledge of test equipment and know test and measurement techniques. What is not clear is how this apparently "inborn" knack of electronic problem-solving is acquired. What do they have which others do not? Do they learn and build it up on their own experience or do they acquire trouble-shooting techniques and strategies by observing others? Can this "knack" be taught in the schools of instruction and if so how should it be taught?

The study used a think-out-loud protocol to collect data on the thinking and reasoning process of two electronic trouble-shooters: a novice and an expert. Subjects were told to speak out loudly whatever came to their mind during the trouble-shooting process. Subjects were not to reflectively penetrate nor transparently present their thinking.

The study explored the cognitive and meta-cognitive strategies used by the two trouble-shooters. Their diagnostic reasoning was investigated and the data coded into thought processes like testing, observing, analyzing and hypothesis generation. This explication of diagnostic cognition suggested that both subjects behaved similarly in the form of diagnostic reasoning. The trouble-shooter started by testing a fault symptom or

checking out a hypothesis and continued on to observe and analyze the test results. This resulted in generation of another hypothesis or a further study of the circuit to start another test. This procedure was cyclic in nature and was repeated time and again.

The substance of diagnostic reasoning employed by the two trouble-shooters was, however, quite different. Location of the normal and abnormal brackets was different, and the use of the search strategies within the problem space was inadequate in the case of the novice trouble-shooter. The novice lacked use of adequate search control strategy and failed to identify the correct problem space.

TABLE OF CONTENTS

APPENDICES

CHAPTER I

Nature and Scope of the Study

Introduction

The study of problem solving and finding differences in expert-novice behaviour have been of interest to cognitive and computer scientists, psychologists, and educators alike. The difficulty has been that most of the potent and interesting problems in these domains do not have tractable algorithmic solutions. Moreover, the validation of reasoning processes becomes a gigantic undertaking.

Diagnostic problems usually resist precise description and rigorous analysis. Also, expert diagnosticians, often, are not able to explain why they are experts in their own field. In effect, experts "know more than they can say" or articulate, (Nisbett & Wilson-1977) The domain of electronic trouble-shooting, like that of chess playing and medical diagnosis, may be investigated to understand problem-solving. At least the validation should be easier, as the electronic system can function correctly only after the bug has been removed and the system performs appropriately.

The complex nature of today's space-age commercial and defence electronic systems and equipment require highly skilled maintenance engineers and technicians. Such people have sound knowledge of electronic circuitry and understand the working of the system. They also have the knowledge of test equipment and know test and measurement techniques. The problem is that we do not know how they acquire the "knack" of electronic problem solving and a systematic, logical approach to the determination and correction of any flaws in the operation of the equipment. What do the expert diagnosticians have which others do not? Do they learn and build it up on their own job experiences or do they acquire trouble-shooting techniques and strategies by observing others? Can this "knack" be taught in the schools of instruction and if so how should it be taught?

Objective

The general aim of the thesis was to explore and seek to understand the fault finding process used by expert and novice trouble-shooters. Think-Out-Loud (TOL) techniques were used. Expert and novice trouble-shooters were asked to TOL as they trouble-shot and their thoughts were tape-recorded, transcribed, and analyzed. The TOL process made the subject's own thinking more visible to themselves, as well as to others. Their difficulties were elicited and carefully analyzed to find any useful clues in solving electronic problems.

The task was interesting, as well as potent first because the electronic devices and the circuit to be diagnosed were fairly complex, and second because there was no well developed theory of electronic fault-finding. The study was an attempt to explore the nature of reasoning underlying the diagnostic process and find out what the expert and novice trouble-shooters have in common and how they differ.

Nature of the Problem

The ability to systematically analyze circuits, locate faults and repair them efficiently is the basic skill required by electronic technologists and technicians. Also the economy and life style in a developed country depend on keeping the technological gadgets like computer systems, industrial control equipment, communication systems and the like in good working condition all the time. Trouble-shooting and repair is thus an important task which becomes more exacting as the systems become more complex.

The role of trouble-shooting also becomes more important in the modern recycling society. We are presently accustomed to a largely linear way of using resources. We process raw materials into devices that have planned obsolescence to encourage us to discard them quickly and purchase new products. No wonder our garbage dumps are becoming monumental. Things have to change and we have to change. We must operate in a recycling mode. The point at which a product is discarded must advance and the item must be repaired many more times than is the current practice. This useful economic life should only end when the cost of repair and maintenance becomes prohibitive, or the cost of continued use is greater than the cost of replacement after all factors are considered.

Although the current machines boast of self-diagnosing and self-repairing capabilities, humans have to fix the problems which machines are unable to do by themselves. Only a thorough knowledge of the system to be maintained and considerable experience in the use of trouble-shooting techniques can equip a person to become an expert trouble-shooter. The colleges and universities provide the domain related declarative type of knowledge, but individuals are left on their own to acquire the trouble-shooting experience on the job throughout their working life. How can we impart this knowledge to the students earlier on so that these novice trouble-shooters can become expert trouble-shooters at an early date? What does it take to learn the art of logical problem solving by the trouble-shooters? In order to be able to design a suitable curriculum and a hands-on training program, we must know the differences between the novice and expert trouble-shooters. Textbooks rarely discuss trouble-shooting techniques or strategies. Training institutions assume that the translation of theoretical knowledge would be further confirmed by laboratory work. The student builds a circuit, takes measurements and makes observations, acquires data and then compares the data with the theoretical predictions. Seldom does a student trouble-shoot a non-working circuit which someone else has built after s/he has learnt a great deal of theory. Worst of all, seldom s/he is taught the electronic problem solving strategies for trouble-shooting of electronic equipment.

Trouble-shooting is much like assembling the pieces of a jigsaw puzzle. Different pieces of knowledge acquired previously are put together until suddenly the entire thing falls into place. The knowledge of the defective equipment, the knowledge about the effective use of the test equipment, and the knowledge of schematic drawings and specifications is important but not enough. The techniques of problem solving are also essential to solve the jigsaw puzzle. Unfortunately this problem solving expertise is not easily acquired. Determining the symptoms, localizing the trouble to a functional unit, techniques of isolating and eventually locating the specific trouble comprise and constitute the art of logical trouble-shooting.

Problem Spaces and Problems

The analysis of a cognitive task involves initially specifying the problem space and then specifying the search control knowledge used within that problem space. The problem spaces, which some electronic trouble-shooters call normal and abnormal brackets enclosing the fault area, are developed and narrowed down by them when they engage in goal oriented activity. To understand such activity is to discover what problem space a trouble-shooter is using. For a general problem solving environment, a problem space and a problem can be defined as below:

Problem Space: A problem space consists of a set of symbolic structures (the states of the space) and a set of operators over the space. Each operator takes a state as input and produces a state as output. Sequences of operators define paths that thread their way through sequences of states.

Problem: A problem in a problem space consists of a set of initial states, a set of goal states, and a set of path constraints. The problem is to find a path through the space that starts at any initial state, passes only along paths that satisfy the path constraints, and ends at any goal state.

Let us now look at the problem space or fault bracketing in the domain of electronic trouble-shooting. All symptoms of the trouble are noted and all indicators or output devices in the faulty system are observed closely. A thorough visual inspection will reveal the malfunction often enough to be worthwhile. If a radio set has a problem, then the sound coming from the loud speaker is listened to carefully. Is the sound normal, distorted, low in volume? Does it have hum or is there no sound at all? Are there signs of heat and damage? The abnormal signal paths or data flow is carefully identified in the circuit diagram. The data flow or signal paths could be linear, divergent, convergent, switching, feed back or mixed paths. Each of these paths shall dictate their own type of bracketing techniques and search control within those brackets.

The indicators at the output where the signals are abnormal, form the abnormal brackets of the problem space. The indicators, if any, where the signals are normal establish the normal brackets of the problem space. Once these brackets have been established, then the test points for search control depend upon the signal or data flow path within the brackets. Also the type of checks made depends upon the trouble possibilities covered. The check information is then interpreted for the search control strategy adopted and the brackets are repositioned to reduce the problem space. If the current check was abnormal, the previously abnormal bracket is moved up to this point. Similar repositioning is done for the normal brackets. The checking and bracketing sequence is repeated as necessary. This is a continuing process that produces an ever narrowing series of brackets until the problem space brackets are around just one stage at the blocks level or around just one component at the component level of repair.

Nature of Electronic Trouble-Shooting

Trouble-shooting techniques aim at an efficient method to locate a particular defect or error, or a malfunction in electronic equipment. It is possible to find defects by a meticulous search and analysis of the performance of the equipment. It is also often possible to find defects by testing every component. Still another method concerns itself with the input and output of each functional block or by substitution of these blocks or components. Which method to use will depend largely on what type of defect we are trying to locate and what type of search control strategy we want to employ in that particular problem space. In electronic trouble-shooting the major cost is in locating the fault. The cost of the replacement of the part is minimal and does not depend on how much time was spent on finding the fault.

The process of identifying malfunctions is primarily one of using logical mental processes. Comprehension, understanding, logical reasoning, and other cognitive processes play an important part in the diagnostic process. Hence the art of logical trouble shooting becomes an important task to be analyzed. The ability to solve a particular problem depends upon using the right technique. The problem very often, however, is to decide which technique will be the best to trouble-shoot the defect. That is where the art plays its role and is acquired with experience. The novices can be told about the most frequent troubles in electronic equipment and advised which technique works best with a particular class of defects. However, the expertise in electronic trouble-shooting is another matter.

In difficult cases it may be necessary to use several techniques. Initially, a symptom-function technique can be used to define the problem space. Once the appropriate normal and abnormal brackets have been placed around the problem space, the usual techniques of half split rules for linear, divergent, convergent, feedback and mixed circuits can be applied to split and gradually reduce the problem space. Signal tracing and injection methods help to test parts of the circuits with appropriate test equipment. In some cases, the method of substitution helps to isolate the problem and thereby reduce the problem space. However, the problems like poor solder connection, broken wires, partial short circuits, open and short points within the printed circuit board, wrong component connections and values may defy trouble-shooting techniques. Also we have to decide whether the defect is intermittent or is so elusive that we cannot find it. In many such cases, it may be prudent to just leave that problem and tackle it later.

Regardless of how absurd and impossible a problem seems, every defect can be located. It is said that the experts will usually back off, think, relax, and think again until they can "crack" the problem. How would the novices behave under similar circumstances? Would they just leave and admit failure? The analysis of such processes in real time is one of the most difficult tasks. The events we wish to examine are internal to mind with only some observable behaviours and attitudes. It is believed that electronic trouble-shooting has many affinities with problem solving and, therefore, literature is reviewed in the next chapter on human problem solving. The concept of the problem space as a fundamental category of human goal oriented cognition is also reviewed before looking at the literature on electronic trouble-shooting.

CHAPTER II

Review of Literature

Types of Problem

Electronic problems are of two types, one which concern themselves with designing a new device to solve some difficulty and secondly, to find a solution to an existing malfunction. This study concerns itself with the latter type of a problem, which comprises of the following four steps: (Lenk,1990)

a. Determine the symptoms of failure

b. Localize the trouble to a complete functional unit or module

c. Isolate the trouble to a circuit within the module

d. Locate the specific trouble

In order to understand these steps, let us understand the very basis of problem-solving.

Nature of Problem-Solving

The problems contain information concerning givens, operations and goals, whereas, the solution is a sequence of allowable actions that produces a completely specified goal expression. The general problem-solving method draws inferences from explicitly and implicitly presented information that satisfy one or both of the following criteria:

a. the inferences have frequently been made in the past from the same type of information.

b. the inferences are concerned with properties (variables, terms, expressions and so on) that appear in the goal, the givens, or inferences from the goals and givens.

Wallas (1926) suggests the following stages in general problem-solving :

a. Preparation. Composed of clarifying and defining the problem, along with gathering pertinent information.

b. Incubation. A period of unconscious mental activity assumed to take place while the individual is (perhaps deliberately) doing something else.

c. Inspiration. Suddenly the "Aaha" or "Eureka" feeling is experienced.

In the scientific method, a difficulty is felt; the problem is defined; a search is made; various suggestions appear and are tried out before a solution is accepted. The following ten steps show Osborn's alternations: (Osborn, 1942-43)

a. Think up all phases of the problem.

b. Select the sub-problems to be attacked.

c. Think up what data might help.

d. Select the most likely sources of data.

e. Dream up all possible ideas as key to the problem

f. Select the ideas most likely to lead to the solution.

g. Think up all possible ways to test.

h. Select the soundest ways to test.

i. Imagine all possible contingencies.

j. Decide on the final answer.

Simon (1969), a proponent of the information processing approach to the problem-solving states, " The activity called human problem solving is basically a form of means-end analysis that aims at discovering a process description of the path that leads to a desired goal.....Given a blue-print, find the recipe; given the description of a natural phenomena, find the differential equation for processes that will produce the phenomena..... Problem-solving requires continual translation between the state and process descriptions of the same complex reality.....". We pose a problem by defining the desired goal in terms of the state description. We solve the problem by selecting a process that will produce the desired goal from the initial state. The transition from the initial state through the process to the goal will tell us when we have succeeded. The total process, i.e., the solution, may be entirely new although parts of it may not be new. Therefore, we need not resort to Plato's theory of remembering so that we can recognize a solution. (Plato argues in Meno that problem-solving is remembering because how else could we recognize the answer to a problem if we did not know it).

Approaches in Problem-Solving

There are various approaches to research in human problem-solving:

a. Behaviorist Approach. The behaviorists view problem-solving as a relationship between a stimulus (input) and a response (output) without speculating about the intervening process. Skinner (1957) describes problem-solving in terms of behaviour as a hungry man facing a problem if he cannot emit a response previously reinforced with food. To solve it, he must change either himself or the situation until a response occurs. The behaviour which brings about the change is called problem-solving and the response it promotes, a solution.

b. Information Processing Approach. This is akin to the information processing that accompanies the development of computer programs. Here the emphasis is on the process that intervenes between input and output which leads to a desired goal from an initial state. It is basically a means end analysis that aims at discovering a process description of the path that leads to a desired goal.

c. Trial and Error Approach. The trial and error can be random, systematic or of a classification nature where the sequences of action can be organized into classes that are equivalent (or probably equivalent) with respect to the solution of the problem.

Expertise in Problem-Solving

Research indicates that expert problem-solvers commit fewer errors, can solve problems faster, store related information in closely knit chunk structures. The pause time between retrieving successive information or chunks of information or clues to problem-solving also varies between experts and novices. Larkin (1979) has claimed that a number of physics equations are retrieved by the experts in succession, with very small inter-response intervals, followed by a longer pause. Her novice did not seem to exhibit this pattern of pause times in equation retrieval. McDermott and Larkin (1978) postulate that solution precedes in at least four episodes:

a. Written problem statement.

b. Drawing a sketch of the situation.

c. Qualitative analysis of the problem.

d. Generating the equation.

Larkin (1981) and Simon & Simon (1981) found experts to be four times faster than novices in speed with which they solved a problem. Also they were equally fast in accessing and applying equations during problem-solving. Larkin,(1981) Also Larkin, (1979) suggests that for experts, physics equations are stored in chunks or related configuration so that accessing one principle leads to accessing another principle. Similar results were found in chess playing, where chess pieces were found to be chunked when the inter-piece pause times during recall of a chess position were examined. The qualitative analysis, occurring in the beginning phase of problem-solving, distinguished experts from novice most significantly. (Chi, Glaser, and Rees, 1982) Experts made only one meta-statement per problem whereas the novice made an average of five. (Simon, 1978) These statements were usually observations of errors made, comments on physical meaning of an equation, statements of plans and intentions, self-evolutions and so on. The experts used a working forward strategy whereas the novice used a working backward strategy. (Simon & Simon, 1978) The expert and novices are similar in the "form" of their reasoning but differ in "substance" of content or reasoning. { Chase and Simon (1973) in chess; Elstein, Shulman, & Sprafka (1978) and Johnson et al (1981) in medical problem solving}

Another way to look at problem-solving is to define the problem-space and work with search control strategies in the problem-space to find the solution.

Problems and Problem-Spaces

Human goal oriented cognition deals with reasoning, problem-solving and decision making processes. Substantial research has been done and studies exist in reasoning (Falmagne, 1975, Revlin & Mayer, 1978, Wason & Johnson-Laired, 1972); problem-solving (Greeno, 1977, Newell & Simon,1972); and decision processes (Slovic, Fischoff, & Lichtenstein, 1977). What humans do when they bring to bear what they know to some known end? Newell (1979) suggests an answer in identification of the problem-space and use of search control strategies in finding the solution. This concept is also found in the study of human problem-solving. (Erickson & Jones, 1978; Simon & Lea, 1974) It was originally introduced by Newell & Simon (1972) and is now being used in artificial intelligence where the heuristic search is carried out in problem-spaces. This empirical hypothesis claims that the problem-space is a fundamental category of human goal oriented cognition.

Control over the search is all important and depends on the knowledge that the subject has immediately available. The control processes for strategy selection and decision making involve the application of stored knowledge available in the subject's memory. " A subject can attempt to solve a problem in a problem-space with any body of search control knowledge: from none at all, yielding undirected search; to knowledge that completely specifies all choices correctly, yielding the solution directly." (Newell,

1979) Organizations of sub goals and search control knowledge can coordinate the selection of strategies and actions in various useful ways. The problem-space hypothesis asserts that skilled, routine behavior is organized within the problem-space by the accumulation of search control knowledge.

Review of Research in Electronic Trouble-Shooting

The task of trouble shooting is to locate the reason for the malfunction in a repairable system and then repair or replace the faulty component. The level of repair or replacement specificity depends upon the role of trouble-shooter, and the environmental constraints of the situation. Component level, board level or sub-assembly level repairs are all legitimate to suit specific needs. The trouble-shooter may only elect to replace sub-assemblies or change modules to enable the system to start functioning as soon as possible. In a different situation, component level repair may be more desirable. We would like to know what skills are required to trouble-shoot at different levels of repair; to what extent the skills required are generic and how the expert and novice trouble-shooters differ?

Baldwin (1978) summarized research analysing radar mechanics' weaknesses and reported a number of differences between effective and ineffective trouble-shooters. Ineffective mechanics made fewer checks involving manipulation of control settings and generally failed to observe all gross symptoms. In contrast they used schematics earlier and more frequently than did effective mechanics, and they made more circuitry checks and measurements involving test equipment. After localizing a problem, ineffective mechanics spent more time before attempting a replacement; required a longer time to find physical locations of components and made more errors in repair or replacement of components. Once repair was complete, ineffective mechanics did less checking to verify repairs and failed more often to return the system to operational status. Similar observations have been noted by Glaser and Phillips (1954); Moore, Saltz, and Hoehn (1955); and McDonal, Waldrop and White (1983). Ineffective trouble-shooters demonstrated a lack of elementary knowledge and were poor in executing and verifying the results of their work. When performing tests, poor trouble-shooters made fewer useful tests and more useless tests and were inconsistent in their consideration of test difficulty. The strategic behaviour of poor trouble-shooters was characterized by incomplete and inappropriate use of information, ineffective hypothesis generation and testing, and generally less strategic flexibility.

Training Requirements

Strategic training would seem to pose the greatest conceptual challenge to the instructor. Repair and replacement training seems relatively straight forward. Training persons to perform tests is more complicated as it also involves making inferences and carrying out analysis on measurement data (Morris and Rouse, 1985) Strategic training poses a number of questions. Should people be trained to employ a particular strategy or should they be allowed to discover their own strategies within some envelope of acceptability? If a particular strategy is to be taught, can people be taught to use it? What is the best way to teach a given strategy or may be even what strategy should be taught?

The previous research does not provide enough information to answer these questions. Particularly, the last question is complicated since no major efforts except SOPHIE I to III (Brown, Burton, De Kleer, Bell 1974-76) has been undertaken to address these issues. Also there is no single approach that is appropriate to all situations. The technologists and engineers are taught circuit design, test equipment measurement techniques. The text books rarely cover electronic trouble-shooting and repair strategies. For the industry, processes involved are not important and only the performance criteria is specified, i.e., speed, accuracy, low cost and efficiency. There are, however, some exceptions like military training manuals. The goal of efficiency is probably most appropriate as a subgoal for speed and/or cost, since minimizing the number of tests may in turn be a way of achieving these goals. Inspite of this criteria being desirable some trade offs are often made to suit local priorities and the trouble-shooting approaches adopted. For example, if time is of the essence or the risks associated with inaccuracy are high, saving the cost of a spare part should not be uppermost in the trouble-shooters' mind. On the other hand if the pace is more leisurely, the trouble-shooter may be more concerned about the cost of repair.

The use of trouble-shooting strategies is also a function of human abilities, limitations, and inclinations. For example, even if it is determined that a half split approach is theoretically the best approach for a given problem, the trouble-shooter cannot effectively apply it if s/he has difficulty identifying the remaining problem-space. The application of this strategy becomes more complex when the trouble-shooter has to deal with convergent, divergent, or feed back loops instead of a straight forward linear path for the signals. In most of these training sessions for teaching problem-solving strategies, efforts were made to keep them context free or generic. (Morris and Rouse, 1985) Typically subjects attempted to locate faulty component inputs and/or outputs. This constrained the solutions to be relatively simple for low fidelity trouble-shooting problems. Adverse effects of system complexity and time constraints were noted by Brooke and Duncan (1981). Wohl (1982) examined available data on time required to repair various systems and devised a model to predict system repair time. One of the parameters of that model is complexity index based upon the number of relevant relationships between components. Feedback loops also appear to present problems for trouble-shooters (Rouse 1979). Human strategies are also affected by time constraints (Rouse 1978).

Generation of Hypotheses

Many approaches to trouble-shooting emphasize the need to hypothesize the possible causes of symptoms and possible faults. There is some evidence to suggest that people may have difficulty in generating complete sets of hypotheses. (Mehle, 1980) Gettys, Manning, Mehle and Fisher (1980) observed that subjects seemed to check hypothesis for logical consistency with available information as they were generated.

Use of information

Helping students to organize the information provided to them may influence their trouble-shooting performance. (Miller, 1975) Providing trouble-shooters with guidance in how to analyze symptoms has also been shown to be helpful. (Fattu and Mech 1953) Perhaps the most ambitious attempt to provide guidance in the use of a system of knowledge has been SOPHIE. It is designed with the goal of helping students to obtain a teleological understanding of their system and represents an attempt to provide an opportunity for students to apply their knowledge and "exercise their logical muscles". There is also some evidence that people more often use positive information (i.e., information about bad inputs and outputs) but do not take due account of negative information (i.e., information about what has not failed). (Rouse, 1978) Trouble-shooters apparently experience some difficulty in judging the likelihood that various components will fail. This is in spite of some statistical data being available about component failure rates in the industry. (Mills 1971; Stoluron, Bergrum, Hodson and Silva 1955)

Individual Abilities and Aptitudes

Individual experiences, abilities, aptitudes and cognitive styles have also been studied by researchers in problem-solving domain. Vinebers (1955/1968) compared the abilities of field experienced mechanics and recent training school graduates to repair a particular type of radar. As expected, experienced personnel scored much higher than did the novices on a performance test in which speed of repair was emphasized. Trouble-shooting experience developed over a long period of time, continuing to improve through the highest reported experience level of 25 to 48 months. Apparently the ability to learn from experience also improves with experience. (Rouse 1979) Hunt and Rouse (1981) noticed differences in first and last semester trainees in transfer to a context-specific trouble-shooting task. Potter and Thomas (1976) found that maintenance technicians with experience of six months or less solved fewer problems and used more spare parts than did more experienced personnel. However, when trouble-shooting procedures were available, no experience related differences were observed. Similar results were noted in a study by Elliot and Joyce (1971) in which high school students using a trouble-shooting guide were able to identify faults in electronic equipment as effectively as Air Force technicians using traditional manuals. Duncan (1971) noted a difference between subjects with high ability and low ability in their retention of skills learnt for trouble-shooting. He hypothesized that those people with good retention had learned the rules governing decision tree choices (e.g., a half split approach), whereas those with poor retention had learned the series of steps by rote. Elliot and Joyce (1968) did not find difference between high and medium aptitude subjects in their ability to trouble-shoot actual equipment. They attribute this lack of difference to a variety of abilities other than cognitive skills that are required in actual trouble-shooting. Henneman and Rouse (1984), in a similar study, suggested that trouble-shooting performance may be related to ability only if some minimum threshold of ability is not present. Highland et al (1956) found in an oscilloscope test that technical knowledge of the oscilloscope catered for 60% of performance, electronic fundamentals accounted for 40% and reasoning ability accounted for only 7%.

Several measures of cognitive style, ability, and aptitudes were obtained from students in the Navy's Basic Electricity and Electronics School. (Federico, 1982-83; Federico & Landis 1979-80). Students high in achievement were found to be discriminating, reflective, high in general and logical reasoning and good at numerical operations. Individual differences in experience, cognitive abilities, and aptitudes have been shown to affect trouble-shooting performance. Vineberg reports that experience is necessary if the acquisition of essential skills requires extensive practice, or if the learning ability is improved by feedback from related actions. Also, lack of experience has less impact upon performance as more guidance in trouble shooting is provided. High cognitive ability provided a greater ability to employ half-split approach on complex problems. It also enabled one to learn more prototypical examples.

Computer Based Trouble-Shooting

Many expert systems have been constructed using knowledge of humans in particular domains. In the field of electronic trouble-shooting, a series of expert systems SOPHIE I to III are the oldest and most well known. (Brown, Burton, and deKleer, 1982) SOPHIE (Sophisticated Interactive Environment) sponsored by the U.S. Department of Defence (AFHRL, ARPA, Tri Services) after limited use for on-site job training over the ARPA network for two years, is no longer maintained. Other examples are LES (Lockheed Expert System) {Laffey et al (1986)}, and CRIB (Computer Retrieval Incidence Bank) {Hartley (1984)}. LES is used to trouble-shoot a large signal switching network known as the baseband distribution subsystem (BDS). The BDS accepts up to 40 baseband input signals and connects them under computer control to any one of up to 304 baseband signal output ports. The BDS structure allows connection of any one of its 40 input signals to any one or a combination of all its 304 output ports with essentially no signal degradation. The BDS consists of 16 equipment cabinets, a terminal and a line printer. The expert system performs corrective maintenance on the BDS by rapidly isolating the faulty chassis-mounted piece that caused the failure. The faulty module may be any one or more of the approximately 3000 printed circuit boards, 1000 cables or other devices that make up the BDS. Such a large collection of components make fault diagnosis a complicated task.

CRIB

The aim for CRIB was also strictly commercial to reduce the cost of training new and existing engineers on new equipment and to increase productivity by reducing the average time per fault investigation.

Earlier, a project called Deemen by the same group had made it evident that expertise of most field engineers is not in assuring correct electronic functioning of the machine but rather in module interfaces. Therefore, the approach to diagnosis through simulation of machine function was rejected. The research team found that most previous attempts along these lines failed through the enormity of the task. Instead, the diagnostic strategies had only to help isolate the replaceable parts, or sub-units and the interfaces between them. They concentrated on the questions like what sort of knowledge does an engineer need to find faults on malfunctioning computers, and how does the engineer use this knowledge to find and correct the fault? They soon realised all that was really needed was the location of the fault within a sub-unit. Where sub-units shared hardware interfaces, eg cable or connector, relationships between them were represented as additional sub-units at their same level. The reports on Deemen project suggested a diagnostic spiral called TOAST:

Test:	Carry out an appropriate test on the machine
Observe:	Observe and record the results
Analyze:	Analyze test results and determine whether to split or test.
Split:	Split the faulty subsystem into faulty and non faulty parts
Test:	Generate an appropriate test for the faulty subsystem.

This testing spiral takes the engineer down the hierarchy of sub-units until the location of the fault is essentially pin pointed to repair or replace a module.

SOPHIE I to III

The intentions of the researchers in SOPHIE (I to III) were to explore an interactive learning environment that encourages explicit development of hypotheses by the student carrying out problem-solving. The American Air Forces (major sponsors in the research) were interested in using computers for their component-level trouble-shooting particularly in a laboratory setting. SOPHIE uses a general purpose electronic simulator in order to provide a simulation of the domain both for the student and itself. (Nagel and Pederson,1973) SOPHIE was to fulfill the need for an environment in which to experiment with new ways of teaching problem-solving skills, such as electronic trouble-shooting, without being constrained only to pose problems that can be safely handled in a laboratory setting. Problems could also be analyzed in a hazardous and destructive environment.

SOPHIE's educational role is that of a "lab" where the student has a chance to apply his/her knowledge and receive informed feedback in the domain of electronic trouble-shooting. Since the problem-solving activity revolves around a model of a circuit whose components can be faulted, trouble-shooting means performing a series of measurements to propose and test hypotheses concerning the location and nature of the fault. Not only does the student have a chance to apply his/her theoretical knowledge of electronic laws to understand the "causality underlying circuit mechanisms", s/he also acquires general trouble-shooting strategies. Brown et al (1982) reflect on the use of quantitative simulation of making inferences, and their inability to give a full account of the causality underlying its inferences. Causality is pedagogically important because it is the main ingredient of the kinds of explanations human students can understand. In a trouble-shooting context, causality, more than information content, drives the diagnostic reasoning and the decision to perform measurements. This and other short comings of SOPHIE-1 motivated much of the further research. SOPHIE-II was not an attempt to deal with the fundamental limitations of quantitative simulation mentioned above; rather it was an improvement in its pedagogical setup. (Brown et al,1976) A trouble-shooting expert was added to the simulated lab. This expert demonstrated trouble-shooting strategies, given a faulted circuit. In contrast with SOPHIE-I's approach, this trouble-shooting expert reasoned qualitatively, making casually meaningful measurements and explaining its strategic decisions as it proceeded. Still it was not sophisticated enough from an A.I. standpoint, since it merely followed a predetermined decision tree. SOPHIE-III attacked the problem of reasoning (Brown et al 1982) and was divided into trouble-shooting expert and an electronic expert, each implemented in a separate module. The trouble-shooting expert worked on top of the electronics expert. (Brown et al 1980-1982) They proposed a theory of qualitative reasoning about mechanisms. They realized that many expert trouble-shooters diagnose systems that they had never seen before. They found that experts construct their own qualitative, causal models of how a system functions given a description of its structure and what it is supposed to do. What could be the basis of this skill? This involves a qualitative understanding of how the system functions in contradiction to the analytic or quantitative models often taught to engineers. "These models appear to have many of the properties of a simulation which is, metaphorically speaking, "run" in the mind's eye or what might be called an envisionment". By running such an envisionment, the expert can find some of the underlying causality. By observing students using SOPHIE systems, it became apparent that they were acquiring only one aspect of the skill of trouble-shooting; i.e., using knowledge of circuit components to localize faults. However, the understanding of how components interacted with each other proved extremely difficult even after extensive training with the system. Further questions arose: (1) What were the mental models of how and why a given device behaved that experts seem to understand and novices did not? (2) What kind of explicit explanations could SOPHIE give that would facilitate the meaningful acquisition of these mental models? If they could be identified and described, then the models could help in curriculum design for teaching electronic trouble-shooting strategies.

In addition to above-mentioned shortcomings, there were other issues like what were to be the basic assumptions on which the representation and reasoning were to be based? Assumptions such as a single fault to be searched for, are good working premise for trouble-shooting, but are often violated in real situations. The second problematic area mentioned by Brown et al (1982) is the encoding of circuit specific knowledge, originally present in the quantitative simulator of SOPHIE-I and later contained in SOPHIE-III's production rules and behaviour tree. The complexity of the domain of electronics by itself was a major problem. Separate projects like WEST, BUGGY, and BLOCKS were started for the purpose of investigating various related issues in simpler domains. The coaching of problem-solving activities was explored in WEST, student modelling in BUGGY, and information about theoretical trouble-shooting in the BLOCKS tutor.

Approaches in Trouble-Shooting Training

Let us now consider the various training approaches that have been tried and the effects these approaches have had upon trouble-shooting performance: (1) instruction in the theory upon which the system is based; (2) provision of opportunities for trouble-shooting practice; (3) guidance in the use of system knowledge, and (4) guidance in the use of algorithms or rules. In the two former cases the trouble-shooter is expected to develop an appropriate strategy rather than to follow a prescribed strategy. In the latter two approaches, the trouble shooter is given information about how to proceed.

Theoretical Instruction

It is a very traditional approach of learning about the functioning of the system and the trouble-shooter is expected to develop an appropriate strategy for trouble-shooting the system by himself or herself. Most of electronics education at colleges and universities is based on this approach, and a lot of research has been conducted in this environment. The results of these studies indicate that instruction in theoretical principles is not an effective way to produce good trouble-shooters. (Schorgmayer and Swanson, 1975; Shepherd et al, 1977; Miller, 1975; Van Matre & Steinemann, 1966; Steinemann et al, 1967; Williams & Whitmore, 1959 and Foley, 1977) Research in other domains such as process-control (Brigham & Laios, 1975; Crossman & Cooke 1974; Kragt & Landeweered, 1974; Morris & Rouse, 1985) and mathematical problem-solving (Mayer & Greeno, 1972; Mayer et al, 1975) showed similar results. The explicit training in theories, fundamentals, or principles failed to enhance performance and sometimes actually degraded performance. Fundamental understanding has been empirically shown to be useful for answering theoretical questions but not for solving- problems.

Opportunity for Practice

The essence of this approach is to provide the trouble-shooter with opportunities to practice solving-problems using the actual system or some form of simulation. This approach is seldom used in isolation and is usually used in conjunction with some theoretical instruction. However, opportunity for practice is the primary goal as is often the case with most of the military schools of instruction. Rigney et al (1978-80) conducted studies using GMTS (Generalized Maintenance Trainer Simulator) and EEMT (Electronics Equipment Maintenance Trainer) which demonstrated that practice in trouble-shooting improves performance. Duncan and Shephard (1975) also reported a general trend toward faster diagnosis with practice but no statistical tests were performed.

Guidance in the Use of Context-Specific Knowledge

The goal of this approach is to create conditions in which the trouble-shooter tries to apply the knowledge to problem-solving, with or without explicit instructions. For example, a trouble-shooter might be told to generate hypotheses as to the cause of symptoms prior to beginning work. Evidence suggests that encouraging trouble-shooters to plan before acting can enhance their performance. Miller (1975) described instructions on a training course for radar mechanics, in which an effort was made to relate instruction in system functioning to actions performed during trouble-shooting. For example, system behaviour was presented in terms of causal sequences rather than a more traditional left to right presentation of schematics. A control group, on the other hand, received instruction in the theory upon which the system was based on a left to right presentation of schematics. No extraordinary attempt was made to relate the information to actual equipment. Both groups had limited access to the actual radar for trouble-shooting practice. The experimental group was found to be faster in performing checks and adjustments, was more often successful in trouble-shooting, made fewer errors in general, and scored better on quizzes. Fattu and Mech (1953) also show that providing trouble-shooters with guidance in how to analyze symptoms is helpful in trouble-shooting. It may, however, be noted that the studies in which positive effects were found involved guidance that was rather explicit, i.e., students were told to generate hypotheses, chunk information, and analyze symptoms in a prescribed way.

Guidance in the Use of Algorithms or Rules

This category of training approaches include those that attempt to provide the trouble-shooter with a particular strategy or at least constrain the set of strategies used. This category has also been widely researched. Typically, studies in this category attempted to constrain the trouble-shooter's strategy in one of the following four ways.

a. The trouble-shooters were not explicitly told what should or should not be done. They were only provided with examples of the "right" way to do things. Their trouble-shooting behaviour was then observed to see if these examples were followed. (Crooks et al, 1977 and Hopf-Weichel et al, 1979) Some evidence suggests that providing trouble-shooters with good examples can have a beneficial effect on their performance. However, learning from examples may be confined to persons with high ability.

b. Trouble-shooters were sometimes supplied with feedback as to the acceptability of their actions, but the criteria for acceptable actions were not stated. College students were given a set of symptoms and were asked to identify the component common to those symptoms. (Brooke et al, 1978-80) Aiding in the form of action-related feedback was also investigated in a series of experiments. (Rouse & Hunt, 1984) Trouble-shooting performance may be enhanced if action-related feedback is provided. If feedback is in the form of identifying the feasible set of alternatives, positive transfer effects may be noted if the trouble-shooter has some level of prior experience or the feedback is supplied in a variety of contexts. Explicit feedback improves performance, but unexplained ratings about the quality of actions have produced negative results.

c. Trouble-shooters were told about appropriate algorithms or rules and were observed to determine whether or not the approach was followed. Algorithm of choice has mostly been the half-split rule with the goal of minimizing the number of tests required to localize the source of a failure. (Goldbeck et al, 1957) It was found that if the system is simple, then teaching trouble- shooting about the half-split concept may enhance their performance. However, if the system is complex, additional instruction and practice in identifying the feasible set of alternatives may be required. Brooke et al (1983) also investigated the value of instruction in the half-split approach. There were two independent variables in their research: the availability of strategic instructions, and the availability of aiding. The instructions consisted of a discussion of the concepts of half-split and bracketing and a caution to make diagnoses only with sufficient information. Aiding involved providing feedback when tests made were redundant or diagnoses were premature. It was reported that subjects tended to make premature diagnoses if not provided with instruction or aiding, and did not improve over time. It was also concluded that instructions were generally more effective in influencing trouble-shooting strategies than was aiding, and that the efficiency of testing was more easily improved than were diagnostic errors.

d. More like aiding, the trouble-shooter's task was fully proceduralized. The trouble-shooters learned a list of rules, which they sought to apply when making diagnoses. Rules are not always memorised, but they are always accessible, either on line or in hard copy form, and are retrieved as needed. Potter and Thomas (1976) observed technicians as they performed electronics trouble-shooting tasks and reported differences in number of correct solutions and time to solution. Smillie & Porta (1981) and Elliot (1966) noted improvements in the number of correct solutions, number of checks and un-necessary replacements, and solutions time when proceduralized aids were used rather than more traditional approaches such as technical orders. Studies indicate that proceduralization may be a very effective means of influencing trouble-shooting performance, largely independent of ability or experience. (Elliot, 1965-67; Elliot & Joyce 1968-1971) In one experiment, proceduralization enabled high school students with no trouble-shooting experience to find faults as accurately as Air Force technicians. Within reason, as procedures became more explicit, less ability and experience are needed for comparable performance.

Summary

The similarities and differences between experts and novices are now summarized. The studies in the domain of chess and in medical problem-solving indicate that experts and novices are similar in the "form" of their reasoning but differ in "substance" of content or reasoning. Experts can be four times faster than novices in speed when solving problems and make fewer mistakes. The qualitative analysis, occurring in the very beginning phase of problem-solving, distinguished the experts from novices most significantly. Novices made meta-statements like observations of errors made, self evaluations, and expressions of failure five times more than experts. The pause times between retrieving successive information or chunks of information or clues to problem-solving also vary considerably between experts and novices. Information is stored in chunks or related configuration by experts, so that accessing one thought leads to accessing another thought.

Trouble-shooting experience developed over a long period of time helped the experts to score much higher than novices when speed and efficiency of repair was emphasized. Individual abilities and aptitudes helped in retention of the techniques and strategies learnt. Apparently, the ability to learn from experience also improves with experience. Experts have been found to be discriminating, reflective, high in general and logical reasoning and good at numerical operations. Individual differences in experience, cognitive abilities, and aptitudes have been shown to affect trouble-shooting performance. High cognitive ability provided a greater ability to employ half-split approach on more complex problems.

CHAPTER III

METHOD

The Methodology of Think-Out-Loud Protocols

TOL has proven to be a useful research tool in human problem-solving. (Newell & Simon, 1972 and Ericsson & Simon, 1984) In these procedures, the subjects report on thoughts and actions while they solve problems. It is not known if this methodology was ever used to capture the thought processes of electronic trouble-shooters. However, it has been used extensively in other domains of learning particularly in reading comprehension and problem-solving. Olshavsky (1976-1977) was one of the first investigators to use TOL procedure to study reading strategies. Other studies in this domain include Garner and Alexander (1982); Alvermann (1984); Baker and Brown (1984) to name a few.

There have also been some voices of concern about this methodology. Perhaps the most basic concern is the accessibility of cognitive and meta-cognitive processes for subsequent analysis. (Nisbett and Wilson, 1977) Even Ericsson and Simon (1980), in their paper on verbal report as data, emphasise that recurrent processes that have become automated are particularly problematic. This may result in incomplete data, and possibly inappropriate inferences about strategic processing. Meichenbaum (1980) cautions us in this regard and warns not to equate language with thought. We may not be able to draw inferences about thought processes themselves, yet inferences could be drawn at higher level cognitive and meta cognitive strategies.

Verbal facility is a second major concern. The obligation to speak out loud may interfere with the problem-solving activity of the trouble-shooter. To minimise obstruction, interruptions should be minimised. (Kellog, 1982) Ericsson and Simon (1980) report that subjects may stop verbalizing or may provide incomplete verbalizations when they are working under heavy cognitive load. A number of guidelines are suggested by researchers for eliciting verbal reports of cognitive and metacognitive strategies and are given below:

A. Ask trouble-shooters to report what they think and do and not why. The amount of inference required is thus constrained.

B. Ask trouble-shooters to speak out loudly whatever comes to their mind. Subjects should not plan what to say or speak after the thought, but rather let their thoughts speak. It is most important that they keep talking.

C. Prompt full reporting in a nonqueing fashion and with minimum process disruption.

D. Use multimethod assessment. By using a set of different methods, data can be collected on actual strategies used by trouble-shooters. As Kail & Bisanz (1982) put it, "no single approach is sufficient for unambiguous and comprehensive identification of a person's cognitive strategies".

In short, it is suggested that the information should be heeded to and asked for at the time of the activity. TOL protocols provide us the opportunity to capture the information being attended to or recently acquired. This information is available in sensory memory and the short term memory with a limited capacity and short duration.

(Ericsson and Simon, 1980) The instruments and measures are to be designed accordingly. A number of sample studies (Karpf, 1973; Carroll & Payne, 1977; Kazdin, 1976) report that level 1 and 2 verbalization (concurrent verbalization) had no affect on the effectiveness of task performance. (Ericsson and Simon, 1980) Also on a wide range of problems varying in difficulty, no significant difference was found between a silent control condition and a verbalizing condition. These findings also suggest that the internal structure of the thought processes is not changed as a result of the verbalizing activity.

Hoc and Leplat (1982) emphasize three broad categories of factors: (1) the kind of process studied, (2) the type of instruction given for verbalization and (3) the moment of verbalization in relation to the way in which the process unfolds. Subjects describe the experience as they live through it. Subjects need not reflectively penetrate and transparently present their thinking. It is the task of the researcher to penetrate their descriptions in order to reflectively articulate the phenomenon. (Aanstoos, 1983) "It can be most precisely understood as an expression of, and hence a reference to, the lived experience of the subject". (Giorgi, 1982) TOL offers an opportunity to collect systematic observations about the thinking that occurs during the task and for studying these higher level processes. (Olson et al, 1981) Giorgi (1975) exemplifies this by way of identifying meaning units, specifying their central themes and then articulating their psychological sense or meaning. The aim of the study is not to assess the objective accuracy of the subject's thinking, but rather to discern its structure. (Aanstoos, 1983)

Analytic Procedures for Think-Out-Loud Data

A rigorous analysis of the protocol then becomes the necessary first step. The researcher reads the protocol and each time a transition in meaning is perceived, the underlying thought process is delineated. Next, the phenomenal themes that emerge as constituents are clarified and made explicit. They can also be appropriately coded. "Think aloud data should not be taken as direct reflections of thought processes but rather as data which are correlated with underlying thought processes". (Olson et al 1981) The strategies, knowledge sources, and cognitive styles must be inferred from the data.

Thinking-Out-Loud as a Method for Studying Real Time Trouble-Shooting Techniques

The complex nature of today's commercial, industrial and military electronic systems and equipment requires highly skilled maintenance technicians. The technician is required to have a thorough knowledge of the defective equipment, competence in the use of test equipment, and a systematic and logical approach to the determination and correction of any flaws in the operation of the equipment. Trouble-shooting is a complex process and the trouble-shooter is expected to have most or all of the following.

a. Knowledge of equipment performance under normal working conditions.

b. Know the function of and manipulation of all equipment controls and adjustments.

c. Know the correct use of test equipment and be able to interpret the test results.

d. Be able to understand schematics and analyze logically the information about correctly operating and malfunctioning parts and components of the equipment.

e. Apply a systematic and logical procedure to locate the fault. This means knowing about the working and malfunctioning parts of the equipment, identification of the problem space and skilful use of strategies and techniques to reduce the problem space until the fault is located.

f. Expertise in skills needed to repair the fault.

g. Knowledge of an appropriate check-out procedure on the repaired equipment to ensure that proper repair job has been done.

The comprehension and understanding of these underlying processes and procedures is a difficult task. It is difficult to devise means to externalise these mental thought processes employed by novice and expert trouble-shooters and at the same time make them readily observable. Two prominent methods currently used to externalize cognitive and meta-cognitive strategies are interviews and TOL protocols. However, because interviews produce retrospective verbalisation, they have come under heavy criticism for their oft-reported unreliability. (Nisbett and Wilson, 1977) White(1980) says that a long time lapse between thinking/doing and providing the verbal report of what was thought and done allows memory failure and is, therefore, unreliable. Hence, introspective verbalisation was not considered for the analysis of cognitive and meta-cognitive strategies.

The verbal protocols using TOL method, on the other hand, have been used successfully in the domain of problem-solving. (Newell and Simon, 1972); Ericson and Simon, 1984) The subjects report on thoughts and actions while engaged in cognitive processing. It is still imperative that the focus of TOL task should be to get the subjects to report the contents of their immediate awareness rather than to report explanations and justifications of their behaviour. The subjects are asked to talk-out-loud what they are thinking about right now, and not what they remember thinking about sometime ago. They are asked not to plan what to say or speak after the thought, but rather let their thoughts speak as though they are thinking-out-loud (TOL). They are to speak out loudly saying whatever came to their mind. Second, TOL data is not to be taken as direct reflection of thought processes but rather as data which are co-related with underlying thought processes. TOL data should provide a sample of what's on the subjects mind during the task, and they may not necessarily reveal the strategies, knowledge sources or trouble shooting rules or procedures actually used. These cognitive and meta-cognitive processes must be later inferred from the TOL data. These cautions are very important as Ericson and Simon (1984) acknowledge that most of criticism of verbal reports as data is based on faulty assumptions about the reasonable use of such data. The protocol is then transcribed and categorised by coding various thought processes

Electronic problem-solving involves a broad array of processes, from sensory and perceptual ones to higher level processes such as reasoning, inference, hypotheses generation and decision making. TOL verbal protocol is considered to be an adequate method to study these higher level processes in electronic trouble-shooting. TOL protocol is specialized for the study of the externally guided thinking and it is assumed that these processes are most available to consciousness instantly as the subject is trouble-shooting the electronic equipment. TOL task offers an opportunity to collect systematic observations about the thinking that occurs during electronic problem-solving. The outputs of these processes are verbal, and samples of them are sufficient for the investigator to infer trouble-shooting techniques and strategies used in solving electronic problems. TOL protocol is used as a discovery procedure for studying these higher level processes.

The trouble-shooters need to learn procedures and component processes for testing, observing, and analysing the circuits as well as routines for organizing these processes. TOL helps to look at these thought processes and the nature of trouble-shooting strategies. Paris et al (1983) call them "skills under consideration". They remind us that these strategies must be selected by the trouble-shooter from alternative activities, and it must be intended to attain a goal and to complete a task. It is as important for us to know when trouble-shooters use a strategy as it is to know how they use it. A strong relation between cognitive experiences and adept strategy use is suggested by Forrest-Presley and Gillies (1983), who argue the meta-cognitive activity directs the flexible use of various strategies. The analysis of the TOL data will, therefore, concentrate on the analysis of cognitive experiences of the trouble-shooters and their use of various strategies.

Type of Instructions

The importance of being clear and explicit to subjects cannot be over emphasized. Comprehensive instructions were prepared (Appendix A) about the objectives of the study, details of the experimental procedures, and the urgency of continuously speaking out loud whatever came to their mind while solving the electronic problem. The verbalization of the subjects' thought processes was emphasized. The instructions also contained a description of the system, maintenance procedures adopted in the real world and narrowing down of the problem space to the board level. In this background the problem was defined, fault symptoms were explained, and normal operating sequence described. In short the instructions were made as explicit as possible keeping in view the real-world situations and making the problem as realistic as possible.

Subjects

The subjects were Bachelors of Engineering, one with considerable (15 years) electronic trouble-shooting experience and the other a fresh graduate from University of British Columbia. They were, however, not familiar with TOL protocols. The instructions were, therefore, verbally explained and correct working of the equipment was demonstrated before the fault finding session started. No other help was provided to the subjects and they were not allowed to ask any questions from the observer. He was present only to remind the subjects to keep talking-out loud, in case they were silent for more than 30 seconds. All necessary circuit diagrams were provided.

Type of Material

The defective piece of equipment was an electronic circuit board, fully interfaced with input and output devices to check out proper functioning of the system. The power supply consisted of an adapter to the wall socket and another electronic circuit board to provide appropriate voltages to the system. The test equipment provided was an oscilloscope, digital multi-meter and a logic probe. The fault was inserted in the main logic board. The subjects talked-out-loud while they trouble-shot and this verbal protocol was tape- recorded. The equipment under test was a microprocessor based system for locking and unlocking of a security vault using a four digit code. On-site repair was carried out by replacing the faulty board, which was brought back to the shop for further repairs.

Instrument and Measures

The subjects were given the instruction sheet to read and understand the correct functioning of the system. A copy is attached as Appendix A. They were also shown the correct working of the system before a fault was inserted in the printed circuit board in their absence. An audio tape recorder was used to record their TOL protocol. The observer who was sitting behind the subject, was not allowed to answer any questions. His only job was to remind the subject to keep talking-out-loud in case the subject was silent for more than 30 seconds. The trouble-shooting environment was made natural and realistic as much as possible. The protocol was transcribed and then various thought processes were separated for further analysis. The protocols and thought processes are attached as

Appendices B,C,D, and E for both the subjects.

Data Analysis

The transcription, coding, and analysis of TOL verbal protocol was time-consuming and tedious. However, it helped to explicate the higher level processes involved in electronic trouble-shooting. It also proved useful in studying individual differences in trouble-shooting strategies employed by the two trouble-shooters. It provided the data base to explore what the good trouble-shooters have which the poor trouble-shooters do not have.

The verbal protocol was segmented and coded into appropriate thought processes, e.g., test, observation, analysis, hypothesis, etc. These labels then provided the basis for further study into the cognitive and meta-cognitive strategies adopted by the subjects during trouble-shooting. This interpretive analysis helped to formulate causal links and knowledge about strategies used, which could be utilized to develop learning strategies and student's mental models for teaching electronic trouble-shooting.

The Researcher as Part of Instrument

"The researcher is a valuable research instrument whose field experiences provide insights and whose personal talents and experiential biases may facilitate data analysis." (Marshall,1984) Cognitive psychologists like Bransford (1979) and Gibson (1966) have also exposed the myth of the "neutral" observer. (Tuthill & Ashton, 1983) Prior knowledge affects perception and future knowledge acquisition. (Glaser, 1984) My previous knowledge of electronic trouble-shooting and thirty years of maintenance and repair experience in the military and industrial environment has provided me some insight into the strategies used by expert and novice trouble-shooters. These experiential biases have now helped me in coding and analysis of the data. I have been designing electronic circuits, building prototypes, manufacturing, testing and quality assurance. I have also been actively involved in training, installation, maintenance and repair of electrical and electronic equipment. The intuitive insight into electronic trouble-shooting helped me to uncover patterns of significance in data analysis. (Schwartz & Schwartz, 1955) The circuit used in this study for trouble-shooting was designed by me and this equipment has been in use for a number of years. A recommended strategy for trouble-shooting this circuit is shown as a flow chart in figures #2a and #2b.

CHAPTER IV

Drawing Valid Meaning From Qualitative Data

Cognitive Task Analysis

There are few agreed-on cannons for analysis of qualitative data and, therefore, the truth claims underlying such work are uncertain. (Miles and Huberman,1984) The processes of data reduction, data display, conclusion drawing and verification must be considered. The conclusions drawn can later be tested quantitatively for their plausibility, robustness, sturdiness, and validity. The TOL protocol of both the subjects was segmented into thought processes. Each thought process was then encoded from the information contained in the segment itself. The subject's TOL process as data was taken for granted and the study sought to reveal in their coding not only the succession of known states, cognitive and metacognitive strategies, but also the productions that were executed to move from one knowledge state to the next. Project Deemen (Diagnostic Men), a fore-runner of "CRIB" expert trouble-shooting system (already discussed in Chapter II) suggested a testing spiral or a search control strategy which takes the trouble-shooter down the hierarchy of sub-units until the location of the fault is sufficiently pin pointed. (Hartley, 1984) Protocol statements or thought processes were coded as word problem analysis (WPA); test (T); test and observation (T&O); observation (O); observation analysis (OA); circuit analysis (CA); and hypotheses generation (h,H). Hypothesis (H) was generated when the thought process identified a definite malfunctioning part or component. The hypothesis (h) was only a thought advancing the causal reasoning and helping the trouble-shooter advance through the hierarchy of the search control in the problem space. The evaluation of the thought processes and their coding was subjective by nature and was based upon the reasoning deduced from the statements made by the subjects.

A hypothetical model of the domain to help identify objects and relations in the domain was developed. This theoretical model makes full use of half split rule for whatever circuit group or circuit arrangement may be under consideration. Links or relationships were traced for each type of data flow in linear, convergent, divergent, switching, feedback or a mixed configuration. It also follows the information funnel principle which is a concept that helps pick the type and location of the check appropriate to the number of trouble possibilities bracketed in the problem space. The utility or usefulness of the check was evaluated by the relative value of the information gained by making the check to the cost or difficulty required to make the check. The analysis on the observations made on the most recent test carried out may help to generate a hypothesis. Failing this a new test has to be made or the analysis may be carried out on the schematic diagram in order to generate a new hypothesis, which may only be a new thought or a reason to test again. The number and type of tests made will, therefore, indicate the comparative effectiveness of the trouble-shooting process. The elements of the thought process also give an indication of the quality and effort spent on testing, observing, analyzing, and generation of hypotheses. Summaries have been made for each fault analysis for both the subjects for comparison purposes.

Analysis of the Form of Diagnostic Reasoning

There is a striking similarity in the cyclical nature of the cognitive tasks performed by both the subjects. The basic pattern of testing, observing, analysing, and hypothesis generation is the same. The new cycle always starts from test phase and then proceeds towards generating a meaningful hypothesis, failing which the cycle is repeated again and again till a conclusive and a successful hypothesis can be generated. This pattern was followed when the subjects had success in fault finding (Faults A&B) as well as when they faced difficulties (Faults C&D). It conforms to the findings in medical problem-solving (Johnson et al, 1981; Elstein et al, 1978) and in chess playing (Chase & Simon,1973). When in difficulty, both the subjects spent more time in consulting and analysing schematic diagrams. Subject #1 consulted the circuit 14 times for fault C. Subject # 2 consulted the circuit 26 times for fault D and still could not find the fault. They also generated too many unproductive hypotheses in a difficult situation (32 times by subject #1 in fault C and 28 times by subject # 2 in fault D even though he could not find the fault). Most of these hypotheses were incorrect and were not the result of a logical reasoning process. It seems that they guessed quite often. However, this period of difficulty high-lighted their differences in the substance of their reasoning. Subject # 2 abandoned the strategy of "divide and conquer" and at best was using "trial and error approach". Subject #1 moved out of the problem space (C051) but corrected himself soon after (C059) and started trouble-shooting within the problem space. Let us now look at their reasoning process with a view to analyze the substance of reasoning.

Analysis of Substance of Diagnostic Reasoning

The type and number of tests made by the subjects indicate the difference in reasoning process and their trouble-shooting strategies. A comparative summary of thought processes explicated by both subjects is shown in Figure #1. The subject #2 initially spends considerable time in unnecessary testing (19 Vs8) and subsequent analysis (17 Vs 8) for Fault A. This shows his lack of experience in using the search control strategies. Inappropriate tests may also lead to incorrect hypothesis generation and create doubts and confusion. Subject # 1 carries out 58 tests in Fault C and generates 32 hypotheses, most of which were unnecessary. A recommended sequence of tests for all faults is shown in Figure #2 (a&b). The two subjects also differed significantly in type and quality of hypothesis (H) generation (1,5; 1,1; 13,5; 2,14++). Subject #2 generated too many hypotheses, most of which were incorrect. Subject # 1 generated 13 hypotheses in Fault C when he ventured out of the problem space and went astray. Both subjects generated wrong hypotheses in Fault #s C and D respectively and stuck to them for too long. Subject #1 managed to correct the situation by returning back to the problem space and was eventually successful. However, he wasted too much time in circuit analysis and meaningless tests. Subject # 2, in a similar situation, approached the problem space from one end and kept testing the circuit bit by bit. He did not use the "half-split" rule, and the "information funnel" principle. He eventually gave up and failed to find the fault. An appropriate use of these fundamental principles could have helped him to find the fault. Instead, he failed to use any worthwhile strategy and ended up in frustration and confusion. The two subjects were quite different in substance of their reasoning process.

Subject #2 shows weakness in deciding about check points, observations, operational evaluation and mental decisions. Operational evaluations relate to the first step of determining the symptoms and then in accordance with information funnel principle deciding where to make the tests. He ends up making too many unnecessary checks. Also subject #2 in Fault #D failed to localize the trouble to a functional unit. Doing this eliminates the necessity of making illogical checks of all units. Subject #1 was over confident and moved on to a "rosy garden path" without thorough testing of the divergent data flow paths. Subject #2 failed to isolate the trouble to the single stage for Fault #D and kept using "hit and trial" strategy at best, till he got frustrated and abandoned the trouble-shooting process. He failed to make appropriate voltage and resistance measurements to identify the faulty stage. He also confused himself by considering too many un-related details by consulting the main schematics too many times.

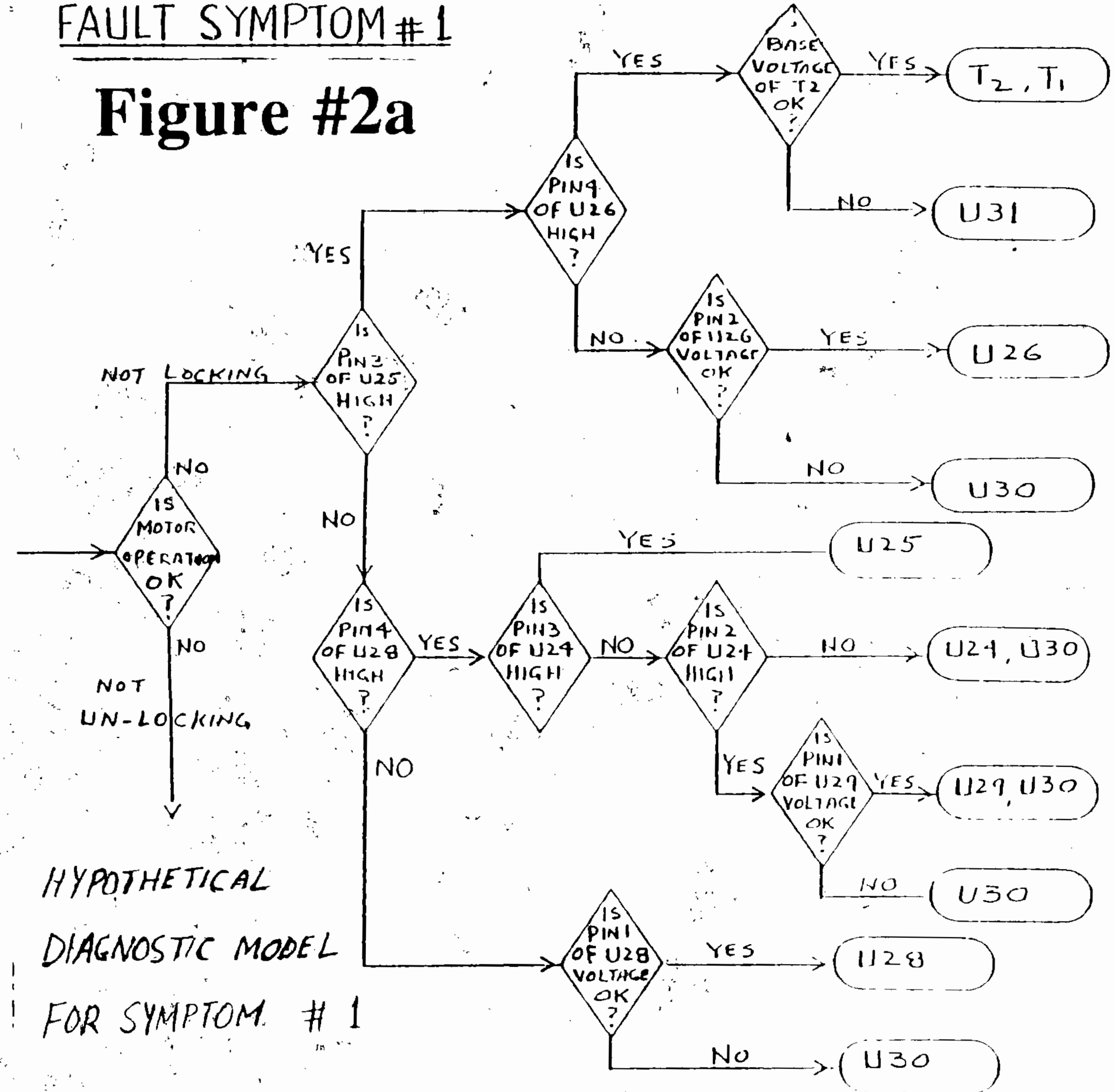
SUMMARY OF THOUGHT PROCESSES

FAULT NUMBER		TEST	TEST & OBSERVATION	OBSERVATION	OBSERVATION ANALYSIS	CIRCUIT ANALYSIS	HYPOTHESIS GENERATION		TOTAL
							-R	H	
A: NOT LOCKIING	#1	5	3	6	5	3	4	1	27
	#2	16	3	13	7	10	2	5	56
B: NOT UN-LOCKING	#1	6	1	6	3	2	2	1	21
	#2	3	4	2	3	3	4	1	21 +1 (WPA)
C: NOT UN-LOCKING	#1	39	19	41	26	14	19	13	176+3(WPA)
	#2	11	1	12	2	3	2	5	36
D: NOT LOCKING	#1	12	8	11	10	7	7	2	58
	#2	34	6	19	16	26	14	14	129+1(WPA) SUBJECT #12 COULD NOT SOLVE PROBLEM

Figure #1

FAULT SYMPTOM #1

Figure #2a



HYPOTHETICAL DIAGNOSTIC MODEL FOR SYMPTOM # 1

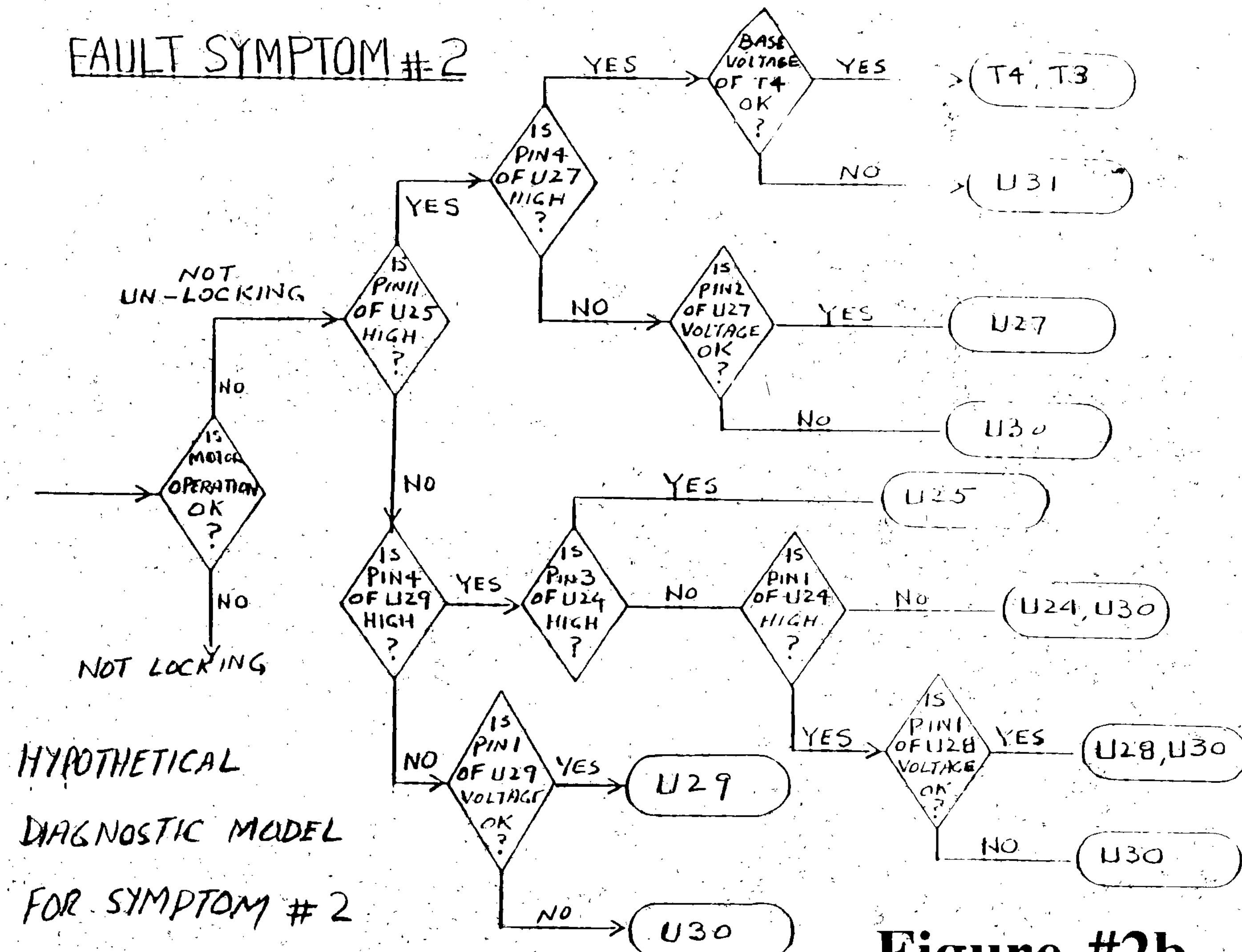

FAULT SYMPTOM #2
IS MOTOR OPERATION OK ?
NO
NOT UN-LOCKING
NO
NOT LOCKING
IS PIN11 OF U25 HIGH ?
YES
NO
IS PIN4 OF U27 HIGH ?
YES
NO
BASE VOLTAGE OF T4 OK ?
YES
NO
T4, T3
U31
IS PIN2 OF U27 VOLTAGE OK ?
YES
NO
U27
U30
IS PIN4 OF U29 HIGH ?
YES
NO
IS PIN3 OF U24 HIGH ?
YES
NO
U25
IS PIN1 OF U24 HIGH ?
NO
YES
U24, U30
IS PIN1 OF U28 VOLTAGE OK ?
YES
NO
U28, U30
U30
IS PIN1 OF U29 VOLTAGE OK ?
YES
NO
U29
U30
HYPOTHETICAL
DIAGNOSTIC MODEL
FOR SYMPTOM # 2

Figure #2b

CHAPTER V

Cognitive and Metacognitive Strategy Analysis

Background

The analysis of a cognitive task involves initially determining the problem space and then specifying the search control knowledge used within that problem space in order to find the fault (Newell, 1979). It has also been stated that the goal of a trouble-shooting algorithm is to keep dividing the circuit into two parts or spaces and then to infer which portion of the circuit contains the fault. The search control or the trouble-shooting logic is recursively applied to the faulty segment until the fault has been localized.

This study looks at the cognitive and meta-coghitive strategies used by both the subjects. In particular, their identification and definition of the problem space (Bracketing) and their use of search control strategies to reduce the problem space, till the fault has been found, shall be examined. Bracketing is also known as the good-input/bad-output technique. This technique requires moving the brackets one at a time (either the good input or the bad output) and making the tests in accordance with half-split rule. The search control strategies depend upon the nature of data or signal flow in the circuit under test. The key strategy is the continuous narrowing down of the trouble area by making logical decisions and performing logical tests. The nature and type of tests depends on the circuit being linear, divergent, convergent, feed-back, switching or a combination of these types. The information funnel principle allows the trouble-shooter to check a great number of fault possibilities first. The type of check should be appropriate to the number of possible defective components. The statistical data on component failure rates can also provide some guide-lines.

FAULT A

Subject #1

He initially defines the problem space and establishes the normal bracket (A004) and the abnormal bracket (A006). He uses a system function technique to further define the problem space (A009). He wants to repeat his functional checks to be sure of the problem space before he starts actual measurements (A011, A012). He then uses the half-split rule and makes his first check with a logic probe (A013). He has fully utilized the system function technique as his search control strategy, in order to fully comprehend the extent of the problem. He, however, fails to reduce the problem space by relocating the abnormal bracket. The normal bracket is gradually moved up until he found the problem at pin 6 of U25. Once he suspects the component (IC U25) as being defective, he promptly replaces it and thus solves the problem. His normal and abnormal brackets being around just one component, leaving no doubt in his mind that the component is defective.

Subject #2

Identification of the problem space by subject #2 is not very clear. He simply starts testing the circuit at the input and continues to check the digital logic progressively towards the other end. He generates his first hypothesis at A019 that U25 pin 6 is likely to be faulty. He visually looks at the component (IC U25) but cannot find (or comprehend) the problem. He does not have his problem space well defined. He does not seem to have enough flexibility in his search control strategy and his fault hypothesis is rigid. He is only looking for a bent pin or a bad trace which he does not find. In the absence of a definite search control strategy, he consults the main schematic diagram (A035) and does the circuit analysis. Because of ambiguity in defining the problem space accurately, he ends up enlarging the problem space rather then narrowing it (A044) down. He uses naive and elementary search control knowledge and hesitates too long before actually suspecting the IC itself (A054) and replacing it with a known good IC.

Summary

Subject #1 Spent more effort in defining the problem space using system function technique. Subject #2, on the other hand, hurried into the logic state measurements starting from the input end and his search control strategy was rigid. He generated ineffective hypotheses and stuck with bad hypotheses for a longer period of time (A010, A030, A036).

FAULT B

Subject #1

The subject uses the knowledge obtained during the previous fault effectively. This helps him to move the normal bracket correctly forward in order to narrow down the problem space (B006, B014). He, however, is still very cautious and does not relocate the abnormal bracket in order to narrow down the problem space. After seeing the motor operate properly when locking, there is no need to check the upper half of the circuit. At the most one check at pin 3 of U25 should have been enough. At last when he establishes the brackets around G3 (U25), he solves the problem quite easily(B018).

Subject #2

The subject does not carry out functional check of the system in order to confirm the nature of the problem. He, instead, jumps into the problem space without identifying the problem space and establishing the normal and abnormal brackets.. He starts circuit analysis without sufficient functional analysis of the system. Through circuit analysis, he predicts that pin 11 (U25) should be low (B004) but fails to test it till much later (B017). Because he had not identified the problem space correctly through functional check, he unnecessarily wastes time in circuit analysis, hypothesis generation, test and observation (B005-B008). He has, however, learnt and built confidence since his previous fault finding. This time he does not hesitate to replace U25 and thus solves the problem

Summary

Both the subjects show greater cognitive ability and understanding of the problem. Previous learning has improved their comprehension. They can identify the problem space and their search control strategy is also more sophisticated. They use information funnel principle to narrow down the problem space. Experience with the task leads to the growth of search control knowledge (Newell; 1979). Subject #1 is, however, more cautious in the beginning. Subject #2 generates an early hypothesis through circuit analysis but does not check it out. He goes through many unnecessary steps and at the end solves the problem by the method of substitution, with the help of a good working part.

FAULT C

Subject #1

He seems to be cautious in the beginning and spends too much time doing the word problem analysis. He establishes the problem space by putting the abnormal bracket at pin 4 of U28 (C013). Initially, his search control strategy is fairly adequate and his previous experience helps him to narrow down the problem space considerably. This initial success builds over-confidence that leads him on to a "rosy garden path" (C049). He fails to look at all the possible faults in the problem space and bypasses the problem. He forgets that this part of the circuit has a divergent signal flow and application of the half-split rule would, therefore, be different. He starts using elementary search control strategy and starts replacing components one after the other (C065). He pursues the wrong hypothesis (C088) and his search control strategy becomes very elementary. Failing to recognise the circuit as being divergent, he moves out of the problem space. His steadfastness and determination, however, is noteworthy and he stays calm. At last, he comes back in the problem space and finds the fault. Inspite of his finding out his mistake during circuit analysis (C126) he reverts back to his incorrect hypothesis (C130). He fails to test the ground potential (C128) and remembers incorrectly that he had changed the resistor. He, however, regains confidence by re-establishing the problem space (C148) and by using a better search control strategy and analysis (C162-C164). This narrowing down and sophisticated analysis bears fruit immediately (C167) and he finds the fault.

Subject #2

Although he takes a good start by identifying the problem space at an early stage

(C12) yet his problem space reduction strategies are elementary and he unnecessarily changes U24 (C006). He gets into the habit of changing components without adequate testing or genuine suspicion (C015). Such a strategy is wasteful in resources and time. However, he remains within the problem space and uses basic search control strategy. That bears fruit early and he generates correct hypothesis (C024). He revalidates this hypothesis (C029) and solves the problem quite early (C035) as compared to subject #1 (C175).

Summary

As the subjects learn through their fault finding sessions, they are improving their trouble-shooting strategies. The faults inserted are also made that much more difficult. As the confidence level increases, so does the chance of pitfalls. Subject #1 gets into such a problem. It shows his expertise and experience when he does extricate himself from the incorrect hypothesis and back into the reduced problem space. Subject #2 has learnt considerably and shows much more expertise in identifying the problem and the use of search control strategies. He makes 12 tests for which he consults the circuit diagram thrice only. He is still extravagant in his tests and replaces components unnecessarily. It is remarkable to note how calm and determined subject #1 was in spite of his difficulties and doubts.

FAULT D

Subject #1

The problem space is identified early (D004). Although, the search control strategy is not optimum, the problem space is reduced gradually. The subject unnecessarily checks out areas where there cannot be any problem. He is cautious and wants to assure himself. Initially (D021) he suspects U25, but on rechecking, declares it to be good (D027). He uses forward checking strategy (D040) in order to reduce the problem space (D041). The normal and abnormal brackets are eventually placed around U31 pins 13 and 2. This resistor is the problem which he identifies and replaces to solve the problem.

Subject #2

He incorrectly identifies the problem space. Not only does he generate an incorrect hypothesis, he persists on it for too long. Eventually, he measures the voltage across the diode part of the opto-coupler OC2 but fails to draw the correct conclusion (D050). He is very rigid in his thinking and reasoning. He does not think of the other possibilities (D055) and only keeps replacing the two integrated circuits time and again (D059). He is showing helplessness and frustration while still sticking to the incorrect hypothesis (D063,D072). He then tries to establish the normal bracket in order to identify the problem space but for no reason replaces U24 (D081). His search control strategy is very elementary and mainly depends on component replacement. Gradually, he reaches the fault area by forward probing and fixes one end of the problem at pin 2 of U31 (D096). He fails to check the other end of the resister. He still does not have a sound search control strategy and is working on impulse (D013, D038). Instead of concentrating on the problem space that now he has reached, he is going in circles (D110). He moves out of the problem space and starts circuit analysis again (D117). Once again he moves back into the problem space (D122) but fails to generate a correct hypothesis (D123) and moves away (D124). He fails to find the problem and eventually decides to stop further trouble-shooting. He exhibits a lot of frustration.

Summary

It is very interesting to compare the attitude and the use of search control strategies of subject #1 in fault C and subject #2 in fault D when both of them incorrectly define the problem space, generate a wrong hypothesis and persist on it for an unduly long time. Subject #2 shows helplessness and frustration, whereas subject #1 stays calm, corrects his hypothesis, and identifies the correct problem space. There is a marked difference between their use of search control strategies for reduction of the problem space. Inspite of difficulties and outside interferences, subject #1 does not give up and exhibits determination and flexible use of search control strategies. When in difficulty subject # 2 is found to be impulsive and subject # 1 as reflective.

CHAPTER VI

Findings of the Study

The two subjects doing the trouble-shooting were similar in the "form" of their reasoning and were different in the "substance" or content of their trouble-shooting process. Details of findings of the study are given below:

1. Similarities

a. Both the subjects had adequate understanding of the circuits and working of the system. They also used the basic test equipment quite effectively.

b. The cyclical nature of the diagnostic process was quite similar in both the cases. It started either with testing of a previous hypothesis or checking of fault symptom. In the very beginning of the trouble-shooting process it could start from the word problem analysis itself or later from the circuit analysis. Whatever the reason for testing, the results were observed and analyzed. At this stage, they either generated a hypothesis indicating a specific fault or about the next stage in the diagnostic process. Whenever they could not make any headway with their current reasoning, they went back to more testing or circuit analysis to look for different clues.

c. Verbalization and speaking out continuously was a problem for both of them. The verbal facility was hampered when the actions were simple or highly automated. This problem was, however, more pronounced in case of the junior engineer (subject #2).

2. Differences

a. An important difference was in their technique of trouble-shooting. Subject #2 started his trouble-shooting from the left (input side) and moved progressively to the right (output side) checking out component after component. That is why he had much more difficulty in finding the last fault #D and eventually he gave up finding that fault. On the other hand, subject #1 identified the problem area faster by using the half-split rule. The only time he got into difficulty was in fault #C when he failed to apply this rule correctly. Possibly, he was over-confident. Without checking all the fault possibilities in a divergent data path, he stepped out of the problem space and went down the garden path. He had acquired the "knack" of quick identification and fast reduction of the problem space.

b. Subject #1 started trouble-shooting with a careful, critical, and thoughtful look at the symptoms displayed. Subject #2, however, jumped into the problem-solving process more or less immediately without adequate checks of the system.

c. Subject #2 used the detailed schematic diagram more often and tried to consider all the details simultaneously, which made identification and reduction of the problem space more difficult. Subject #1 made good use of the simplified diagram and hardly ever consulted the detailed schematic.

d. Subject #1 always made a final check of the system for proper operation after the trouble was found. Subject #2 failed to do so in some cases.

e. It is interesting to compare the behavioural attitude of the subjects when in difficulty, i.e., subject #1 in fault #C and subject #2 in fault #D. Subject #2 exhibited turbulent emotions, frustrations, and anxiety when he said in fault #D:

> D063 "..oh...nothing is going through my mind...I am stunned...have no idea..I have no idea what's wrong...I haven't got the foggiest idea..."

He expressed such feelings at a number of times before he finally quit finding that fault.

Subject #1 on the other hand, in a similar situation of difficulty, stayed calm and controlled his anxiety. Some of his thoughts in a difficult period are given below:

C072 "..ok..am I reading it correctly?..."

C097 "..and it did not do anything...hmmm..interesting.."

C101 "ok..let's see what's going on now...ah.."

C122 "...and nothing happens..."

f. Another difference is that subject #1 was reflective and subject #2 was impulsive. This can also be seen by interpreting their behaviour when they were in difficulty. When subject #1 had suspected a resister to be a possible problem, he said:

C163 "...hello...what we got here...U30 ((pin))12.."

Later, when he found out that this resister was the actual problem, he reflected back and said:

C170 "...normally pretty unusual for a resister to go..but I guess it's possible..."

C172 "...very unlikely the resistor will go like that...well it's possible...I guess.."

C175 "...that was the least likely candidate but actually that was the problem.."

Subject #2 showed an impulsive behaviour in a similar difficult situation. He kept substituting the resistor pack U30 unnecessarily and I had to tell him that he had already changed it three times.

D038 "...do you have another one of U((30))...please...((you have changed it three times))..this was not a resistor... ((all of these are resistors))"

This means that he had been changing this component on sudden impulse without giving due thought. He was not even sure if it was a resistor pack, although he had changed it three times.

Linkage With Literature

The results of this study indicate a close relationship with the results obtained from the studies in chess playing and medical problem solving; which also indicate that the experts and novices are similar in the "form" of their reasoning but differ in "substance" of content or reasoning. {Chase & Simon (1973) in chess; Elstein et al. (1978) and Johnson et al. (1981) in medical problem solving}

The qualitative analysis occuring in the beginning and functional check at the end. to ensure that the goal has been achieved, are also born by other studies. Novices making meta-statements and behavioural attitude differences between experts and novices support the findings of studies in other domains. The expert (subject #1) was faster in three of the four fault-finding sessions and made fewer mistakes. He had also acquired enough experience over a long period of time which helped him to achieve higher efficiency and speed of trouble-shooting. Apparently, the ability to learn from experience had improved with experience.

The results of this study are also in harmony with respect to the expert being discriminating, reflective, high in general and logical reasoning. High cognitive ability of the expert provided him with a greater ability to employ half-split rule and information funnel principle.

CHAPTER VII

Conclusion and Recommendations

One way to know about good trouble-shooting strategies and techniques is to get them from the expert trouble-shooters. TOL protocols have proved to be quite useful in this regard in other domains. This study was an attempt to find the differences between experienced trouble-shooters or practitioners and fresh engineering graduates from the university.

The need for training fresh graduates of the engineering technologies in the art of logical trouble-shooting has become obvious. Perhaps a good starting point may be to provide the student with an increased understanding of the nature of thinking, reasoning, and understanding. These cognitive tasks and thought processes can provide the foundation for the problem-solving. Although no single method of training has shown universal superiority, it has been observed that when information is learnt in the act of problem solving, it is more usable than the same information learned by rote. (Anderson and Johnson, 1966; Szekely, 1950) Therefore, it is recommended that these strategies be taught as part of problem solving. The methodology of TOL protocol for learning about the electronic trouble-shooting strategies is quite useful. The recorded verbal protocols, although time consuming, will help to articulate the thought processes of the students and help in formulating the student models. Cognitive and meta-cognitive strategies can, therefore, become explicit. Most importantly, the student trouble-shooters can learn from their own mistakes. Trouble-shooting practice games, where one student inserts a fault in the circuit as well as writes an appropriate trouble-shooting strategy and the other student who is not told about the fault and carries out the actual fault finding. The two strategies are later compared and pros and cons of each discussed mutually.

Future Research

It is strongly recommended that research should be conducted on electronic trouble-shooting in order to further investigate the differences between effective and ineffective trouble-shooters. The nature of investigation can be qualitative as well as quantitative. The sample used should be much bigger for the quantitative study and should focus on the nature of search control strategies within the problem space.

For future research, a multi method approach is recommended, i.e., TOL protocol along with an interview and a stimulated recall method. The subjects should be helped to improve their verbal facility before starting the TOL protocol. Although, interviewing after the protocol has the obvious drawback of introspective thinking, yet a knowledgeable researcher could use it to externalize cognitive and meta-cognitive strategies. Another method recommended by Garner et al. (1983) to examine strategies of experts and novices is peer tutoring. In this way, the strategies used by experts and novices can be identified with less ambiguity than if any single method was used.

APPENDIX A

Instructions and Procedures for Subjects

Objective

In this study, we are interested in investigating electronic trouble-shooting techniques with a view to understand expert and novice trouble shooter's diagnostic strategies and cognitive processes. The study intends to find information that could eventually help novices learn the art of logical trouble-shooting by following the techniques and strategies used by experts. Your cooperation as a subject is highly appreciated.

Experimental Procedures

You will be asked to find a number of faults that will be inserted in the circuit one after the other. As you solve these problems, you are requested to think-aloud by speaking out loud 'every thought' that you might say to yourself silently. We are interested in what you might say to yourself silently. We are interested in what you think and what you say to yourself as you go through the diagnostic process. You are requested to please speak out loudly saying whatever comes to your mind. Please do not plan what to say or speak after the thought, but rather let your thoughts speak, as though you were thinking out loud. Just act as if you are alone in the room speaking to yourself. If you are silent for more than 30 seconds, the observer sitting behind you will remind you by saying, "Please think-out-loud". It is most important that you keep talking. The observer can not say anything else or answer any questions under any circumstances.

System Description

The system used for this study is a Z-80 based micro-computer system, which uses a personally selectable 4 digit code for locking and un-locking of a security vault. A number of these vaults have been installed in the rooms of a hotel. A central desk top computer is monitoring the usage as well as the serviceability of these vaults. You are the field engineer employed for the maintenance of the system and through a sophisticated diagnostic software you have located the faulty vault. On-site repair was done by replacing the faulty board which you have brought back to your shop for further repairs.

Component Level Repairs

You are also provided with a bench test set up, for repairing boards, wherein the locking mechanism is simulated by a manual switch. The lock and un-lock positions have been marked on the switch. This test simulator is in front of you along with the schematic of the printed circuit board. Further diagnostic tests (using a test EPROM) have proved that the motor drive interface circuitry has a fault. A simplified diagram of the circuit having the fault is also provided. The test equipment available to you is a logic probe, a digital multimeter and an oscilloscope. You are requested to trouble shoot and fix the following fault.

FAULT SYMPTOMS #1

Symptoms

When you want to lock the vault, the motor does not turn to activate the locking mechanism. However, if the lock switch is manually closed to simulate a locked vault, the displayed digits disappear and then the unlocking mechanism functions normally.

Operating Sequence

1. Press any 4 digit code of your choice on the keyboard.
2. Your selected code digits should light up on the display.
3. Press enter.
4. The LED indicator changes from green to red, showing that the computer has sent out the locking code, ie D1 = 1 and D2 = 0 (refer to the simplified schematics)
5. The problem is, however, that the motor does not operate to activate the locking mechanism.
6. Please fix this problem and keep talking out loud while you trouble-shoot this circuit.

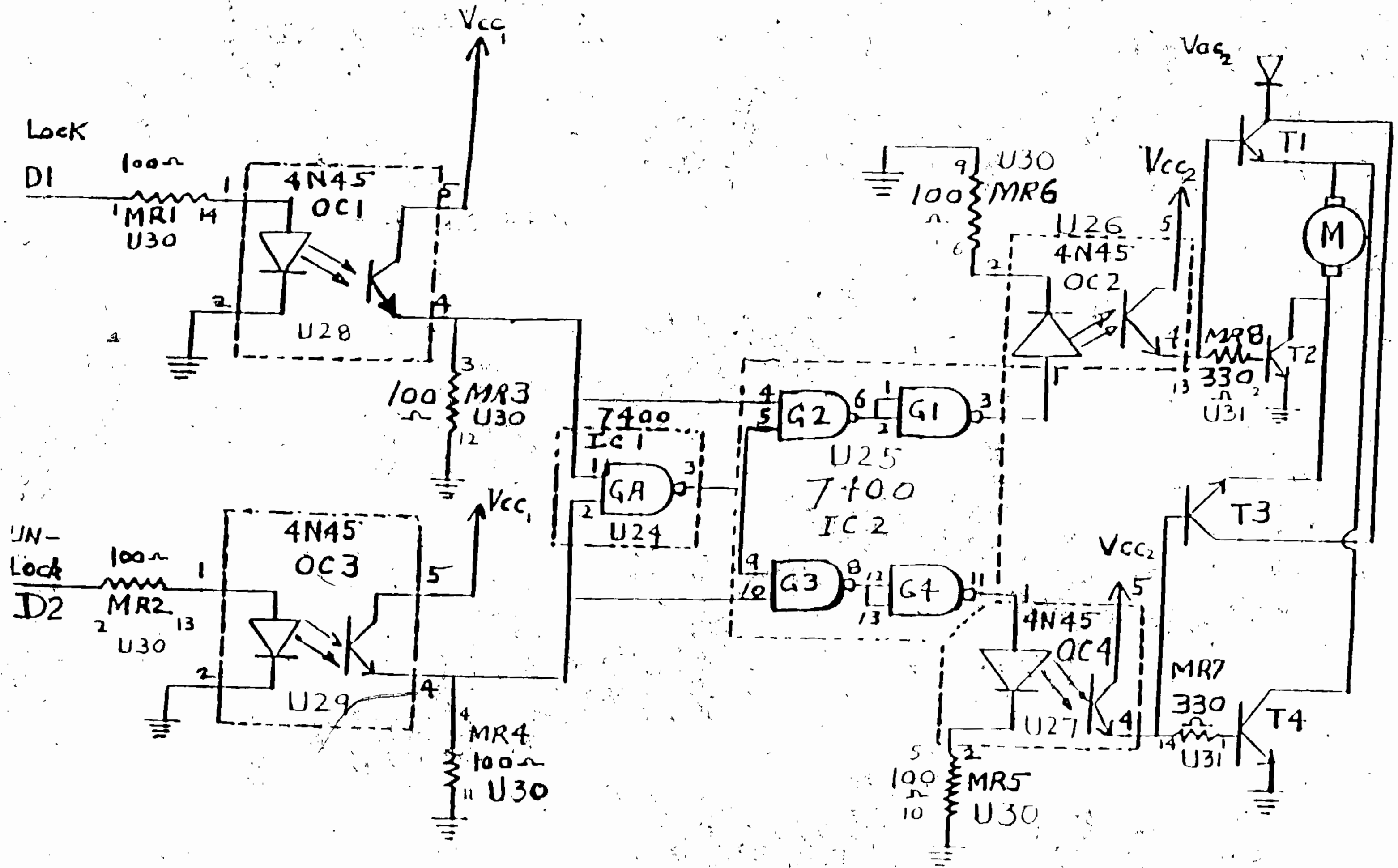
FAULT SYMPTOM #2

Symptoms

The locking function of the motor drive interface and drive mechanism is working fine. However, for un-locking, the selected digits are displayed but the motor does not operate to drive the un-locking mechanism after entering the correct code.

Operating Sequence

1. Please lock the vault using a secret code of your own choice. Press the manual switch to the lock position, in order to simulate a locked vault.
2. Now enter the same secret code to unlock the vault.
3. The digits get correctly displayed but the motor does not operate to activate the unlocking mechanism.
4. Please trouble shoot and find the fault while thinking and talking-out-aloud all the time.



MOTOR INTERFACE

Figure #3

D1	D2	ACTION
0	0	DO NOTHING
1	0	LOCK
0	1	UN-LOCK
1	1	DO NOTHING

APPENDIX B

VERBAL PROTOCOL

Subject #1

FAULT A

Fault Symptom #1: (Motor does not lock. Un_locking is ok. U25 pin6 is broken)

000/ The Problem is we enter 4 digit code of your own choice and press enter. Well let us try that ...001/ What's going on? 002/ I am going to enter 1 2 3 ..Actually I have 1 1 2 ...alright ...and ....enter. 003/ Now the lock was supposed to move ...Didn't move ...We get a red light on there ...Ok ..004/ So the computer has sent out the locking code D1=1 and D2=0....We don't know that...alright ...OC1 ...opto coupler 1 ...U28...alright ok. U25 U27 U28 ok. Alright plugged in here...Pin 1 is zero. D1 is zero...and....((Circuit showed a problem which was not part of the study. Protocol resumed after it was corrected)).......

005/ D1 should be 1 which is here. MR1 ... yea U30 ...ok. I better get used to these numbers. This has to be U 30 I guess. U 30...ok..So Pin 1 should be high. It's high and 2 ((D2))should be low. It's low. So computer is sending the right code. So far it is making sense. 006/ However, the motor does not operate. 007/ The display code does not disappear because motor driving mechanism is not closing the lock switch. 008/ However, if the lock switch is manually closed, the displayed digits disappear. Yeah ..they do disappear.... right. 009/ The displayed digits disappear and then the unlocking mechanism functions normally. Yeah ....ok ..alright..so only problem is that its not locking. 010/ Now, ok ..well let's have a look. OK. We getting the right code...so... ok... the motor runs ...we found that....so unlock is 01 and lock is 10...ok. 011/ I think I am going to again try...Get back to the locking arrangement and just go to the other side of opto isolator and see if that is functional all right. 012/ I think I have to recycle the whole thing I guess. So I can enter any code now. 1 2 3 4 ...ok ....it goes back to red light.. ok ..just verify one more time that...yeah ...we have one zero code ...that's good. 013/ Alright, now we should go to U24 pin 1...ok ..014/ U24 pin1 is low..ok...that's high ...015/ so...it's emitter follower...so when D 1 is high, it should be conducting. 016/ And U 24 one should be high ...017/ It is high 018/ And two should be low. So both isolators are working. 019/ Then we go to pin 3 ..020/ OK..1 is high 2 is high and 3 is high. 021/ That makes sense. So that NAND gate is ok. 022/ Now the next step will be to go to G2 and I will look at that ...so U25 pin 4 1 2 3 4 024/ U 25 pin 4 is high. This is interesting circuit. 025/ OK..5 is..4..is high, 5 is high and 6...There is a problem with 6 026/ It should be low. So that is the problem, I think.

FAULT B

Fault Symptom #2 (Locking mechanism is ok. Problem is with unlocking. U25 pin 8 is bent.)

000/ O.K. we start...we select a code 1234 enter....O.K 001/....now we try to unlock 1234 and enter 002/ and nothing happens 003/...now for unlock we should have a code D1 zero and D2 one 004/ and so let's verify that 005/....O.K.. D1 zero and D1((D2)) is high 006/

Now we quickly go over U24 GA to make sure it's functioning 007/ so U24 pin 1 is high. Pin2 is low 3 is high 008/ O.K. 009/ now let's go to U25 G2 Pin 1234 010/ Pin4 is low 5 is high 011/...O.K. 4 is low 5 is high 6 is high so that's fine 012/...let's follow that further with G1 013/..U25 G1 Pin 1. 014/. 2 is high 3 is Low 015/ so that chain is fine...let's go to the other side now 017/ U25 G3 pin 9 and 10...018/ 9 is high 10 is high and 8 has a problem....so U25 G3 output should be low but its floating 020/...so that is our problem....

FAULT C

Fault Symptom #2 (Locking mechanism is working fine. Problem with un-lock, U30 pin 12 not grounded)

000/ The locking function of the motor drive interface and drive mechanism is working fine. For unlocking, however, the selected digits are displayed but the motor does not operate to drive the unlocking mechanism 001/... we have same problem but ...alright...let's have a look at it 002/. So we enter a code.....o.k. 003/ the locking mechanism is working properly........and nothing happens. 004/ O.K. let us ...so, for unlock we should have D1 zero D2 one 005/...go back and verify that 006/...o...1 007/ we go back to U24 008/ ...GA pin1 and 2 009/....U24 pin 1 is should be high should be low ...and its not 010/. so looks like that u28 optical encoder...we follow that chain now ...011/ let us go back to U28 and look at pin 4...012/ U28 pin 4 013/ yeah pin 4 is floating 014/... pin 5 should have supply which it does... so that's fine...we already ...verified the D1 is low 015/...U28 optical encoder...opto isolator rather is gone...so we should change that 016/....power off..let us get a screwdriver...yeah it will be better 017/...here is the bad one.....O.K. 018/ let us bend the pins slightly in ..all right..let us supply the power again 019/..and running through diagnostics O.K. 020/ Now let us try...021/ we should unlock and try it again 022/. 1234 enter 023/ ...it's locked now 024/ let us try to unlock 025/ ...123... 026/ I made a mistake and I should clear it 027/ ..12... 028/ that's interesting ..o.k so....now we have a different problem...everytime I enter a digit, it enters twice 029/...1 ...030/ that's strange 031/ ...so we had some problem and it doesn't seem to repeat itself ((it is only a switch debounce problem)) ...we still locked. alright...its not unlocking and 032/ so let us go back to see what is going on 033/. U24 pin 1.. 034/ well 1 is still low 0035/ ...ok D1 is low D2 is high ok...let us go to the actual optical... 036/ U28(pin)1 is low 037/ ok..that is.. 038/ 2 is low 039/ so that is fine and 040/ we should look at 5 ..should be going to the supply 041/ 1234...5 is going to the supply and 042/ 4 is floating still 043/. well let us see that there is a short there is possibility of ..4 is floating actually..I will measure the voltage on 4 and see what we have 044/ ...5 is reading 8 volts 045/ ...that is strange 046/ ...why voltage is so high ? oh just a second...

047/ let us put the other IC..that's it 048/. Put the IC in there...power supply want to look around the IC 049/ ...oh dear..I know what I have been doing 050/ ...I have not been looking any further than U24 051/ ... There is the possibility of U25 of course because that is what's ...eating it..so U25 probably was the problem and I have been chasing the wrong stuff..because I wasn't paying any attention to the circuit 052/ ..ok we have another U25 which is ... 7400 ... OK another 7400 ... ((Chip is being changed)). Apply power OK 053/ ... and look at the voltage 054/... alright..let us try ...we are unlocked so enter a code..clear.. 4 055/... what's going on 056/ OK I was not unlocked ... problem ...

OK ... 3 ... 057/ ... OK let us try unlocking it again ... 1234 enter 058/ ... and nothing is happening ... its interesting 0059/ ... OK let us go back and see what do we have now 060/ ... U24 pin 1 is still pretty high 061/ ... its 1.5 OK right that is quite strange 062/ ... OK well let us make sure we still have D1 zero 063/ ... Yeah D1 zero ... Yeah D1 zero and D2 is one 064/. That is still OK 065/ ... what is going on here ... we changed all the three ICs ... did not have any effect 066/ ... OK the circuit diagram is supposedly complete ...

INTERRUPTION

CONTINUED LATER

067/ ... first of all we should try to lock alright I'm going to enter ... the power is on to the system so I'm gonna enter my code 1234 068/ ... OK ... the lock is turning and I can have simulator as locked 069/. Then I go back to the unlock situation and try the code again 123 070/ I made a mistake so clear it again 071/ 1234 enter and it is working 072/ OK am I reading it correctly 073/ ... locked the vault using a secret code of your own choice press the main switch to the lock position..in order to simulate lock...vault.. ok..may be I should follow this again ok so I should enter the switch..is in unlock position..ok.. 074/ I enter the code again 1234... enter ok I simulate lock condition by putting the switch over the lock position ok now I should enter the code and see if it opens 1234 enter 075/ ..and nothing happens 076/ ...ok the digit is digits correctly displayed...but the motor doesn't move 077/ ...ok so we should look at the circuit diagram which for the unlock position we should have D1 zero and D2 should be one 078/ so looking at the circuit diagram ok D1 is at U30 pin 1 U30 pin 1 ok U30 pin 1 I'm putting the logic probe on it and it is U30 pin 1 is low 079/ and this is how it should be unlocked 080/ and......the D1 should be high so that is ah 081/ ..I'm looking at now the U30 pin2 so the codes coming from the processors seem to be ok 082/ so the next step will be then ah...lets go to the other side of this opto isolator and see if that is functional 083/ so to look at D1 we should go to U24 pin 1 and see what the... if it's high or low so U24 pin1 ..U24 pin 1 here's 084/ U24 pin 1 ok its neither high nor low 085/ ok lets go to pin2 086/, Pin 2 2 is high 087/ so D2 is high so something strange going on pin1 which is neither high neither low in what we expect here is low and 088/ ....that could be two causes of this problem either the U24 gate has gone..gate GA is gone or the opto isolator has a problem and I guess I could...just quickly look at other U24 7400 series gates so lets look at ah...other gates on the same .... same IC and see if they have some strange behavior 089/. Gate number 1 had a problem, number 2 is pin 4 ....5 and 6 that seems to be normal and pin 8 is the output 9 090/ ..yeah that pin 9 and 10 again are floating ah 091/ ok..so seems to be two of the gates on U24 are bad 092/ so its quite ah likely actually its pretty good guess that the U24 is the bad not the ah U28 isolator so, if I could have ah the soldiering iron and I'd like to try a different IC 7400 093/ ok...ah...lets switch the power off ok lets get this ah U24 out of here can you get me a screw driver,.. thank you ok actually I don't need this right now I'll just take this chip out and put another one in there this is the bad one so this is the new 7400 ok like that's in there and we have to now ah apply the power again ok the ok its gone through the entire diagnostics 094/

E21 code is showing and ah its its finished the diagnostics 095/ so I'm going to try to see if it works again 096/ 1234 enter ok simulate the locked situation and go back and try unlocking it 12 ... 1234 enter 097/ and it didn't do anything hmmm interesting 098/ ...alright lets go back and check it again 099/ U24 pin 1 100/ same problem 101/ ok lets see what's going on now ah 102/ ..lets look at the back of this U board if anything strange 103/ don't see any obvious 104/ ah..problem there..ok..ahah...U24 is it used somewhere else or not I see U24 is only one gate which is being used ok whether its the output also going to G2 which is ah another 7400 IC 105/ so I could ah try replacing that I guess. Actually I have this old IC which I took out from the other one I could, I could, I could use that one 106/ so here goes the power 107/ ...huhhmm...its interesting maybe our 108/ let me apply the power again 109/ may be I had a problem with this ah the unlock switch ah has 3 positions 110/ may be it was sitting in the middle 111/. lets quickly try it one more time 112/ ok just going through the diagnostic 113/ actually I just don't even need to wait for that because the gate is ah floating 114/ so lets just change the chip that's come out here's a new one I hope these chips are ok ha ha ha 115/ Right all right apply the power again 116/ Right we have unlocked position running the diagnostics 117/ but we don't need to wait for that I can just measure U24 right away 118/ ok U24 pin 1 is high pin 2 is high 119/ seem to be a bit better 120/ so lets just try locking it 121/ 1234 enter ok lock it ok then we go back and try unlock it 1234 enter 122/ and nothing happens 123/ alright lets just see where we stand now 124/ U24 pin1 right same situation ok well 125/ I think I should also change the opto coupler U28 because this thing is only gong to 2 places either to U24 or U25 126/ so all the places going to is that ah and actually third one more place is the ahhahh the resistor network and one could even measure the resistance first of all on those see see what it is like 127/. ok U30 pin 3 to ground should be 100ohms pin 3 in 12 12345678 14 13 12 is 100ohms and pin 12 will be grounded so where's the ground here 128/, ok that seems to be grounded 129/ so that's yeah the resistor seems to be ok 130/ ok then alright I'll change the coupler U28 yeah U28 131/ here's the old chip and I'm going to put the new one in there... alright...lets one more time ...the power 132/ and lets just look at what we have pin U24 pin 1 ok alright 133/ lets put it in the unlock position and enter 134/ the code 1234 enter 135/ ok 136/ lets try unlocking it now 1234 enter 137/ and no go at all 138/ ok lets go back to U24 pin 1 139/ this is floating now that is quite interesting 140/ ok here the signal is only going to 3 places resistor is ok we changed that the interesting thing why is it floating ok ahahah U24 is not used anywhere else ok ahah now what has happened to U30 ok lets measure the voltages now gotta measure the DC voltage on U30 pin 3 which is the one which seems to be stranger...sitting at 4 volts no ah 1.3 volt ok and 4 is the high one that's so looks like there is too much current some how on coming out of the opto coupler ...and...U30 ...well....looks..seems to be ok in terms of ..100 or MR3 is 100ohm 141/ ...check MR1 142/ ...ok MR1 143/ ..let power off here ...oh MR1 pin 1 and 14 144/ ok...that is 100ohm alright 145/ ok pin 2 of the optocoupler should be grounded 146/ and let us verify that U28 pin 2 147/ yes that is grounded 148/. ..Ok well that does not leave too many things that could be causing it. Its not being loaded. its sitting high so the 149/ ..may be the Vcc...supply is too high... or hmmm 150/ ..ok let us just measure the voltages again...its supply voltage..U28 pin 5...U28 pin 5 ...U28 pin 5...U28 pin 5....12345 and the ground ...where is the ground here 151/. Pin 2 is the ground..looks 5 volts 152/ ...and U29 pin 5 ...pin 2 ..345 153/ ...ok seems the supply is going there..alright 154/ ...I guess I should visually examine this see whats happening 155/ ...U24..looks pretty clean Ok U25 is ...seems isn't shot on the PC..Ok hmmm...U24 pin 1 ...that looks reasonable 156/ ... oh yes that's pretty peculiar...yeah D1 is low but is it still conducting seems to be too much leakage in the optocoupler so ...and U25 is ..we changed that and its going no where else..U26..U30 157/ ...Hmmm let us supply the power...and right now its running diagnostic lets see what's happening there U24 158/ ...1 is high, 2 is high 2 is low ok 159/ ...yeah maybe I should look and use the scope and actually see what it looks like...here 160/ ...ok let's measure the voltage around the IC 161/ ...ok U24 ...ok supply voltage is good 162/ ...yes supply is good ground is good...U25 is fine U24 is fine that is narrowing down the process here we already confirmed its grounded 163/ ...hello ...what we got here U30 ..12 164/ here is minus 5.5 volts what's that? 165/ 3..4.. U30 12 1 2 3 4 5 6 7 8 9 10 11 12 166/ well that's interesting U30 12 should be grounded why it's sitting at 5 volts..5.5 volts so 167/ ...either there is internal short in U30 or whats going on in that area... so best thing is ...well I can try different resistant network 168/ ...could I have that ...Ok let us try different resistor 169/ ...and see what we got now 170/ ...normally pretty unusual for a resistor to go but I guess its possible 171/ ...ok...right we go to unlock position 172/ ...very unlikely the resistor will go like that...well its possible I guess 173/ ...we run through the diagnostic and so lets now ...enter our code 1111..I am going to try this 1111...enter.. 174/ well it is 175/ ...that was the least likely candidate but actually that was the problem.

FAULT D

Fault Symptom #1 (Locking of the motor drive has problem. Un-locking is OK. U31 pin 13,2 is broken)

000/ ok problem is when you want to lock the vault ...the motor does not turn to activate the locking mechanism. However, if the lock switch is manually closed to simulate a locked vault ..the displayed digits disappear and then the unlocking mechanism functions normally 001/ Alright..let us follow so we are in unlock position...press any 4 digits code of your choice on the keyboard:..1111 enter 002/ ok...the L.E.D. indicator changes to red 003/ and the code should be D1 is 1 and D2 is zero. Let us verify that 004/ ...ok... D1 is 1 D2 zero...ok.only problem motor doesn't seem to be activating 005/ ..ok..so we have...I looked at U24 006/ ... I should look at U24 pin1 007/ ... U24 pin 1 is high..and pin 2 is low...well soon I come into that gate 008/ and since its a NAND gate the output should be high 009/ U24 pin3 is high 010/ ok 011/ ...now let us...we should look at U25 pin 5 pin 4 and pin 5 012/ pin 4 is high 5 is high ..and 6 is low 013/ ...so that's alright and that output of gate G2 on U25 goes to G1 on U25 014/ ...where 1 and 2 is low and 3 is high 015/ ...so U25 seems to be ok 016/ let us look at the other side 017/ ...G3 on U25 at pin 9 and 10 018/ ...9 is high 10 is low...and 8 is floating 019/ ... ok let us look at alright let us measure the voltages around that 020/ I see something funny going on ...U25 ...its high 021/ ...I think U25 is gone 022/ ... let us make sure...8 ok 023/ what's going on here 024/ ...let us try U25 pin 9 ..8,9,10.....oh 025/ ..that's ok 026/. and we should look at output of so both of these are 027/...seem to be ok 028/..so let us summarize G1 ie U25 pin 3 is high and 11 14 13 ..11 is low..ok..alright....((please keep thinking.... talking out loud)) 029/ let us look at ...U26 now . U26 is one without 030/ ...U25 3 is high...U26 1 is high ..ok.. 031/ yeah that input is fine so we should look at pin 4 of U26 032/ ...pin 4 is high 033/ ...let us look at U27 that is the other opto isolator 034/ ...U27 pin 1 is low and pin 4 of same chip is low 035/ ...so we got high and low ok..hmmmm yeah that interesting ...so that logic part appears to be ok...and...ok...logic part appears to be alright we go 1 ...zero 036/ so T1 should be conducting because base is high OK 037/ T1 let me just refresh my memory here ... we are still in the lock position ... so D1 is high D2 is low ... everything normal there ... ok ... let us go around U24 one more time in case I was not paying any attention 038/ ... 1 ... 2 same low 3 ... 4 is high ... 6 is low ... this is ok right 8 is high 9 is high ... 10 is low that is fine ... 11 is low ... 12 is high 13 is high ... 039/ yes this looks normal 040/ ... problem has to be ... so ... Yeah those couplers also look fine also ... well ... 041/ that leaves us with few transistors to worry about or the motor itself 042/ ... ok ... how can we check the Vcc2 ... Vcc2 is on pin 5 of opto coupler so let us measure the voltage ... ok ... U26 pin 5 ... 245 ... 9.45 volts 043/ ... presumably that's ok I don't know how exactly that the right voltage 044/ .. assuming that is alright ... ok where is T1 transistor here ... T1 transistor ... there is Q1 ... Q2 ... alright 045/ ... those transistors are one thing that could be problem or any of those transistors 046/ ... actually the motor has to run ... to get positive to conduct and we should look at that voltage going out to the motor ... and let us see how ... is easy ... that 047/ ... let us see the motor voltage across the motor terminals 048/ ... we don't see any voltage at all 049/ ... the reason for this ... ok ... this ... when U26 is conducting then T1 should be conducting and we should have voltage there so ... and on this side so Q1 should be conducting and Q2 should be off ... and the motor should drive that way 050/ ... ok ... what is the actual voltage let us see on the Q1 the output of U26 pin 4 ... U26 pin 4 051/.... it's 10 volts 052/ because it's conducting right ... Yeah U27 pin 4 should be zero 053/ ... right so 054/ ... it is conducting alright and the 10 volt applied there and there 055/ ... ok one could also be worth looking at the voltage on base of T2 ...which is U31 pin 2...U31 pin 2 056/ resistor U31 pin 2 is sitting at zero volts...U31 pin 2 057/ ...well that's the problem.

APPENDIX C

Verbal Protocol

Subject: #2

Fault A.

Fault Symptom #1. (Motor does not lock. Unlocking is OK. U25 pin 6 is broken).

Ok ... 000/ It's not locking properly ... so let's see ... D1 ... D2 ... is zero. D1 ... D2 is zero. So 001/ ... I am entering the code ... 1111 ... enter 002/ ... I expect D1 to be high ... D2 to be low 003/. D1 high D2 low 004/ ... U28 ... let's see here. IC U24 ... pin 1 ... pin 1 U24 ... U27, U25, U24 ... pin 1 should be high ... high ... pin 2 should be low 005/. Its low 006/ ... so pins 4 and 5 ... let's see, 1 and zero is zero ... not is one and one is zero. One and one is one and not is zero ... zero and zero ... and not is one so pin 3 of U25 should be high 007/ ... pin3 of U25 008/ ... and it's low.

So let's see pin4 U25 ... is high 010/ pin5 ... should be low 011/. But why it's high? 012/ ... Pin5 is high ... One and zero zero 013/ ... pin5 is high 014/. That's correct ... One ... one and zero ... is one ... one zero zero ... Not is one ... 5 is high 015/ ... 4 is high ... pin6 ... is zero 016/ ... pin 6 is low ... It's not low ... it's nothing 017/ ... 4, 5 one and one is zero 018/ ...

Pin 1 and 1 is one now is zero ... pin 6 should be ... zero ... pin 6 ... 4, 5, 6 019/ ... Ok seems like there is fault ... U25 pin 6 ((keep speaking please)) ... It ... am I suppose to fix this ? ((Yes . You are suppose to fix it)) Ok ... ((But keep speaking please)) 020/ Ok U25 pin 6 seems to be low or is not 021/ ... nothing on it. No voltage on it 022/. I am going to change ... You have pliers or anything. ((Do you want pliers ?)) May be ... ((Ok I will give you pliers)) ... Ok ... ((yes . Keep speaking please)) yeah OH 023/ ... Pin is not bent or any thing 024/ ... Doesn't seem like anything is wrong 025/. Pin 5 underneath ? ... 12345 ... 2345 ... and 026/ traces seem to be OK ... and OH! 027/ ... let's try this again ... 1111 ... enter 028/ ... and OK again its gone 029/ ... pin1 ... pin 4 of U25 and pin 5 U25 ... were supposed to be one's ... pin 4 and pin 5 are both high ... good ... pin 6. There is nothing at pin 6 030/ ... and let's see if there is power to 031/ ... pin 123 ...6 7... pin 7 is low ... pin 16 ... pin 14 is 032/ high so there is power to the board ... and to the chip ... pin 6 ... is not proper 033/ ... and let's see pin 6 U25 ... pin 12345 ... 034/ pin 6 does not go anywhere 035/ ... should go to pins 1 and 2 of U25 and large schematic and U25 ... U25 ... U25 pin 1, 2 go to pin 6 ... Pin 1 and Pin 2. Let's see here ... U25 pin 9 and 10 zero and one. One and zero is zero ... zero and not is one ... one and one not is zero ... 036/ Pin 11 should be zero. 037/ 7, 8, 9, 10, 11 ... 038/ is nothing there. 039/ Pin 8 040/ there is nothing there ... pin 10 ...9, 10 ... OH! ... ((Keep speaking please)) 041/. I am just redialling the number again 042/ and power is back on again ... 043/ pin ... U25 pin 9 ... 789 is high, pin 10 is low as I expected ... so 044/ pin 8 should be high ... 045/ pin 8 is high ... so pin 11 9, 10, 11 is low but pin 3 is low. 4, 5, 6 ... 046/ pin 6 is not there! Ah! ... 047/ fault at pin 6 ... pin 6 of U25 ... 048/ One and zero ... One ... one of U24 high ... low is low NOT it's high high and high ... pin 6 should be low ... 123456 ... 049/ seems to be a fault at pin 6 of U25 ... Ok ... ((please keep speaking)) ... 050/ Ok I have to check why pin 6 does not go high ... Let's see ... Probe should be able to tell ... 051/ Pin ... that's the ground ... ((please keep speaking)) and pin 6 is low ... 052/ I expect it to be high ... but with the probe its not there at all ... 053/ and let's see may be a trace is cut or something ... 054/ may be at first ... Pin 6 Pin 1 ... Pin 2 ... I am doing ... taking out the chip ... and U25 ... and ... do you have another chip ? Ok ... 055/ and let's see if it works now. 1111 ... let's see enter ... and its working. So the fault was chip at U25.

Fault B.

Fault Symptom #2. (Locking mechanism is Ok. Problem is with unlocking: U25 pin 8 is bent)

000/ The unlocking ... the motor does not operate because ... the unlocking is not done properly ... 001/ I press my code and it doesn't seem to go in 002/ so let's see ... Unlock should be D1 zero D2 one ... zero ... one ...one. One and zero ... zero so there should be high one ... 9 and 10 are one ... So pin 8 of U25 ... 6, 7, 8 should be low 003/ and it is 004/ and pin 11 ... 9 10 11 should be low 005/. Let's see ... zero and one . D1 zero D2 one ... zero and one is zero NOT is one ... One and zero is zero NOT is One ... one not is zero ... 006/ Pin 3 should be zero ... 007/ Pin 3 should be low ... 008/ ... and it's low ... 009/ and pin 9 is one ... pin 10 is one ... one and one is ... high and high one and one is low ... 010/ and it should be low ... pin 12 ... U25 pin 8 is ... 011/ Let's see ... pin 9 of U25 is high. Pin 10 is high ... 012/ so high and high is high and NOT ... is low ... so high and high ... is low. 013/ Pin 8 should be low 014/ and it is low ... and 015/ low inverted is high ... 016/ and pin 11 should of U25 .... 017/ 7 8 9 10 11 ... pin 11 ... pin 8 is low ... 9 and 10 ... U25 pin 9 and 10 ... is one NOT is ... zero ... and zero ... 11 should be one ... 4 5 6 7 8 9 10 11 ... and it's not ... 018/ Do you have another ... U25 ... Yes ... 019/ and there is no power ... Oh! ... 020/ Ok... That is the fault ...

Fault C.

Fault Symptom #2 (Locking mechanism is working fine. Problem with unlocking. U30 pin 12 is not grounded)

000/ 1111 ... and enter ... 001/ that's fine ... 002/ and 1111 003/ and its not unlocking .... properly 004/. So let's look at the schematic ... Unlock O and one ... so pin ... U24 pin 3 ... should be high ... U24 ... U25 where is U24 ... U13 ... U16 ... U24 ... pin 3 is low ... one one zero zero pin 3 ... should be one ... Pin 3 Oh 005/ let's check U24 ... pin 3. ((keep speaking please)) 006/ and may be I can find another U24 ... 007/ for U24 ... and let's see if ... it sounds any better .... and let's try it again ... 1111 code ... enter ... 008/ it's locking properly ... 009/ 1111 .... 010/ still not unlocking. 011/ May be there is more than one fault ... Pin 3 U24 ... is still low. pin 1 is high Pin 2 is not there ... low high .. Pin 1 of U24 is not there ... Pin 1 of U24 is not there ... 012/ so let's see D1 ... U28 pin 4 should be one ... U22 ... 20, 21 ... U28 ... where's U28 ... and 26, 27 , U29 ... U28 ...there U28 pin 4 ... is not ... 013/ may be it's not powered. 014/ pin2 to ground pin5 to power ... 015/ and is there another U28 ? ... ((Yes. I can give you another one)) 016/ and putting U28 back in again ... and pin 1 pin 2 pin 3 ... OK. Let's try again 1111 Ok let's see 1111 ... 017/ open 018/ 1111 ... 019/ still not locking ... 020/ let's check it ... D1 should be low ... so pin1 should be high ... its low ... Sorry pin 1 is low ... pin 2 is low ... pin 4 is not there. Pin 5 is high ... 021/ pin 4 ... 022/ let us check the trace ... and .. Oh! ... 123 ... let's see then ... 023/ pin ... U28 pin 4 is not done properly ... 024/ let's see U30 pin 12 ... 025/ resistor U30 ... U30 pin 12 U30 pin 12 ... U28, U29 ... U31 ... U26 ... U27 ... 026/ U30 ... Pin 12 ... 9 10 11 12 027/ is tied high U30 pin 12 is tied high 028/ should be low ... 029/ so the fault seems to be U30 pin 12. It's not tied to ground 030/ Let's check it ... entering the code ... 031/ it's locking fine and ... 032/ Unlock ... and 1111 033/ it's not unlocking. 034/ Let's check it ... where's the screw driver U30 pin 12... 035/ and OH! the pin 12 is cut.

Fault D.

Fault Symptom #1 (Locking of the motor drive has problem. Unlocking is Ok. U31 pin 13, 2 is broken)

000/ Ok Let's see ... does not lock properly ... so 1111 enter ... 001/ it's not locking .. 002/ so locking is one zero ... D1, D2 is one zero ... so U28 pin 1 should be high and its not ... Let's see U28 pin 1 ... pin 4 should be high as well ... 003/ Yes pin 4 is high .. U30 pin 12 ... 7 8 9 10 11 12 ... its tied low ... pin 5 of U28 is tied high ... pin 2 is tied low ... 004/ D1 should be high ... 005/ lets see U28 pin 1 ... 006/ try another U28 pin 1 ... ((yeah ! please keep speaking)) and U28 pin 1 OK and let's try U28 pin 1. 007/ Trying up gain ... and ... its in open position ... and 1111 ... enter 008/ and its not locking still ... 009/ so let's check ... U30 pin 11 ... 010/ U30 7 8 9 10 11 is tied low 011/, pin 5 is tied high ... and D2 is zero ... so pin1 U30 ... is now ... is high ... ((please keep speaking)) 012/ Ok ... pin 1 U30 is high ... and pin 2 is low ... pin 1 is high pin 2 is low ... that's fine pin 4 should be low ... that's high ... U29 ... pin 1 is low ... pin 2 is low ... pin 5 is high ... that's fine ... and ... pin 1 of U28 is not fine ... is not high ... pin 1 U28 and ... pin 1 U28 ... what could be wrong with pin 1 U28 ? ... pin 1 U28 ... 013/ Do you have yet another one , may be ? ... ((yeah . I will give you)) ... ((keep speaking please)) ... something wrong with pin 1 of u28 ... 014/ let's see U28 pin 1 ... pin 5, 4 and 5 ... U28 pin 1 OK ... let's see ... let's check it ... pin 1 U28 ... and there we go ... its in ... 015/ power is back ... 016/ 1111 ... enter ... 017/ its in open position but does not lock properly ... 018/ let's see ... It's not the chip ... U28 pin 1 ... D1 ... should be one ... 019/ and let's see U28 on other schematic ... pin 1 (the subject is now locking at the main schematic) ... U28 ... U27 , U26 24, 25 ... Oh there is U28 ... U28 ... U10, Y5 ... pin 7 of U10 ... 020/ pin 7 of U10 ... U10 pin 7 ... 3 4 5 6 7 ... is high one ... 021/ which it should be ... pin 7 U10 is high 022/ and should be going ... LED ... and then from the LED ... to pin 1 of U30 and its high and pin 1 of U30 ... and pin 14 ... is not there 023/ ... So let's see I am replacing U30 ... something wrong with pin 1 of U30 024/ ... I am removing U30 ... and replacing it ... Let's see and ... try it again ... 1111 025/ and it's still not fine 026/ Let's see ... Ok ... pin 1 is fine now ... U28 ... pin 1 of U28 is not fine ... U30 ... U28 ... 027/ let's see is it a trace cut ? ((Please keep speaking)) 028/ and let's see ... 028/ I can't see the trace underneath ... to U28 ... U28 pin 1 ... pin 14 of U30 ... OH! ... pin 14 U30 is going to U26 pin 1 and now ... let's see ... pin 1 of U28 ... pin 14

030/ ... This chip is not right ... 031/ Let's see ... and is there another one for this ... I am looking for another U30 ... ((please keep speaking)) U30 pin 1 U30 pin 1 ... OK replacing U30 ... OK ... let's power it up again ... Now ... 1111 ... 032/ its not locking ... 033/ let's see ... Now ... U30 pin 14 ... 034/ still not there ... 035/ pin 1 is high ... U30 pin 1 is high ... U 14 ... is not there ... pin 14 ... is not there ... Pin 14 ... Pin 14 ... is ... let's see. 036/ Is there a short there between pin 14? ... 037/ No short ... 038/ Do you have another one of U ... please ((You have changed three times)) This was not a resistor ... ((All of these are resistors)) ... 039/ OK ... But this wouldn't help ... 040/ OK ... U30 pin 1 to pin 14 ... (subject is again looking at the main schematic) ... 14 ... 1111 ... It does not go high ... so let's see ... U28 pin 2 is grounded pin 5 is high ... and pin 4 is high ... and nothing at pin 1 ... Nothing at pin 14 and nothing at pin 1 ... U30 pin 1 to pin 14 ... 041/ let's check it ... may be internally something is broken ... 042/ and let's see ... Ohmmeter ... Putting ohmmeter between ... pin 1 and U28 ... should be open circuit 043/ which it is ... 044/ pin 1 and pin 14 ... see ... 100 ohms ... Should be 100 ohms ... pin 1 ... Oh ... its 100 ohms between pin 1 and pin 14 ... 100 ... and pin 14 is high ... 045/ let's try again ... its open ... want to lock it ... 046/ It's not locking .... 047/ Pin 1 is not going high ... U28 pin 2 is high ... 048/ and let's check U28 ... the diode there ... 049/ U28 its diode ... between pin 1 and 2 of U28 ((Please keep speaking)) ... Pins 1 to U28 is ... OH! hang on ... Let's try this U28 pin 1 ... to pin 2 050/ its high ... 1 to pin 2 ... 1.3 volts ... 051/ Pin up power and lock ... 052/ It's not locking ... 053/ pin 1 to pin 2 of U28 ... Pin 1 to Pin2 ... Pin 4 ... Oh ... I am ... ((please keep speaking)) ... Boy! ... right now nothing is going through my mind ... can't see what's wrong now 054/ ... that resistance is high ... 1 is high 14 is low ... U28 pin 5 is high ... D1 ... is one ... for locking its high and its high and ... oh boy! ... ((please keep speaking)) 055/ I don't Know what's wrong ... 056/ let's see ... 1111 ... 057/ It's not locking ... 058/ Pin 1 of U28 is ... U30 sorry U30 pin 1 is high ... pin 14 is not ... Oh ... let's see what could be wrong ... Tried replacing the resistor ... that didn't help ... 059/ let's see ... let me try replacing it again ... 060/ checking the volt ... resistance between ... pin 1 and pin 14 ... pin 1 to pin 14 ... 061/ 100 ohms ... 062/ fine ... pin 1 ... Ok ... so ... pin 1 is high ... pin 14 is not ... it should be high ... 063/ OH ... nothing is going through my mind ... I am stunned ... Have no idea ... ((please keep talking out loud)) ... I have no idea what's wrong ... Why isn't pin 14 going high ... U28 pin 1 to pin 14 ... why is that pin 14 is not there either ... I haven't got the foggiest idea ... 064/ There is 100 ohms between there ... I saw nothing wrong ... between pin 1 and pin 14 ... ((please keep talking out loud)) pin 1 ... and pin 14 ... pin 14 goes to ... 065/ see the trace goes 066/ ... under U26 ... pin 14 067/. I shouldn't do that. 068/ Let's see U28 pin 1 ... U28 pin 1 ... 069/ Let's do continuity test between pin 14 of U30 and pin 1 of U28 ... 070/ it's high ... 071/ pin 1 of U28 ... and pin 14 ... pin 1 of U28 and pin 14 of U30 ... is high ... so ... ((please keep speaking)) 072/ I don't know what could be wrong 073/ ... Let's see Pin 1 to pin 14 is fine ... 074/ there is 100 ohms ... but nothing going through ... 075/ let's see the motor was fine ... and let's see what else ... pin 1 ... pin 4 ... 076/ let's check the voltage here ... 077/ One ... pin 1 U24 ... 26,25,24 ... is high ... pin 2 is low ... 1 is high ... pin 3 is high ... 078/ one zero ... one low ... 1 is high ... pin 4 is low ... 079/ U24 pin 1 and pin 4 is same should be the same ... Let's see ... 080/ pin 7 is ground ... pin 14 is high ... 081/ let's replace U24 ...

082/ U24 is replaced ... let's see ... 083/ let's lock it again ... 084/ checking ... 1111 ... enter ... 085/ why ... wonder ... pin 1 is low pin 4 is high ... oh ... U25 ... pin 4 ... and U24 pin 1 is high ... pin 4 is high ... pin 3 of U24 ... is high ... high high ... low ... 086/ pin 3 of U25 should be high ... 087/ so its high ... ah ...

U25 ... 9 ... 4 5 6 7 8 9 ... high , 088/ pin 10 should be low ... 089/ low ... high and low ... is low ... Not is high ... Not is low ... pin 11 should be low ... 090/ is low ... pin 1 U26 is high 091/ U30 pin 9 should be grounded ... 092/ 9 ... is low . 093/ Pin 6 should be high ... 094/ Pin 6 is not there ... 3 4 5 6 ... pin ... U 26 ... 1 and 2 ... 4 ... pin 4 is low pin 5 ... U26 oops U26 ... pin 1 is high , pin 4 is high ... pin 5 is high ... pin 4 is U26 pin 4 is high ... pin ... U31 ... 095/ now let's see pin 2 of U31 seems to be bent ... 096/ see U31 ... Oh ... boy ... I will try that ... ((please keep talking loud)) ... and just fixed U31 pin 2 ... 097/ and let's try it again ... 098/ let's see ... 1111 ... still not working ... 099/ see U31 pin 2 is low U26 pin 4 is high ... pin 13 U31 ... is low ... U31 pin 13 is low ... and 4 is high ... How is that ? ... 13 is low ... U31 pin 13 is low ... see to turn motor on ... I need ... 100/ let's see pin 7 ... 1 ... pin 14 U31 ... low ... pin 1 low ... 14 and 1 ... low ... 2 and 13 low ... 4 ... U27 is low ... 4 U26 is high. 101/ let's see ... U26 102/ checking out U26 ... replacing U26 ... 1111 ... enter ... 103/ doesn't lock ... 104/ motor is connected ... the diode is connected. No disconnection here ... Ok. Let's see again ... 105/ U26 pin 4 is high ... U31 pin 13 is low ... 106/ Low and low ... pin 2 of U31 is low ... pin 1 of U31 is low ... so that's off ... Let's see pin ... T1 ... where's T1 ... T1 ... U1 ... U31 ... U26 ... Where's T1 Ok ... 107/ There ... T1 should be ... is high and ... T3 is ... Let's see

T3 ... is Q3 ... is tied high ... 108/ Now T2 ... is Q2 ... T1 ... 109/ What's the matter ... ((Please keep talking out loud)) ... 110/ T1 ... T3 ... T2 ... let's see ... base of T1 ... T1 ... is tied high ... T2 ... base is low... so it;s off ... this transistor is off ... T3 base is ... T1 ... so this is high ... T3 ... see ... T3 is tied low ... the base of T3 is low ... so T3 ... its low ... so ... T3 is off ... T4 ... the base of T4 ... is low ... This is turned off ... it's low ... high ... low ... T4 ... T1 ... T1 is tied to ... T4 is tied high ... T1 is tied high ... 111/ Yeah ... 1111... Oh! oof ... ((Please keep talking out loud)) ... 112/ I really don't know what's wrong ... ((please keep talking)) Let's see what else ... Let's check power on ... 113/ It's processor's ... (subject is consulting the main schematic) ... T ... see pin 7 U10 ... high pin 7 is high and pin 1 U30 is also high ... pin 14 ... it's not there ... 114/ and why? ... 115/ Let's see ... motor ... pin ... motor ... motor ... door switch ... T1 ... think its closed ... so T ... 1 goes to pin 1 ... AB ... pin 1 pin 2 and from the door switch pin 2 and its locked. High ... U28 pin 4 is high ... pin 1 ... pin 4 is high of U28 ... 116/ pin 1 looking underneath ... 117/ pin 1 and pin 4 is high ... U25 ... pin 4 is high and U25 pin 4 is high ... pin 3 ... pin 5 is high ... 1, 0 ... pin 3 U25 ... low ... high is high ... U25 pin 3 is high ... pin 1 U26 ... high ... pin 5 ... U26 pin to ground ... U30 pin 9 is grounded ... pin 4 5 6 ... 9 ... see ... U25 pin 7 ... to pin 4 U25 pin 3 is high ... U26 ... pin 1 is high U26 pin 1 ... pin 5 of U26 to pin 5 of U26 to ground ... 118/ see where's ground ... 119/ U24 pin 7 is ground ... to 120/ U26 pin 5 ... U26 pin 5 ... 121/ 9.4 volts which is expected ... so its powered properly ... and ... 122/ T2 pin ... T2 ... let's see ... U31 pin 13 ... U30 ... U31 ... 13 is low ... pin 14 of U26 is high ... Pin 13 is low ... 123/ Board power ... 124/ let's see ... Ahh! ... volts between ground and power ... 125/ Vcc is 9 volts ... 126/ pin 5 ... pin

5 ... 127/ let's see ... pin 5 U26 ... is high ... pin ... ((please keep talking out loud)) ... 128/

I just don't know what's wrong ... ((Would you like to continue))

No, I think I will stop.

APPENDIX D

THOUGHT PROCESSES

Subject: #1

FAULT A

Fault Symptom #1: (Motor does not lock. Unlocking is ok. U25 pin6 is broken)

T	A000	The Problem is we enter 4 digit code of your own choice and press enter. Well let us try that ...
O	A001	What's going on?
T	A002	I am going to enter 1 2 3 ..Actually I have 1 1 2 ...alright ...and ....enter.
O	A003	Now the lock was supposed to move ...Didn't move ...We get a red light on there ...Ok ..
O.A	A004	So the computer has sent out the locking code D1=1 and D2=0....We don't know that...alright ...OC1 ...opto coupler 1 ...U28...alright ok. U25 U27 U28 ok. Alright plugged in here...Pin 1 is zero. D1 is zero...and....((Circuit showed a problem which was not part of the study. Protocol resumed after it was

corrected)).......

C.A A005 D1 should be 1 which is here. MR1 .. yea U30 ..ok. I better get used to these numbers. This has to be U30 I guess. U30..ok..So Pin 1 should be high. It's high and 2 ((D2))should be low. It's low. So computer is sending the right code. So far it is making sense.

O A006 However, the motor does not operate.

O.A A007 The display code does not disappear because motor driving mechanism is not closing the lock switch.

T A008 However, if the lock switch is manually closed, the displayed digits disappear. Yeah ..they do disappear.... right.

O A009 The displayed digits disappear and then the unlocking mechanism functions normally. Yeah ....ok ..alright..so only problem is that its not locking.

O.A A010 Now, ok ..well let's have a look. OK. We getting the right code...so... ok... the motor runs ...we found that....so unlock is 01 and lock is 10...ok.

h	A011	I think I am going to again try...Get back to the locking arrangement and just go to the other side of opto isolator and see if that is functional all right. I think I have to recycle the whole thing, I guess
T&O	A012	So I can enter any code now. 1 2 3 4 ...ok ...it goes back to red light.. ok ..just verify one more time that...yeah ...we have one zero code ...that's good.
T	A013	Alright, now we should go to U24 pin 1...ok ..
O	A014	U24 pin1 is low..ok...that's high ...
C.A	A015	so...it's..emitter follower...so when D 1 is high,it should be conducting.
h	A016	And U 24 one should be high ...
T&O	A017	It is high
C.A	A018	And two should be low. So both isolators are working.

h	A019	Then we go to pin 3...
T&O	A020	OK..1 is high 2 is high and 3 is high.
O.A	A021	That makes sense. So that NAND gate is ok.
h	A022	Now the next step will be to go to G2 and I will look at that ...so U25 pin 4 1 2 3 4
O	A024	U 25 pin 4 is high. This is interesting circuit.
O.A	A025	OK..5 is..4..is high, 5 is high and 6...There is a problem with 6.
H	A026	It should be low. So that is the problem, I think. ((The subject then replaces the IC and tests the system.))

SUMMARY

T	T&O	O	O.A	C.A	H	Total
5	3	6	5	3	5	27
					(h H)	
					(4+1)	

FAULT B

Fault Symptom #2. (Locking mechanism is ok. Problem is with unlocking. U25 pin 8 is bent.)

T&O	B000	O.K. we start...we select a code 1234 enter....O.K
T	B001	...now we try to unlock 1234 and enter
O	B002	and nothing happens
C.A	B003	...now for unlock we should have a code D1 zero and D2 one
T	B004	and so let's verify that
O	B005	....O.K.. D1 zero and D1((D2)) is high
C.A	B006	Now we quickly go over U24 GA to make sure it's functioning
T	B007	so U24 pin 1 is high. Pin2 is low 3 is high
O	B008	O.K.
T	B009	now let's go to U25 G2 Pin 1234

O	B010	Pin4 is low 5 is high
O.A	B011	...O.K. 4 is low 5 is high 6 is high so that's fine
h	B012	...let's follow that further with G1
T	B013	..U25 G1 Pin 1.
O	B014	2 is high 3 is Low
O.A	B015	so that chain is fine...
h	B016	let's go to the other side now
T	B017	U25 G3 pin 9 and 10...
O	B018	9 is high 10 is high and 8 has a problem...
O.A	B019	so U25 G3 output should be low but its floating
H	B020	...so that is our problem....

SUMMARY

T	T&O	O	O.A	C.A	h,H	Total
6	1	6	3	2	2+1	21

FAULT C

Fault Symptom #2. (Locking mechanism is working fine. Problem is with unlocking. U30 pin 12 is not grounded.)

WPA	C000	The locking function of the motor drive interface and drive mechanism is working fine. For unlocking, however, the selected digits are displayed but the motor does not operate to drive the unlocking mechanism
WPA	C001	we have same problem but ...alright...let's have a look at it
T	C002	So we enter a code.....o.k.
O	C003	the locking mechanism is working properly........and nothing happens.
C.A	C004	O.K. let us ...so, for unlock we should have D1 zero D2 one
T	C005	...go back and verify that
O	C006	...0...1
C.A	C007	we go back to U24

T	C008	...GA pin1 and 2
O	C009	...U24 pin 1 is should be high should be low ...and its not
C.A	C010	so looks like that u28 optical encoder...we follow that chain now ...
h	C011	let us go back to U28 and look at pin 4...
T	C012	U28 pin 4
O	C013	Yeah pin 4 is floating
C.A	C014	... pin 5 should have supply which it does... so that's fine ...we already ...verified the D1 is low
H	C015	...U28 optical encoder...opto isolator rather is gone...so we should change that
T	C016	...power off..let us get a screwdriver...yeah it will be better
O	C017	...here is the bad one.....O.K.

T	C018	let us bend the pins slightly in ..all right..let us supply the power again
O	C019	And running through diagnostics O.K.
O.A	C020	Now let us try...
h	C021	we should unlock and try it again
T	C022	1234 enter
O	C023	...it's locked now
A	C024	let us try to unlock
T	C025	...123...
O	C026	I made a mistake and I should clear it
T	C027	... 12 ...
O	C028	that's interesting ..o.k. so....now we have a different

problem...everytime I enter a digit, it enters twice

T	C029	... 1 ...
O	C030	that's strange
O.A	C031	So we had some problem and it doesn't seem to repeat itself ((it is only a switch debounce problem)) ...we still locked. alright...its not unlocking and
b	C032	so let us go back to see what is going on
T	C033	U24 pin 1..
O	C034	well 1 is still low
C.A	C035	...ok D1 is low D2 is high ok...let us go to the actual optical...
T&O	C036	U28(pin)1 is low
O.A	C037	ok..that is..

T&O	C038	2 is low
O.A	C039	so that is fine and
C.A	C040	we should look at 5 ..should be going to the supply
T&O	C041	1234...5 is going to the supply and
T&O	C042	4 is floating still
O.A	C043	well let us see that there is a short there is possibility of ..4 is floating actually..I will measure the voltage on 4 and see what we have
T	C044	...5 is reading 8 volts
O	C045	...that is strange
O.A	C046	...why voltage is so high ? oh just a second...
H	C047	let us put the other IC..that's it

T	C048	Put the IC in there...power supply want to look around the IC
h	C049	...oh dear..I know what I have been doing
C.A	C050	...I have not been looking any further than U24
H	C051	There is the possibility of U25 of course because that is what's ...eating it..so U25 probably was the problem and I have been chasing the wrong stuff..because I wasn't paying any attention to the circuit
T	C052	ok we have another U25 which is ... 7400 ... OK another 7400 ... ((Chip is being changed)). Apply power OK
O	C053	... and look at the voltage
T	C054	alright..let us try ...we are unlocked so enter a code..clear.. 4
O	C055	what's going on
O.A	C056	OK I was not unlocked ... problem ... OK ... 3 ...
T	C057	... OK let us try unlocking it again ... 1234 enter

O	C058	... and nothing is happening ... its interesting
h	C059	OK let us go back and see what do we have now
T&O	C060	U24 pin 1 is still pretty high
O.A	C061	its 1.5 OK right that is quite strange
h	C062	OK well let us make sure we still have D1 zero
T&O	C063	Yeah D1 zero ... Yeah D1 zero and D2 is one
O.A	C064	That is still OK
C.A	C065	what is going on here ... we changed all the three ICs ... did not have any effect
h	C066	OK the circuit diagram is supposedly complete ...

INTERRUPTION - Continued Later

T	C067	first of all we should try to lock alright I'm going to enter ... the

power is on to the system so I'm gonna enter my code 1234

O	C068	OK ... the lock is turning and I can have simulator as locked
T	C069	Then I go back to the unlock situation and try the code again 123
O	C070	I made a mistake so clear it again
T	C071	1234 enter and it is working
O	C072	OK am I reading it correctly
WPA	C073	Locked the vault using a secret code of your own choice press the main switch to the lock position..in order to simulate lock...vault.. ok..may be I should follow this again ok so I should enter the switch..is in unlock position..ok..
T	C074	I enter the code again 1234... enter ok I simulate lock condition by putting the switch over the lock position ok now I should enter the code and see if it opens 1234 enter
O	C075	and nothing happens

O.A	C076	ok the digit is digits correctly displayed...but the motor doesn't move
h	C077	ok so we should look at the circuit diagram which for the unlock position we should have D1 zero and D2 should be one
T&O	C078	so looking at the circuit diagram ok D1 is at U30 pin 1 U30 pin 1 ok U30 pin 1 I'm putting the logic probe on it and it is U30 pin 1 is low
O.A	C079	and this is how it should be unlocked
T&O	C080	and......the D1 should be high so that is ah
O.A	C081	I'm looking at now the U30 pin2 so the codes coming from the processors seem to be ok
h	C082	so the next step will be then ah...lets go to the other side of this opto isolator and see if that is functional
T	C083	so to look at D1 we should go to U24 pin 1 and see what the... it

it's high or low so U24 pin1 ..U24 pin 1 here's

O	C084	U24 pin 1 ok its neither high nor low
T	C085	ok lets go to pin2
O	C086	Pin 2 2 is high
O.A	C087	so D2 is high so something strange going on pin1 which is neither high neither low in what we expect here is low and
H	C088	that could be two causes of this problem either the U24 gate has gone..gate GA is gone or the opto isolator has a problem and I guess I could...just quickly look at other U24 7400 series gates so lets look at ah...other gates on the same .... same IC and see if they have some strange behavior
T&O	C089	Gate number 1 had a problem, number 2 is pin 4 ....5 and 6 that seems to be normal and pin 8 is the output 9
O	C090	yeah that pin 9 and 10 again are floating ah

A C091 ok..so seems to be two of the gates on U24 are bad

H C092 so its quite ah likely actually its pretty good guess that the U24 is the bad not the ah U28 isolator so, if I could have ah the soldiering iron and I'd like to try a different IC 7400

T C093 ok...ah...lets switch the power off ok lets get this ah U24 out of here can you get me a screw driver,.. thank you ok actually I don't need this right now I'll just take this chip out and put another one in there this is the bad one so this is the new 7400 ok like that's in there and we have to now ah apply the power again ok the ok its gone through the entire diagnostics

O C094 E21 code is showing and ah its its finished the diagnostics

O.A C095 so I'm going to try to see if it works again

T C096 1234 enter ok simulate the locked situation and go back and try unlocking it 12 ... 1234 enter

O C097 and it didn't do anything hmmm interesting

h	C098	...alright lets go back and check it again
T	C099	U24 pin 1
O	C100	same problem
O.A	C101	ok lets see what's going on now ah
h	C102	lets look at the back of this U board if anything strange
O	C103	don't see any obvious
C.A	C104	ah..problem there..ok..ahah...U24 is it used somewhere else or not I see U24 is only one gate which is being used ok whether its the output also going to G2 which is ah another 7400 IC
H	C105	so I could ah try replacing that I guess. Actually I have this old IC which I took out from the other one I could, I could, I could use that one
T	C106	so here goes the power

O	C107	Huhhmm...its interesting maybe our
T	C108	let me apply the power again
O	C109	may be I had a problem with this ah the unlock switch ah has 3 positions
O.A	C110	may be it was sitting in the middle
h	C111	lets quickly try it one more time
T	C112	ok just going through the diagnostic
O	C113	actually I just don't even need to wait for that because the gate is ah floating
H	C114	so lets just change the chip that's come out here's a new one I hope these chips are ok ha ha ha
T	C115	Right all right apply the power again
O	C116	Right we have unlocked position running the diagnostics

O.A C117 but we don't need to wait for that I can just measure U24 right away

T&O C118 ok U24 pin 1 is high pin 2 is high

O.A C119 seem to be a bit better

h C120 so lets just try locking it

T C121 1234 enter ok lock it ok then we go back and try unlock it 1234 enter

O C122 and nothing happens

O.A C123 alright lets just see where we stand now

T&O C124 U24 pin1 right same situation ok well

H C125 I think I should also change the opto coupler U28 because this thing is only gong to 2 places either to U24 or U25

C.A C126 so all the places going to is that ah and actually third one more place is the ahhahh the resistor network and one could even measure the resistance first of all on those see see what it is like

T&O	C127	ok U30 pin 3 to ground should be 100ohms pin 3 in 12 12345678 14 13 12 is 100ohms and pin 12 will be grounded so where's the ground here
O	C128	ok that seems to be grounded
O.A	C129	so that's yeah the resistor seems to be ok
H	C130	ok then alright I'll change the coupler U28 yeah U28
T&O	C131	here's the old chip and I'm going to put the new one in there... alright...lets one more time ...the power
h	C132	and lets just look at what we have pin U24 pin 1 ok alright
h	C133	lets put it in the unlock position and enter
T	C134	the code 1234 enter

O	C135	ok
h	C136	lets try unlocking it now 1234 enter
T&O	C137	and no go at all
h	C138	ok lets go back to U24 pin 1
T&O	C139	this is floating now that is quite interesting
C.A	C140	ok here the signal is only going to 3 places resistor is ok we changed that the interesting thing why is it floating ok ahahah U24 is not used anywhere else ok ahah now what has happened to U30 ok lets measure the voltages now gotta measure the DC voltage on U30 pin 3 which is the one which seems to be stranger...sitting at 4 volts no ah 1.3 volt ok and 4 is the high one that's so looks like there is too much current some how on coming out of the opto coupler ...and...U30 ...well....looks..seems to be ok in terms of ..100 or or MR3 is 100ohm
h	C141	check MR1

T&O	C142	ok MR1
T	C143	let power off here ...oh MR1 pin 1 and 14
O	C144	ok...that is 100ohm alright
C.A	C145	ok pin 2 of the optocoupler should be grounded
H	C146	and let us verify that U28 pin 2
T&O	C147	yes that is grounded
O.A	C148	Ok well that does not leave too many things that could be causing it. Its not being loaded. its sitting high so the
H	C149	may be the Vcc...supply is too high... or hmmm
T	C150	ok let us just measure the voltages again...its supply voltage..U28 pin 5...U28 pin 5 ...U28 pin 5...U28 pin 5....12345 and the ground ...where is the ground here.
O	C151	Pin 2 is the ground..looks 5 volts

T	C152	and U29 pin 5 ...pin 2 ..345
O	C153	ok seems the supply is going there..alright
h	C154	I guess I should visually examine this see whats happening
T&O	C155	U24..looks pretty clean Ok U25 is ...seems isn't shot on the PC..Ok hmmm...U24 pin 1 ...that looks reasonable
C.A	C156	oh yes that's pretty peculiar...yeah D1 is low but is it still conducting seems to be too much leakage in the optocoupler so ...and U25 is ..we changed that and its going no where else..U26..U30
T	C157	Hmmm let us supply the power...and right now its running diagnostic lets see what's happening there U24
O	C158	1 is high, 2 is high 2 is low ok
h	C159	yeah maybe I should look and use the scope and actually see what it looks like...here
T	C160	ok let's measure the voltage around the IC

O	C161	ok U24 ...ok supply voltage is good
O.A	C162	yes supply is good ground is good...U25 is fine U24 is fine that is narrowing down the process here we already confirmed its grounded
T	C163	hello ...what we got here U30 ..12
O	C164	here is minus 5.5 volts what's that?
O.A	C165	3..4.. U30 12 1 2 3 4 5 6 7 8 9 10 11 12
C.A	C166	well that's interesting U30 12 should be grounded why it's sitting at 5 volts..5.5 volts so
H	C167	either there is internal short in U30 or whats going on in that area... so best thing is ...well I can try different resistant network
T	C168	could I have that ...Ok let us try different resistor
O	C169	and see what we got now

O.A	C170	normally pretty unusual for a resistor to go but I guess its possible
T	C171	ok...right we go to unlock position ((on the simulator switch))
O.A	C172	very unlikely the resistor will go like that...well its possible I guess
T&O	C173	we run through the diagnostic and so lets now ...enter our code 1111..I am going to try this 1111...enter..
O	C174	well it is ((working properly. Subject tests the system.))
O.A	C175	that was the least likely candidate but actually that was the problem.

SUMMARY

WPA	T	T&O	O	O.A	C.A	h,H	Total
3	39	19	41	26	14	42	176
				(19+13)			

FAULT D

Fault Symptom #1. (Locking of the motor has a problem. Unlocking is ok. U31 pins 13 & 2 are broken.)

WPA	D000	ok problem is when you want to lock the vault ...the motor does not turn to activate the locking mechanism. However, if the lock switch is manually closed to simulate a locked vault ..the displayed digits disappear and then the unlocking mechanism functions normally
T	D001	Alright..let us follow so we are in unlock position...press any 4 digits code of your choice on the keyboard...1111 enter
O.	D002	ok...the L.E.D. indicator changes to red
T	D003	and the code should be D1 is 1 and D2 is zero. Let us verify that
O	D004	ok... D1 is 1 D2 zero...ok.only problem motor doesn't seem to be activating
O.A	D005	ok..so we have...I looked at U24

h	D006	I should look at U24 pin1
T&O	D007	U24 pin 1 is high..and pin 2 is low...well soon I come into that gate
O.A	D008	and since its a NAND gate the output should be high
T&O	D009	U24 pin3 is high
O.A	D010	ok
T	D011	now let us...we should look at U25 pin 5 pin 4 and pin 5
O	D012	pin 4 is high 5 is high ..and 6 is low
C.A	D013	so that's alright and that output of gate G2 on U25 goes to G1 on U25
T&O	D014	where 1 and 2 is low and 3 is high
O.A	D015	so U25 seems to be ok
h	D016	let us look at the other side

T	D017	G3 on U25 at pin 9 and 10
O	D018	9 is high 10 is low...and 8 is floating
T	D019	ok let us look at alright, let us measure the voltages around that
O	D020	I see something funny going on ...U25 ...its high
H	D021	I think U25 is gone
T&O	D022	let us make sure...8 ok
O.A	D023	what's going on here
T	D024	let us try U25 pin 9 ..8,9,10.....oh
O	D025	that's ok
T	D026	and we should look at output of so both of these are
O	D027	seem to be ok

C.A	D028	so let us summarize G1 ie U25 pin 3 is high and 11 14 13 ..11 is low..ok..alright....((please keep thinking.... talking out loud))
T	D029	let us look at ...U26 now . U26 is one withouc
O	D030	U25 3 is high...U26 1 is high ..ok..
O.A	D031	yeah that input is fine so we should look at pin 4 of U26
T&O	D032	pin 4 is high
h	D033	let us look at U27 that is the other opto isolator
T&O	D034	U27 pin 1 is low and pin 4 of same chip is low
O.A	D035	so we got high and low ok..hmmmm yeah that interesting ...so that logic part appears to be ok...and...ok...logic part appears to be alright we go 1 ...zero
h	D036	so T1 should be conducting because base is high OK
C.A	D037	T1 let me just refresh my memory here ... we are still in the lock

position ... so D1 is high D2 is low ... everything normal there ... ok ... let us go around U24 one more time in case I was not paying any attention

T&O D038 1 ... 2 same low 3 ... 4 is high ... 6 is low ... this is ok right 8 is high 9 is high ... 10 is low that is fine ... 11 is low ... 12 is high 13 is high ...

O.A D039 yes this looks normal

C.A D040 problem has to be ... so ... Yeah those couplers also look fine also ... well ...

T&O D041 that leaves us with few transistors to worry about or the motor itself

T&O D042 ok ... how can we check the Vcc2 ... Vcc2 is on pin 5 of opto coupler so let us measure the voltage ... ok ... U26 pin 5 ... 245 ... 9.45 volts

O.A D043 presumably that's ok I don't know how exactly that the right voltage

C.A	D044	assuming that is alright ... ok where is T1 transistor here ... T1 transistor ... there is Q1 ... Q2 ... alright
h	D045	those transistors are one thing that could be problem or any of those transistors
C.A	D046	actually the motor has to run ... to get positive to conduct and we should look at that voltage going out to the motor ... and let us see how ... is easy ... that
T	D047	let us see the motor voltage across the motor terminals
O	D048	we don't see any voltage at all
C.A	D049	the reason for this ... ok ... this ... when U26 is conducting then T1 should be conducting and we should have voltage there so ... and on this side so Q1 should be conducting and Q2 should be off ... and the motor should drive that way
T	D050	ok ... what is the actual voltage let us see on the Q1 the output of U26 pin 4 ... U26 pin 4

O	D051	it's 10 volts
O.A	D052	because it's conducting ((not conducting)) right ... Yeah U27 pin 4 should be zero
T	D053	right so
O	D054	it is conducting alright and the 10 volt applied there and there
h	D055	ok one could also be worth looking at the voltage on base of T2 ...which is U31 pin 2...U31 pin 2
T	D056	resistor U31 pin 2 is sitting at zero volts...U31 pin 2
H	D057	well that's the problem. ((subject test the system))

SUMMARY

WPA	T	T&O	O	O.A	C.A	h,H	Total
1	12	8	11	10	7	9	58
						(7+2)	

APPENDIX E

Thought Processes

Subject: #2

Fault A

Fault Symptom #1. (Motor does not lock. Unlocking is ok. U25 pin 6 is broken.)

C.A	A000	It's not locking properly ... so let's see ... D1 ... D2 ... is zero. D1 ... D2 is zero. So
T	A001	I am entering the code ... 1111 ... enter 002/ ...
GA	A002	I expect D1 to be high ... D2 to be low
T&O	A003	D1 high D2 low
C.A	A004	U28 ... let's see here. IC U24 ... pin 1 ... pin 1 U24 ... U27, U25, U24 ... pin 1 should be high ... high ... pin 2 should be low.
T&O	A005	Its low
C.A	A006	so pins 4 and 5 ... let's see, 1 and zero is zero ... not is one and one is zero. One and one is one and not is zero ... zero and zero ... and

not is one so pin 3 of U25 should be high

T	A007	pin3 of U25
O	A008	and it's low.
T&O	A009	So let's see pin4 U25 ... is high
h	A010	pin5 ... should be low
C.A	A011	But why it's high?
T	A012	Pin5 is high ... One and zero zero
O	A013	pin5 is high
O.A	A014	That's correct ... One ... one and zero ... is one ... one zero zero ... Not is one ... 5 is high
T	A015	4 is high ... pin6 ... is zero
O	A016	pin 6 is low ... It's not low ... it's nothing

O.A	017	4, 5 one and one is zero
C.A	A018	Pin 1 and 1 is one now is zero ... pin 6 should be ... zero ... pin 6 ... 4, 5, 6
H	A019	Ok seems like there is fault ..: U25 pin 6 ((keep speaking please)) ... It ... am I suppose to fix this ? ((Yes . You are suppose to fix it)) Ok ... ((But keep speaking please))
T	A020	Ok U25 pin 6 seems to be low or is not
O	A021	nothing on it. No voltage on it.
T	A022	I am going to change ... You have pliers or anything. ((Do you want pliers ?)) May be ... ((Ok I will give you pliers)) ... Ok ... ((yes . Keep speaking please)) yeah OH
O	A023	Pin is not bent or any thing
O.A	A024	Doesn't seem like anything is wrong.
T	A025	Pin 5 underneath ? ... 12345 ... 2345 ... and

O	A026	traces seem to be OK ... and OH!
T	A027	let's try this again ... 1111 ... enter
O	A028	and OK again its gone
C.A	A029	pin1 ... pin 4 of U25 and pin 5 U25 ... were supposed to be one's ... pin 4 and pin 5 are both high ... good ... pin 6. There is nothing at pin 6
H	A030	and let's see if there is power to
T	A031	pin 123 ...6 7... pin 7 is low ... pin 16 ... pin 14 is
O.A	A032	high so there is power to the board ... and to the chip ... pin 6 .. is not proper
T	A033	and let's see pin 6 U25 ... pin 12345 ...
O	A034	pin 6 does not go anywhere
C.A	A035	should go to pins 1 and 2 of U25 and large schematic and U25 ..

		U25 ... U25 pin 1, 2 go to pin 6 ... Pin 1 and Pin 2. Let's see here ... U25 pin 9 and 10 zero and one. One and zero is zero ... zero and not is one ... one and one not is zero ...
h	A036	Pin 11 should be zero.
T	A037	7, 8, 9, 10, 11 ...
O	A038	is nothing there.
T	A039	Pin 8
O	A040	there is nothing there ... pin 10 ...9, 10 ... OH! ... ((Keep speaking please)).
T	A041	I am just redialling the number again
O	A042	and power is back on again ...
C.A	A043	pin ... U25 pin 9 ... 789 is high, pin 10 is low as I expected ... so
T	A044	pin 8 should be high ...

O	A045	pin 8 is high ... so pin 11 9, 10, 11 is low but pin 3 is low. 4, 5, 6 ...
O.A	A046	pin 6 is not there! Ah! ...
H	A047	fault at pin 6 ... pin 6 of U25 ...
C.A	A048	One and zero ... One ... one of U24 high ... low is low NOT it's high high and high ... pin 6 should be low ... 123456 ...
H	A049	seems to be a fault at pin 6 of U25 ... Ok ... ((please keep speaking)) ...
T	A050	Ok I have to check why pin 6 does not go high ... Let's see ... Probe should be able to tell ...
O	A051	Pin ... that's the ground ... ((please keep speaking)) and pin 6 is low ...
O.A	A052	I expect it to be high ... but with the probe its not there at all ...
H	A053	and let's see may be a trace is cut or something ...

O.A	A054	may be at first ... Pin 6 Pin 1 ... Pin 2 ... I am doing ... taking out the chip ... and U25 ... and ... do you have another chip ? Ok ...
T	A055	and let's see if it works now. 1111 ... let's see enter ... and its working. So the fault was chip at U25.

SUMMARY

T	T&O	O	O.A	C.A	h,H	Total
16	3	13	7	10	7	56
					(2+5)	

Fault B

Fault Symptom #2. (Locking mechanism is ok. Problem is with unlocking. U25 pin 8 is bent.)

WPA	B000	The unlocking ... the motor does not operate because ... the unlocking is not done properly ...
T&O	B001	I press my code and it doesn't seem to go in
C.A	B002	so let's see ... Unlock should be D1 zero D2 one ... zero ... one ...one. One and zero ... zero so there should be high one ... 9 and 10 are one ... So pin 8 of U25 ... 6, 7, 8 should be low
T&O	B003	and it is
h	B004	and pin 11 ... 9 10 11 should be low.
C.A	B005	Let's see ... zero and one . D1 zero D2 one ... zero and one is zero NOT is one ... One and zero is zero NOT is One ... one not is zero ...
h	B006	Pin 3 should be zero ...

T	B007	Pin 3 should be low ...
O	B008	and it's low ...
C.A	B009	and pin 9 is one ... pin 10 is one ... one and one is ... high and high one and one is low ...
h	B010	and it should be low ... pin 12 ... U25 pin-8 is ...
T&O	B011	Let's see ... pin 9 of U25 is high. Pin 10 is high ...
O.A	B012	so high and high is high and NOT ... is low ... so high and high ... is low.
h	B013	Pin 8 should be low
T&O	B014	and it is low ... and
O.A	B015	low inverted is high ...
T	B016	and pin 11 should of U25 ....

O.A	B017	7 8 9 10 11 ... pin 11 ... pin 8 is low ... 9 and 10 ... U25 pin 9 and 10 ... is one NOT is ... zero ... and zero ... 11 should be one ... 4 5 6 7 8 9 10 11 ... and it's not ...
H	B018	Do you have another ... U25 ... Yes ...
T	B019	and there is no power ... Oh! ...
O	B020	Ok,.. That is the fault ...

SUMMARY

WPA	T	T&O	O	O.A	C.A	h	H	Total
1	3	4	2	3	3	4	1	21

Fault C

Fault Symptom #2. (Locking mechanism is working fine. Problem is with unlocking. U30 pin 12 is not grounded.)

T	C000	1111 ... and enter ...
O	C001	that's fine ...
T	C002	and 1111
O	C003	and its not unlocking .... properly.
C.A	C004	So let's look at the schematic ... Unlock O and one ... so pin ... U24 pin 3 ... should be high ... U24 ... U25 where is U24 ... U13 ... U16 ..wU24 ... pin 3 is low ... one one zero zero pin 3 ... should be one ... Pin 3 Oh
h	C005	let's check U24 ... pin 3. ((keep speaking please))
H	C006	and may be I can find another U24 ...
T	C007	for U24 ... and let's see if ... it sounds any better .... and let's try it again ... 1111 code ... enter ...

O	C008	it's locking properly ...
T	C009	1111 ....
O	C010	still not unlocking.
O.A	C011	May be there is more than one fault ... Pin 3 U24 ... is still low. pin 1 is high Pin 2 is not there ... low high ... Pin 1 of U24 is not there ... Pin 1 of U24 is not there ...
C.A	C012	so let's see D1 ... U28 pin 4 should be one ... U22 ... 20, 21 ... U28 ... where's U28 ... and 26, 27 , U29 ... U28 ...there U28 pin 4 ... is not ...
H	C013	may be it's not powered.
T&O	C014	pin2 to ground pin5 to power ...
H	C015	and is there another U28 ? ... ((Yes. I can give you another one))
T	C016	and putting U28 back in again ... and pin 1 pin 2 pin 3 ... OK. Let's try again 1111 Ok let's see 1111 ...

O	C017	open
T	C018	1111 ...
O	C019	still not locking ...
C.A	C020	let's check it ... D1 should be low ... so pin1 should be high ... its low ... Sorry pin 1 is low ... pin 2 is low ... pin 4 is not there. Pin 5 is high ...
H	C021	pin 4 ?
T	C022	let us check the trace ... and ... Oh! ... 123 ... let's see then ...
O	C023	pin ... U28 pin 4 is not done properly ...
h	C024	let's see U30 pin 12 ...
O	C025	resistor U30 ... U30 pin 12 U30 pin 12 ... U28, U29 ... U31 ... U26 ... U27 ...
T	C026	U30 ... Pin 12 ... 9 10 11 12

O	C027	is tied high U30 pin 12 is tied high
O.A	C028	should be low ...
H	C029	so the fault seems to be U30 pin 12. It's not tied to ground.
T	C030	Let's check it ... entering the code ...
O	C031	it's locking fine and ...
T	C032	Unlock ... and 1111
O	C033	it's not unlocking.
T	C034	Let's check it ... where's the screw driver U30 pin 12...
O	C035	and OH! the pin 12 is cut.

<u>SUMMARY</u>

<u>T</u>	<u>T&O</u>	<u>O</u>	<u>O.A</u>	<u>C.A</u>	<u>h</u>	<u>H</u>	<u>Total</u>
11	1	12	2	3	2	5	26

Fault D

Fault Symptom #1. (Locking of the motor has a problem. Unlocking is ok. U31 pins 13 & 2 are broken.)

T	D000	Ok Let's see ... does not lock properly ... so 1111 enter ...
O	D001	it's not locking ...
C.A	D002	so locking is one zero ... D1, D2 is one zero ... so U28 pin 1 should be high and its not ... Let's see U28 pin 1 ... pin 4 should be high as well ...
T&O	D003	Yes pin 4 is high ... U30 pin 12 ... 7 8 9 10 11 12 ... its tied low ... pin 5 of U28 is tied high ... pin 2 is tied low ...
O.A	D004	D1 should be high ...
T	D005	lets see U28 pin 1 ...
H	D006	try another U28 pin 1 ... ((yeah ! please keep speaking)) and U28 pin 1 OK and let's try U28 pin 1.
T	D007	Trying up gain ... and ... its in open position ... and 1111 ... enter

O	D008	and its not locking still ...
h	D009	so let's check ... U30 pin 11 ...
T&O	D010	U30 7 8 9 10 11 is tied low
O.A	D011	pin 5 is tied high ... and D2 is zero ... so pin1 U30 ... is now ... is high ... ((please keep speaking))
C.A	D012	Ok ... pin 1 U30 is high ... and pin 2 is low ... pin 1 is high pin 2 is low ... that's fine pin 4 should be low ... that's high ... U29 .. pin 1 is low ... pin 2 is low ... pin 5 is high ... that's fine ... and .. pin 1 of U28 is not fine ... is not high ... pin 1 U28 and ... pin 1 U28 ... what could be wrong with pin 1 U28 ? ... pin 1 U28 ...
H	D013	Do you have yet another one ; may be ? ... ((yeah . I will give you)) ... ((keep speaking please)) ... something wrong with pin 1 of u28 ...
T	D014	let's see U28 pin 1 ... pin 5, 4 and 5 ... U28 pin 1 OK ... let's see ... let's check it ... pin 1 U28 ... and there we go ... its in ...

O	D015	power is back ...
T	D016	1111 ... enter ...
O	D017	its in open position but does not lock properly ...
O.A	D018	let's see ... It's not the chip ... U28 pin 1 ... D1 ... should be one ...
C.A	D019	and let's see U28 on other schematic ... pin 1 (the subject is now locking at the main schematic) ... U28 ... U27 , U26 24, 25 ... Oh there is U28 ... U28 ... U10, Y5 ... pin 7 of U10 ...
T	D020	pin 7 of U10 ... U10 pin 7 ... 3 4 5 6 7 ... is high one ...
O.A	D021	which it should be ... pin 7 U10 is high
C.A	D022	and should be going ... LED ... and then from the LED ... to pin 1 of U30 and its high and pin 1 of U30 ... and pin 14 ... is not there
H	D023	So let's see I am replacing U30 ... something wrong with pin 1 of U30

T	D024	I am removing U30 ... and replacing it ... Let's see and ... try it again ... 1111
O	D025	and it's still not fine
C.A	D026	Let's see ... Ok ... pin 1 is fine now ... U28 ... pin 1 of U28 is not fine ... U30 ... U28 ...
H	D027	let's see is it a trace cut ? ((Please keep speaking))
T	D028	and let's see ...
O.A	D029	I can't see the trace underneath ... to U28 ... U28 pin 1 ... pin 14 of U30 ... OH! ... pin 14 U30 is going to U26 pin 1 and now ... let's see ... pin 1 of U28 ... pin 14
H	D030	This chip is not right ...
T	D031	Let's see ... and is there another one for this ... I am looking for another U30 ... ((please keep speaking)) U30 pin 1 U30 pin 1 .. OK replacing U30 ... OK ... let's power it up again ... Now ..

1111

O D032 its not locking ...

T D033 let's see ... Now' ... U30 pin 14 ...

O D034 still not there ...

C.A D035 pin 1 is high ... U30 pin 1 is high ... U 14 ... is not there ... pin 14 ... is not there ... Pin 14 ... Pin 14 ... is ... let's see.

H D036 Is there a short there between pin 14? ...

T D037 No short ...

H D038 Do you have another one of U ... please ((You have changed three times)) This was not a resistor ... ((All of these are resistors)) ...

O D039 OK ... But this wouldn't help ...

C.A D040 OK ... U30 pin 1 to pin 14 ... (subject is again looking at the main schematic) ... 14 ... 1111 ... It does not go high ... so let's see ... U28 pin 2 is grounded pin 5 is high ... and pin 4 is high ... and nothing at pin 1 ... Nothing at pin 14 and nothing at pin 1 ... U30 pin 1 to pin 14 ...

h	D041	let's check it ... may be internally something is broken ...
T	D042	and let's see ... Ohmmeter ... Putting ohmmeter between ... pin 1 and U28 ... should be open circuit
O	D043	which it is ...
O.A	D044	pin 1 and pin 14 ... see .... 100 ohms ... Should be 100 ohms ... pin 1 ... Oh ... its 100 ohms between pin 1 and pin 14 ... 100 ... and pin 14 is high ...
T	D045	let's try again ... its open ... want to lock it ...
O	D046	It's not locking ...
O.A	D047	Pin 1 is not going high ... U28 pin 2 is high ...
h	D048	and let's check U28 ... the diode there ...

T	D049	U28 its diode ... between pin 1 and 2 of U28 ((Please keep speaking)) ... Pins 1 to U28 is ... OH! hang on ... Let's try this U28 pin 1 ... to pin 2
O	D050	its high ... 1 to pin 2 ... 1.3 volts ...
T	D051	Pin up power and lock ...
O	D052	It's not locking ...
O.A	D053	pin 1 to pin 2 of U28 ... Pin 1 to Pin2 ... Pin 4 ... Oh ... I am ... ((please keep speaking)) ... Boy! ... right now nothing is going through my mind ... can't see what's wrong now
C.A	D054	that resistance is high ... 1 is high 14 is low ... U28 pin 5 is high ... D1 ... is one ... for locking its high and its high and ... oh boy! ... ((please keep speaking))
H	D055	I don't Know what's wrong ...
T	D056	let's see ... 1111 ...

O	D057	It's not locking ...
C.A	D058	Pin 1 of U28 is ... U30 sorry U30 pin 1 is high ... pin 14 is not ... Oh ... let's see what could be wrong ... Tried replacing the resistor ... that didn't help ...
H	D059	let's see ... let me try replacing it again ...
T	D060	checking the volt ... resistance between ... pin 1 and pin 14 ... pin 1 to pin 14 ...
O	D061	100 ohms ...
O.A	D062	fine ... pin 1 ... Ok ... so ... pin 1 is high ... pin 14 is not ... it should be high ...
H	D063	OH ... nothing is going through my mind ... I am stunned ... Have no idea ... ((please keep talking out loud)) ... I have no idea what's wrong ... Why isn't pin 14 going high ... U28 pin 1 to pin 14 ... why is that pin 14 is not there either ... I haven't got the foggiest idea ...

C.A	D064	There is 100 ohms between there ... I saw nothing wrong ... between pin 1 and pin 14 ... ((please keep talking out loud)) pin 1 ... and pin 14 ... pin 14 goes to ...
T	D065	see the trace goes
O	D066	under U26 ... pin 14.
O.A	D067	I shouldn't do that.
C.A	D068	Let's see U28 pin 1 ... U28 pin 1 ...
h	D069	Let's do continuity test between pin 14 of U30 and pin 1 of U28 ...
T	D070	it's high ...
O.A	D071	pin 1 of U28 ... and pin 14 ... pin 1 of U28 and pin 14 of U30 ... is high ... so ... ((please keep speaking))
h	D072	I don't know what could be wrong

T	D073	Let's see Pin 1 to pin 14 is fine ...
O.A	D074	there is 100 ohms ... but nothing going through ...
C.A	D075	let's see the motor was fine ... and let's see what else ... pin 1 .. pin 4 ...
h	D076	let's check the voltage here ...
T&O	D077	One ... pin 1 U24 ... 26,25,24 ... is high ... pin 2 is low ... 1 is high ... pin 3 is high ...
O.A	D078	one zero ... one low ... 1 is high ... pin 4 is low ...
C.A	D079	U24 pin 1 and pin 4 is same should be the same ... Let's see ...
T	D080	pin 7 is ground ... pin 14 is high ...
H	D081	let's replace U24 ...
T	D082	U24 is replaced ... let's see ...

h	D083	let's lock it again ...
T	D084	checking ... 1111 ... enter ...
O	D085	why ... wonder ... pin 1 is low pin 4 is high ... oh ... U25 ... pin 4 ... and U24 pin 1 is high ... pin 4 is high ... pin 3 of U24 ... is high ... high high ... low ...
O.A	D086	pin 3 of U25 should be high ...
T&O	D087	so its high ... ah ... U25 ... 9 ... 4 5 6 7 8 9 ... high ,
O.A	D088	pin 10 should be low ...
C.A	D089	low ... high and low ... is low ... Not is high ... Not is low ... pin 11 should be low ...
T	D090	is low ... pin 1 U26 is high
C.A	D091	U30 pin 9 should be grounded ...
T	D092	9 ... is low.

C.A	D093	Pin 6 should be high ...
T&O	D094	Pin 6 is not there ... 3 4 5 6 ... pin ... U 26 ... 1 and 2 ... 4 ... pin 4 is low pin 5 ... U26 oops U26 ... pin 1 is high , pin 4 is high ... pin 5 is high ... pin 4 is U26 pin 4 is high ... pin ... U31 ...
H	D095	now let's see pin 2 of U31 seems to be bent ...
T	D096	see U31 ... Oh ... boy ... I will try that ... ((please keep talking loud)) ... and just fixed U31 pin 2 ...
h	D097	and let's try it again ...
T	D098	let's see ... 1111 ... still not working ...
C.A	D099	see U31 pin 2 is low U26 pin 4 is high ... pin 13 U31 ... is low ... U31 pin 13 is low ... and 4 is high ... How is that ? ... 13 is low ... U31 pin 13 is low ... see to turn motor on ... I need ...
T&O	D100	let's see pin 7 ... 1 ... pin 14 U31 ... low ... pin 1 low ... 14 and 1 ... low ... 2 and 13 low ... 4 ... U27 is low ... 4 U26 is high.

H	D101	let's see ... U26
T	D102	checking out U26 ... replacing U26 ... 1111 ... enter ...
O	D103	doesn't lock ...
C.A	D104	motor is connected ... the diode is connected. No disconnection here ... Ok. Let's see again ...
T	D105	U26 pin 4 is high ... U31 pin 13 is low ...
C.A	D106	Low and low ... pin 2 of U31 is low ... pin 1 of U31 is low ... so that's off ... Let's see pin ... T1 ... where's T1 ... T1 ... U1 ... U31 ... U26 ... Where's T1 Ok ...
T	D107	There ... T1 should be ... is high and ... T3 is ... Let's see T3 ... is Q3 ... is tied high ...
C.A	D108	Now T2 ... is Q2 ... T1 ...
h	D109	What's the matter ... ((Please keep talking out loud)) ...

C.A	D110	T1 ... T3 ... T2 ... let's see ... base of T1 ... T1 ... is tied high ... T2 ... base is low... so it's off ... this transistor is off ... T3 base is ... T1 ... so this is high ... T3 ... see ... T3 is tied low ... the base of T3 is low ... so T3 ... its low ... so ... T3 is off ... T4 ... the base of T4 ... is low ... This is turned off ... it's low ... high ... low ... T4 ... T1 ... T1 is tied to ... T4 is tied high ... T1 is tied high ...
T	D111	Yeah ... 1111... Oh! oof ... ((Please keep talking out loud)) ...
h	D112	I really don't know what's wrong ... ((please keep talking)) Let's see what else ... Let's check power on ...
C.A	D113	It's processor's ... (subject is consulting the main schematic) ... T ... see pin 7 U10 ... high pin 7 is high and pin 1 U30 is also high ... pin 14 ... it's not there ...
h	D114	and why? ...
C.A	D115	Let's see ... motor ... pin ... motor ... motor ... door switch ... T1 ... think its closed ... so T ... 1 goes to pin 1 ... AB ... pin 1 pin 2 and from the door switch pin 2 and its locked. High ... U28 pin 4 is high ... pin 1 ... pin 4 is high of U28 ...

O	D116	pin 1 looking underneath ...
C.A	D117	pin 1 and pin 4 is high ... U25 ... pin 4 is high and U25 pin 4 is high ... pin 3 ... pin 5 is high ... 1, 0 ... pin 3 U25 ... low ... high is high ... U25 pin 3 is high ... pin 1 U26 ... high ... pin 5 ... U26 pin to ground ... U30 pin 9 is grounded ... pin 4 5 6 ... 9 ... see ... U25 pin 7 ... to pin 4 U25 pin 3 is high ... U26 ... pin 1 is high U26 pin 1 ... pin 5 of U26 to pin 5 of U26 to ground ...
h	D118	see where's ground ...
C.A	D119	U24 pin 7 is ground ... to
T	D120	U26 pin 5 ... U26 pin 5 ...
O.A	D121	9.4 volts which is expected ... so its powered properly ... and ...
C.A	D122	T2 pin ... T2 ... let's see ... U31 pin 13 ... U30 ... U31 ... 13 is low ... pin 14 of U26 is high ... Pin 13 is low ...
H	D123	Board power ...

T	D124	let's see ... Ahh! ... volts between ground and power ...
O	D125	Vcc is 9 volts ...
h	D126	pin 5 ... pin 5 ...
T	D127	let's see ... pin 5 U26 ... is high ... pin ... ((please keep talking out loud)) ...
h	D128	I just don't know what's wrong ... ((Would you like to continue))

No, I think I will stop.

SUMMARY (Incomplete)

T	T&O	O	O.A	C.A	h	H	Total
34	6	19	16	26	14	14	129

List of References

1. Aanstoos, C.M. (1983) "The thinking aloud method in descriptive research". Journal of Phenomenological psychology.

2. Alvermann, D.E. (1984) " Second graders' strategic preferences while reading basal stories." Journal of Educational Research, 77, 184-189.

3. Baker, L. & Brown, A.L. (1984) " Cognitive monitoring in reading." Understanding reading comprehension: Cognition language, and structure of the prose." International Reading Association, Newark, DE.

4. Baldwin, R.D. (April, 1978) " Training the electronics maintenance technician ". HumRRO(7-78).

5. Bransford, J.D. (1979) " Human cognition learning, understanding and remembering." Belmont, Wodsworth.

6. Brigham, F & Laios, L . (1957) " Operator performance in the control of a laboratory process plant." Ergonomics, 18, 53 - 66.

7. Brooke, J.B. & Duncan, K.D. (1981) " Effects of system display format on performance in a fault location task ". Ergonomics, 24, 175-189.

8. Brooke, J.B; Duncan, K.D. & Cooper, C. (1980) "Interactive instruction in solving fault - finding problems. An experimental study I.J. of Man - Machine Studies, 12. 217 - 227.

9. Brooke J.B; Cooke, J.F. & Duncan K.D. (1983) " Effects of computer aiding and pretraining on fault location. "Ergonomics, 26, 669 - 686.

10. Brooke, J.B; Duncan, K.D. & Marshall, E.C. (1978) "Inter-active instruction in solving fault - finding problems. " I.J. of Man - Machine studies, 10, 603-611.

11. Brown, J.S.; Burton, R.R. & Bell, A.G. (1975) " SOPHIE: A step toward creating a reactive learning environment." Man-Machine Studies.

12. Brown, J.S.; Burton, R.R. & Bell, A.G. (March, 1974) " SOPHIE: A Sophisticated Instructional Environment for teaching Electronic Trouble-Shooting." Bolt Beranek and Newman Inc.

13. Brown, J.S.; Burton, R.R. & DeKleer, J. (1982) " Pedagogical, natural language and knowledge engineering techniques in SOPHIE." Xeros Palo Alto Research Center.

14. Brown, A.L. (1976) " Qualitative knowledge, causal reasoning and the localization of failures." MIT AI TR-362.

15. Carroll, J.S. & Payne, J. W. (1977) " Judgements about crime and the criminal. A model and a method for investigating parole decisions." Perspectives in law and psychology: The criminal justice system (Vol 1), New York, Plenum.

16. Chase, W.G. & Simon H.A. (1973) "Visual information processing" New York. Academic press.

17. Chi, M.T.H. ; Glaser, R.; & Rees, E. (1981) " Expertise in problem solving". Advances in the psychology of human intelligence. Hillsdale, Erlbaum.

18. Crooks, W.H.; Kuppin, M.A. & Freedy, A. (January, 1977) " Application of adaptive decision aiding systems to computer assisted instruction." Perceptronics. Woodland Hills CA.

19. Crossman, E.R.F.W. & Cooke, J.E. (1974) " Manual control of slow - response systems." The human operator in process control. London, Taylor and Francis.

20. DeKleer, J. (1976) " Local methods for localizing faults in electronic circuits." MIT AI AIM-394.

21. Duncan K.D. & Shepherd A. (1975) "A simulator and training technique for diagnosing plant failures from control panels." Ergonomics, 18, 627 - 641.

22. Duncan, K.D. (1971) " Long-term retention and transfer of an industrial search skill." British Journal of Psychology."

23. Elliott, TK. (November, 1967) " The effect of electronic aptitude in performance of proceduralized trouble - shooting tasks". Applied Science Associates, Tech. Report AMRL - TR - 67 - 154.

24. Elliott, T.K. (November, 1966) " Effect of format and detail of job performance aids in performing simulated trouble - shooting tasks." Applied Science Associates, Tech. Report- AMRL - TR - 65 - 154.

25. Elliott, T.K. & Joyce, R.P. (November, 1968) " An experimental comparison of procedural and conventional electronic trouble-shooting." Applied Science Associates.

26. Elliott, T.K. (December 1966) " A comparison of three methods for presenting procedural trouble - shooting information." Applied Science Associates, Tech. Report AMRL - TR - 66 - 191.

27. Elliott, T.K. & Joyce, R.P. (1971) " An experimental evaluation of a method for simplifying electronic maintenance." Human Factors.

28. Erickson, J.R. & Jones, M.R. (1978) " Thinking". Annual review of psychology.

29. Ericsson, K.A. & Simon, H.A. (1980) " Verbal reports as data." Psychological Review, 87, 215-251.

30. Ericsson, K.A. & Simon, H.A. (1984) " Protocol Analysis: Verbal reports as Data." MIT Press, Cambridge, Massachusetts.

31. Falmagne, R.J. (1975) " Reasoning : Representation and Process". Hillsdale. Erlbaum.

32. Greeno J.G. (1978) "Natures of problem solving abilities" Handbook of learning and cognitive processes. Vol 5. Human information processing. Hillsdale, Erlbaum.

33. Fattu, N.A. & Mech, E.V. (1953) " The effect of set on performance in a trouble shooting situation."

34. Gettys, C.F; Manning, C.; Mehle, T. & Fisher, S. (October, 1980) " Hypothesis generation: A final report of three years of research" Decision Processes Laboratory Tech. Report.

35. Miller, E.E. (July,1975) " Instructional strategies using low cost simulation for electronics maintenance." HummRRO.

36. Federico, P.A. (1983) " Changes in the cognitive components of achievement as students proceed through computer-managed instruction." Journal of Computer Based Instruction.

37. Federico, P.A. (1982) " Individual differences in cognitive characteristics and computer-managed mastery learning." Journal of Computer Based Instruction.

38. Federico, P.A. & Landis, D.B. (April, 1980) " Relationships among selected measures of cognitive styles, abilities, and aptitudes." Navy Personnel Research and Development Center.

39. Federico, P.A. & Landis, D.B. (August,1979) " Predicting student performance in a computer-managed course using measures of cognitive styles, abilities, and aptitudes." Navy Personnel Research and Development Center."

40. Foley, J.P.Jr. (December, 1977) " Performance measurement of maintenance." Air Force Human Resources laboratory OH.

41. Forrest-Pressley, D.L. & Gillies, L.A. (1983) " Children's flexible use of strategies during reading." Cognitive strategy research: Educational applications (pp 133-156). New York, Springer-Verlag.

42. Garner, R. & Alexander, P. (1982) " Strategic processing of text : An investigation of the effects on adults' question-answering performance." Journal of Educational Research, 75, 144-148.

43. Gibson, J.J. (1966) " The senses considered as perceptual systems." Boston, MA. Houghton Mifflin.

44. Giorgi, A. (August, 1982) " Theoretical justification for the use of descriptions in psychological research." American Psychological Association, Washington, D.C.

45. Glaser, R. & Phillips, J.C. (August, 1954) " Analysis of proficiency for guided missile personnel: 111 Patterns of trouble shooting behavior". American Institute of Research.

46. Glaser, R. (1984) " Education and thinking: The role of knowledge." American Psychologist, 39, 93-104.

47. Goldbeck, R.A.; Bernstein, B.B.; Hilbix, W.A. & Mars, M.H. (1957) "Application of the half - split technique to problem - solving tasks." Journal of Experimental Psychology, 53, 330 -338.

48. Hartley, R.T. (1984) " CRIB: Computer fault-finding through knowledge engineering." IEEE Computer.

49. Hennman, R.L. & Rouse, W.B. (1984) "Measures of human problem solving performance in fault diagnosis tasks." IEEE Transactions on Systems, Man and Cybernetics.

50. Highland, R.W.; Newman, S.E. & Waller, H.S. (1956) " A descriptive study of electronic trouble-shooting." Air Research and Development Command.

51. Hoc, J.M. & Leplat, J. (1982) " Evaluation of different modalities of verbalization in a sorting task." Int. J. Man-Machine Studies (1983) 18, 283-306.

52. Hopf - Weichel, R; Purcell, D; Freedy, A. & Lucaccini, L. (November, 1979) "Adaptive decision in computer assisted instruction." Perceptronics, Woodland Hills, CA.

53. Huberman, A.M. & Miles, M.B. (1984) " Information up close: how school improvement works." New york, Plenum.

54. Hunt, R.M. & Rouse, W. (1981) " Problem-solving skills of maintenance trainees in diagnosing faults in simulated power plants." Human Factors.

55. Hunt, R.M.; Henneman, R.L. & Rouse, W.B. (1981) " Characterizing the development of human expertise in simulated fault diagnosis tasks." IEEE Systems, and Cybernetics Society.

56. Johnson, P.E.; Duran, A.S.; Hassebrock, F; Moller, J.; Prietula, M.; Feltovich, P.J & Swanson, D.B. (1981) " Expertise and error in diagnostic reasoning." Cognitive Science.

57. Kail, R.V. & Bisanz, J. " Cognitive strategies." Handbook of research methods in human memory and cognition (pp 229-255), New York, Academic Press.

58. Karpf, D.A. (1973) " Thinking aloud in human discrimination learning." Dissertation Abstracts International, 33, 6111-B.

59. Kazdin, A. E. (1976) " Assessment of imagery during covert modelling of assertive behavior." Journal of Behavior Theory & Experimental Psychiatry, 7, 213-219.

60. Kellog, R.T. (1982) " When can we introspect accurately about mental processes?" Memory and cognition, 10, 141-144.

61. Kragt, H. & Landeweerd, J.A. (1974) " Manual skills in process control." The human operator in process control. London, Taylor and Francis.

62. Laffey, T. J.; Perkins, W. A. & Nguyen, T.A. (1986) " Reasoning about fault diagnosis with LES." IEEE Expert.

63. Larkin, J.H. (1979) " Models of competence in solving physics problems" Working paper, Carnagie Mellon University.

64. Larkin, et al (1980) " Expert and novice performance in solving physics problems" Science vol 208.

65. Larkin, J.H. (1977) "Skilled problem solving in experts". Technical reports.

66. Lenk, J.D. (1990) "Practical Electronic trouble-shooting". Englewood Cliffs, NJ. Prentice Hall.

67. Marshall, C. (1984) " The wrong time for mechanistics in qualitative research." In response to Miles & Huberman. Educational Researcher, compiled by Dawson, A.J. Faculty of Education, Simon Fraser University, B.C.

68. Mayer, R.E. ; Strehl, C. & Greeno, J.G. (1975) " Acquisition of understanding and skill in relation to subjects preparation and meaningfulness of instruction." Journal of Educational Psychology, 67, 331 - 350.

69. Mayer, R.E. & Greeno, J.G. (1972) " Structural differences between learning outcomes produced by different instructional methods." Journal of Educational Psychology, 63, 165 - 173.

70. McDermott, J. & Larkin, J.H. (1978) "Proceedings of second conference of the Canadian Society for computational studies of intelligence".

71. McDonald, L.B.; Waldrop, G.P. & White, V.T. (December 1983) "Analysis of fidelity requirements for electronics equipment maintenance " Naval Training Equipment Center.

72. Mehle T. (February 1980) " Hypothesis generation in an automobile malfunction inference task" Decision Processes Laboratories.Technical reports.

73. Meichenbaum, D. (1980) " A cognitive-behavioral perspective on intelligence." Intelligence, 4, 271-283.

74. Mills, R.G. (1971) " Probability processing and diagnostic search" Psychonomic Science.

75. Moore J.V.; Saltz, E. & Hoehn A.J. (September, 1955) Improving equipment maintenance by means of a preplanning technique". Air Force Personnel Training Research Centre.

76. Morris, N.M. & Rouse, W.B. (1985) " Review and evaluation of empirical research in Trouble Shooting." Human Factors, 27(5), 503 - 530.

77. Morris, N.M. & Rouse, W.B. (1985) " The effects of type of knowledge upon human problem solving in a process control task" IEEE Transactions on Systems, Man, and Cybernetics

78. Nagel,L.W. & Pederson, D.O. (April, 1973) " SPICE: Simulation Program with Integrated Circuit Emphasis." Electronics Research Laboratory, University of California, Berkley.

79. Newell, A. & Simon, H.A. (1972) "Human problem solving". NJ, Prentice Hall.

80. Newell, A. (1979) " Reasoning, Problem solving and decision processes: The problem space as a fundamental category". Carnegie Mellon University.

81. Nisbett, R.E. & Wilson, T.D. (1977) "Telling more than we know: Verbal reports on mental processes". Psychological Review 84, 231-259.

82. Olshavsky, J.E. (1976 -1977) " Reading as problem solving. An investigation of strategies." Reading Research Quarterly. 12, 654 - 674.

83. Olson, G.M.; Mack, R.L. & Duffy, S.A. (1981) " Cognitive aspects of genre." Poetics, 10, 283-315.

84. Osborn, A.F. (1942) " How to think up." (1948) " Your creative power." (1952) " Wake up your mind." (1963) " Applied imagination." New York, Scribner's.

85. Paris, S.G.; Lipson, M.Y. & Wixson, K.K. (1983) " Becoming a strategic reader." Contemporary Educational Psychology, 8, 293-316.

86. Potter, N.R. &. Thomes, D.L. (September, 1976) " Evaluation of three types of technical data for trouble-shooting." Systems Research Laboratories.*

87. Revlin, R. & Mayer, R.E. (1978) "Human reasoning" Winston.

88. Rigney, J.W. & Holfman, L.A. (June, 1961) " An experimental study of factors influencing trouble - shooting difficulty. " Electronics Personnel Research Group. University of Southern California.

89. Rigney, J.W.; Towne, D.M; Morna, P.J. & Mishler, R.A. (July, 1980) "Field evaluation of the generalized maintenance trainer simulator." Navy Personnel Research and Development Center San Diego, CA.

90. Rouse, W.B. (1979) " Problem solving performance of maintenance trainees in a fault diagnosis task" Human Factors, 21, 195-203

91. Rouse, W.B. & Hunt, R.M. (1984) " Human problem solving in fault diagnosis tasks." Advances in man - machine systems research Greenwich, CT: JAI Press.

92. Schorgmayer, H. & Swanson, R.A. (August, 1975) " The effect of alternative training methods on the trouble-shooting performance of maintenance technicians." State University OH.

93. Schwartz, M.S. & Schwartz, C.G. (1955) " Problems in participant observation." American Journal of Sociology, 60, 343-354.

94. Sheperd, A; Marshall, E.C.; Turner, A. & Duncan, K.D. (1977) " Diagnosis of plant failures from a control panel." Ergonomics 20, 347-361.

95. Simon, D.P. & Simon, H.A. (1978) " Children's thinking: What develops". Earbaum, Hillsdale.

96. Simon, H.A. (1969) " Information-processing theory of human problem solving." Handbook of learning and cognitive processes (Vol 5). Hillside, NJ, Lawrence Erlbaum Associates, Inc. 1978.

97. Elstein, A.S.; Shulman, L.S; & Sprafka, S.A. (1978) " Medical problem solving: An analysis of clinical reasoning" Harvard University press.

98. Skinner, B.F. (1957) " Verbal behavior." Appleton Century Crofts, New York.

99. Slovic, P; Fischoff, B. & Lichtenstein, S. (1977) " Behavioral decision theory" Annual Review of Psychology.

100. Smillie, R.J. & Porta, M.M. (October, 1981) " Comparison of state tables and ordnance publications for trouble shooting digital equipment." Hughes Aircraft corporation, Tech. Report NPRDC TR 82 -7.

101. Stolurow, L.M.; Bergum, B.; Hodgson, T. & Silva, J. (1955) " The efficient course of action in trouble-shooting as a joint function of probability and cost." Educational and Psychological Measurement.

102. Tuthill, D. & Ashton, P.T. (1983) " Improving educational research through the development of educational paradigms." Educational Researcher, 12(10), 6-14.

103. Van Matre, N.H. & Steinemann, J.H. (December, 1966) " A performance oriented electronics technician training program." U.S. naval personnel research activity San Diego CA. (October, 1967)

104. Vineberg, R.A. (1955, 1968) " A performance test for the radar mechanic and observations on trouble-shooting behavior" HumRRO.

105. Wallas, G. (1926) " The art of thought." New York, Harcourt.

106. Wasson, P.C. & Johnson- Laired, P.N. (1972) " Psychology of reasoning: Structure and content". Harvard University Press.

107. White, P. (1980) "Limitations on verbal reports of internal events: A refutation of Nisbett and Wilson and of Bem" American Psychological Association.

108. Williams, W.L.Jr. & Whitmore, P.G..Jr (1959) " The development and use of a performance test as a basis for comparing technicians with and without field experience." Human Resources Research Office Tech. Report # 52.

109. Wohl, J.G. (1982) "Maintainability prediction revisited: Diagnostic behavior, System complexity, and repair time" IEEE Transactions on Systems, Man and Cybernetics