FAILURE DIAGNOSTIC EXPERT SYSTEMS:  
A CASE STUDY IN FAULT DIAGNOSIS

by

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Report submitted to Faculty of  
Virginia Polytechnic Institute and State University  
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

in  
Systems Engineering

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September, 1991  
Blacksburg, Virginia
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(ABSTRACT)

Downtime associated with fault isolation impacts the performance of any system to a significant degree. Few repairmen are well versed in the art of troubleshooting and experienced repairmen are not always available and/or are very costly. A failure diagnostic expert system provides an effective method of failure diagnosis.

Diagnostic reasoning in expert systems is discussed with demonstrating methodologies by using a 1.6 liter, 1981 model Volkswagen Vanagon as an example. A procedure and methodology for building a diagnostic case base is demonstrated by building a Volkswagen Vanagon diagnostic case base. A significant diagnostic case base was developed in order to demonstrate and evaluate the appropriateness of CBR Express for failure diagnosis. CBR Express is a case-based matching application from Inference Corporation.
ACKNOWLEDGEMENTS

I would like to express my gratitude to my advisor, Dr. J.M. De La Garza for his commitment and patience during the preparation of this project and report.

I would also like to thank Dr. M.C. Vorster and Dean B.S. Blanchard for their service on my advisory committee.

Finally, I would like to thank my family for their support throughout my education.
TABLE OF CONTENTS

Chapter I. Introduction ................................................................. 1
  1.1 General Background .......................................................... 1
  1.2 Objectives of Project and Report .......................................... 2
  1.3 Scope and Methodology ....................................................... 3
  1.4 Project and Report Structure ............................................... 3

Chapter II. Literature Survey .......................................................... 5
  2.1 Overview of Expert Systems ............................................... 5
  2.2 Case-Based Reasoning ....................................................... 6
      2.2.1 Expert Systems Versus Case-based Reasoning .................... 7
  2.3 Overview of Diagnostic Reasoning ........................................ 10
      2.3.1 Fault Diagnostic Terms ............................................. 10
      2.3.2 Diagnostic Process .................................................. 11
      2.3.3 Inference Structure of Diagnostic Knowledge ................... 12
  2.4 CBR Express Overview ...................................................... 14
Chapter III. Expert Systems and Failure Diagnostic Reasoning .......................... 18

3.1 General Description ....................................................................................... 18
3.2 Knowledge Representation ............................................................................. 19
  3.2.1 Rule Based Representation ......................................................................... 19
  3.2.2 Semantic Nets ............................................................................................. 20
  3.2.3 Frame-Based Representation ....................................................................... 22
3.3 Searching the Knowledge Space ..................................................................... 22
  3.3.1 Data- and Goal-Driven Reasoning ............................................................ 23
  3.3.2 Search strategies ......................................................................................... 25
3.4 Dialog Structure ............................................................................................... 25
3.5 Uncertainty ....................................................................................................... 27
3.6 Explanation Facility ......................................................................................... 29

Chapter IV. Building a diagnostic Case Base ....................................................... 33

4.1 Knowledge Acquisition Defined ..................................................................... 33
4.2 Building a Diagnostic Case Base .................................................................... 34
  4.2.1 Failure Mode, Effect and Criticality Analysis ............................................. 35
    4.2.1.1 Analysis Procedure .............................................................................. 35
  4.2.2 Fault Tree Analysis ................................................................................... 42
    4.2.2.1 Analysis Procedure ............................................................................ 42
4.3 Incorporation of Uncertainty .......................................................................... 48
4.4 Repair Actions ................................................................................................ 50
4.5 Variations in Diagnosis .................................................................................. 51

Chapter V. CBR Express Reasoning .................................................................... 53
LIST OF FIGURES

Figure 2.1 : Architecture of Expert Systems Versus
the Architecture of Case-Based Reasoning ........................................... 8

Figure 2.2 : Heuristic Classification ......................................................... 13

Figure 2.3 : CBR Express Reasoning ....................................................... 15

Figure 2.4 : CBR Express Architecture .................................................... 17

Figure 3.1 : Partial Semantic Net ............................................................ 21

Figure 4.1 : Fault Tree Symbols .............................................................. 43

Figure 4.2 : Partial Fault Tree Analysis .................................................... 44

Figure 5.1 : Software Integration ............................................................. 54

Figure 5.2 : CBR Express Reasoning ....................................................... 56

Figure 5.3 : CBR Express Functioning ..................................................... 78

Figure 6.1 : Sample Consultation ............................................................ 80

Figure 6.2 : Sample Consultation ............................................................ 82

Figure 6.3 : Sample Consultation ............................................................ 83

Figure 6.4 : Sample Consultation ............................................................ 84
Figure 6.5 : Sample Consultation ................................................................. 85
Figure 6.6 : Sample Consultation ................................................................. 87
Figure 6.7 : Sample Consultation ................................................................. 88
Figure 6.8 : Sample Consultation ................................................................. 89
Figure B1 : Figure Outlay for Fault Tree Analysis ........................................ 180
Figure B2 : Fault Tree Analysis Part 1 ......................................................... 181
Figure B3 : Fault Tree Analysis Part 2 ......................................................... 182
Figure B4 : Fault Tree Analysis Part 3 ......................................................... 183
Figure B5 : Fault Tree Analysis Part 4 ......................................................... 184
LIST OF TABLES

Table 4.1 : Partial FMECA ................................................................. 36
Table 4.2 : General Case Base ............................................................ 40
Table 5.1 : Case Represented in Schemas .............................................. 58
Table 5.2 : Stored Case Weight Contribution ........................................... 61
Table 5.3 : Feature Weight Contribution ............................................... 70
Chapter I. INTRODUCTION

1.1 General Background

A "system" is a combination of elements forming a unitary whole, structured in such a manner as to accomplish a function which satisfies an intended need. With technological advancement, systems become more and more complex. Thus the skills required to diagnose system failures increase as the complexity of the system increases. Downtime associated with fault isolation impacts the performance of any system to a significant degree. Few repairmen are well versed in the art of trouble-shooting and experienced repairmen are not always available and/or are very costly. Thus an effective method to assist a person in identifying failures would contribute considerably to bettering a system's performance.

An expert system is a computer program that incorporates the knowledge of a expert in a particular field in order to provide knowledgeable advice. Personnel using the software can then make decisions based on the experience and knowledge of the expert. Thus an
expert failure diagnostic system will provide an effective method of failure diagnosis.

Failure diagnosis is an expensive and time consuming task. It is becoming more critical because of increasing equipment complexity and rapid personnel turnover. Service manuals and paper-based maintenance systems are voluminous, take tremendous effort to maintain (update) and are often ineffective due to incompleteness or outright errors. Diagnostic expert systems offer the opportunity for improving the overall effectiveness of diagnostics, maximizing system availability and minimizing logistic costs and delays. Higher accuracy and performance levels are gained due to continuous availability of high-level knowledge. Time-delays get eliminated because of the continuous availability of expert knowledge. Costs are reduced as there is a reduction in high level manpower and no, or very little, consultation fees are necessary.

1.2 Objectives of Project and Report

The objectives of the Project and Report are:

-- To define a methodology for building a case base for a failure diagnostic application by using a Volkswagen Vanagon as an example.

-- To discuss and explain CBR Express diagnostic reasoning and capabilities by using the Volkswagen Vanagon diagnostic case base developed. CBR Express is a case-based matching application from Inference Corporation.
1.3 Scope and Methodology

Failure diagnostic reasoning in expert systems is discussed and explained. Case-based reasoning is one method of performing failure diagnosis by an expert system. A methodology for building a failure diagnostic case base, for case-based reasoning in general, is defined. For demonstrating the methodology for building a case base, a 1.6 liter 1981 model Volkswagen Vanagon is used. A Volkswagen Vanagon failure diagnostic case base for specific use by CBR Express is built. CBR Express is a case-based matching application tool. The reasoning of CBR Express is discussed and explained in detail.

A significant case base is built to demonstrate CBR Express reasoning. However, it should be noted that not every single possible failure can be covered. The fault diagnostic level is dictated by the level at which a non-skilled owner, with limited tools, would normally be able to perform diagnosis. The repair actions are limited to explanations of what to repair rather than how to do repair. However, repair actions that can be accomplished by the non-skilled owner, with limited tools, are explained.

1.4 Project and Report Structure

The remainder of this report consists of six chapters. Chapter II, entitled Literature Survey, gives an overview of expert systems, case base reasoning, diagnostic reasoning, and a general description of CBR Express reasoning and capabilities.
Chapter III, Expert systems and Failure Diagnostic Reasoning, describes expert systems reasoning in the context of failure diagnosis.

Chapter IV, Building a Diagnostic Case Base, details the procedure and methodology for building a diagnostic case base for diagnostic reasoning in general and specifically, by using a Volkswagen Vanagon as an example.

Chapter V, CBR Express Reasoning, includes an in depth discussion of CBR Express reasoning, using CBR Express as a tool to explain diagnostic reasoning. The chapter will show how CBR Express incorporates methodologies discussed in previous chapters by using a Volkswagen Vanagon as an example.

Chapter VI, Sample Diagnostic Consultations, shows sample consultations performed by using CBR Express.

Chapter VII concludes the report with concluding notes on CBR Express and failure diagnosis through the use of expert systems.
Chapter II. LITERATURE SURVEY

Chapter II gives an overview of expert systems, case-based reasoning, and a general description of CBR Express capabilities. The aim of the chapter is to provide a background for understanding diagnosis through case-based reasoning.

2.1 Overview of Expert Systems

Artificial Intelligence (AI) is concerned with making computers exhibit intelligence. The major AI research efforts have been directed toward the areas of robotics, natural language processing, artificial vision, learning and speech, and reasoning capabilities. Expert systems is an applied field of AI that deals with computer reasoning. An expert system is a computer program designed to assimilate the knowledge of human experts, making that knowledge available to other people in a useful way. Expert systems are practical tools that can serve as intelligent job aids to facilitate on-the-job decision making in tasks.
A simple definition of expert systems is given in [Gaschnig 1981].

Expert systems are interactive programs incorporating judgement, rules of thumb, intuition and other expertise to provide knowledgeable advice about a variety of tasks.

Another definition is given by [Edmunds 1988]. An expert system is a computer based system designed to assimilate the knowledge of human experts, making that knowledge conveniently available to other people in a useful way.

Expert systems use domain specific knowledge and are also referred to as "knowledge based expert systems" (KBES). A KBES is a computer program that explicitly capture knowledge of human experts and utilize that knowledge to give advice, make decisions and pass judgement.

2.2 Case-based Reasoning

Case-based reasoning (CBR) is a process of retrieving previously known solutions for a pre described situation. CBR is a technique of comparing a current case to a library of cases with known solutions. The "previous solutions" are stored in "cases" in a case base. After an initial input (description of a case), a matching algorithm is employed to find all cases that are similar, but not necessarily identical, to the search description. Further reasoning takes place for refinement of cases to narrow the solution space down to an exact or closest match [Riesbeck 1989].
Case-based reasoning is particularly suitable for fault diagnosis. The failure is stored as a
case and symptoms as the case descriptions. Initial matching is then done according to
the symptoms given by the user. Further dialog is performed to determine the exact or
closest matched case.

2.2.1 Expert Systems Versus Case-based Reasoning

Case-based reasoning can be looked at as a specific type of an expert system. This
becomes very evident by looking at the architecture of both. Figure 2.1 shows the
architecture of both an expert system and case-based reasoning. As one can see from the
figure, the only difference is that case-based reasoning makes use of a specific inference
method that can be called a case-matching mechanism. The knowledge base is replaced
by a case base.

Both structures consist of six major components. For KBES they are, the user interface,
current context, explanation facility, inference engine, knowledge base, and knowledge
acquisition facility. For CBR they are the user interface, current context, explanation
facility, case-matching mechanism, case base, and knowledge acquisition facility.

User Interface. The user interface allows the user to communicate with the KBES. It
provides for the user-system interactions.

Current Context. The context is the working memory of the system. It reflects all the
information that has been generated during a particular program session.
FIGURE 2.1 Architecture of Expert Systems Versus the Architecture of Case-Base Reasoning
Inference Engine. The inference engine organizes and controls the steps taken to solve the problem. The inference engine incorporates reasoning methods, which act upon input data and the knowledge in the knowledge base to solve a problem.

Case-matching Mechanism. The case matching mechanism matches input data against stored cases and retrieves the case or cases that matches the input data the closest.

Explanation Facility. The explanation facility provides justification for specific conclusions or recommendations and provides the user with information to understand why certain questions are asked.

Knowledge Base. The basic domain knowledge is contained in the knowledge base. The knowledge may be represented in facts and production rules which are the most widely used form of representing knowledge. Other forms of representing knowledge are semantic nets and frames. Rules in rule-based system representations are also referred to as situation-action rules or if-then rules. These are condition-action or condition-conclusion pairs. If the condition is true then a conclusion is made.

Case Base. The domain knowledge that is represented in cases is stored in the case base. The cases may be represented in facts, semantic nets, or frames with production rules providing the control knowledge.

Knowledge Acquisition Facility. The acquisition facility is the means through building and expanding the knowledge base or case base. This can be done manually or automatically. For example, there might be a direct link to a database which feeds the
knowledge base or case base with information.

2.3 Overview of Diagnostic Reasoning

2.3.1 Fault Diagnosis Terms

*Cause and Effect relation.* A cause is a distinct premise or group of premises. An effect is an output condition or system transformation in response to a cause [Carrico 1989]. Cause and effect can have an unlimited iterative relation. The cause is the reason for an effect. An effect is the result of a cause and the effect can be the cause of another effect. For example, in the context of an automobile engine, normal wear-out is a cause for undersize piston rings. Undersize piston rings causes oil deposits on the spark plugs. Oil deposits on the spark plugs cause the engine to misfire. The cause and effect relationship is as follows:

- cause: normal wear-out
- effect: undersize piston rings
- cause: undersize piston rings
- effect: oil deposits on sparkplugs
- cause: oil deposits on sparkplugs
- effect: engine misfires

*Failure.* A failure is the inability of the system or component to perform the required function [Winilund 1965]. A failure is a deviation from the intended function or deviation
from specification. Failures can be classified into primary and secondary failures. A primary failure is the initial failure incurred. A primary failure may be the cause of several secondary failures.

*Symptom.* Symptoms are the effects of a failure. Effects may range from complete system destruction to partial system operation or other failures which may cause their own unique symptoms.

For our example, the normal wear-out is the cause. The undersize piston rings is the failure. Oil deposits on the sparkplugs and engine misfiring are the symptoms.

2.3.2 Diagnostic Process

Diagnostic expert systems can be divided into three classes. They are symptom based, model based and mixed [Dym 1991], [Tong 1989], and [Searls 1989].

Symptom based expert systems use compiled (shallow) knowledge and are based on symptom-to-failure associations. The approach enumerates explicit associations among failure and symptoms. This approach is effective if one solemnly relies on capturing human experienced knowledge.

Model based diagnostic systems use first principles (deep knowledge) based on the description of structure and function of the equipment under diagnosis. Hypotheses of structural faults are generated and verified against actual misbehavior. Tests have to be
generated in order to compare the behavior of the faulty equipment with the correct model. This approach is especially applicable for instances where one wants to gather data continuously from an operating system. This data is then used to reason about changes over time in the state of the system. Thus the system is modeled causally rather than relying solely on heuristics.

The mixed mode approach combines the two approaches discussed above.

2.3.3 Inference Structure of Diagnostic Knowledge.

William Clancey states that all diagnostic systems employ a generic inference structure that he termed heuristic classification [Clancey 1985], [Kowalik 1986], and [Dym 1991]. This structure involves three kinds of knowledge processing in the following order (See Fig 2.2):

1. Data Abstraction. The diagnostic process begins by a raw data description of the state of the system (set of symptoms) from which a set of problem classes are abstracted. The problem classes involved here are usually easily obtained and the hypotheses generated point to classes of faults rather than specific faults.

2. Heuristic Match. Heuristics are used to narrow down the possibilities to one or more solution strategies for that class of problem.

3. Solution Refinement. Available data about the state of the system is then used to refine the solution strategies.
Figure 2.2 Heuristic Classification
2.4 CBR Express Overview

CBR Express is a case-based matching application of ART-IM, the Automated Reasoning Tool for Information Management from Inference Corporation.

From an initial input, a description of a case to search for, CBR Express locates the case or cases that are most similar to the description (See Fig. 2.3). After the initial search a further dialog takes place through questions about matched cases in order to narrow down the possibilities to an exact or closest match. Unsuccessful searches can be stored for future examination. The case base can then be expanded with the unresolved search forming the basis of a new case.

CBR Express also includes an optional call tracking feature for support of help-desk applications. Call tracking associates people and organizations with problems and cases.

A case can be subdivided into three components, namely case description, case questions, and case actions. The case description is a description of symptoms that a failure can cause. Case questions are questions to be answered by the user in order to confirm the case. Case actions are solutions or advice about the problem that forms the case.

CBR Express performs two major functions. They are searching the case base and the maintenance of the case base.

*Searching the Case Base.* In the search mode the interface offers a panel for performing case-base searches. An optional second panel for performing customer tracking is also
Figure 2.3 CBR Express Reasoning.
available. All diagnosis actions are done through the search mode.

*Case Maintenance.* In the maintenance mode cases are created. The case base author has access to three panels, one each for defining cases, questions, and actions.

The CBR Express Architecture consists of five major parts (See Fig. 2.4). They are the user interface, current context, case-matching mechanism, case base, and explanation facility.
Figure 2.4 CBR Express Architecture
Chapter III. EXPERT SYSTEMS AND FAILURE DIAGNOSTIC REASONING

The aim of chapter III is to give an overview of expert system reasoning in the context of failure diagnosis. This discussion will also show my familiarity with the concepts and vocabulary applied in expert system technology. If the reader is already familiar with such concepts, this chapter may be skipped without loosing any continuity.

3.1 General Background

Any expert system has to represent the domain knowledge by some representation methodology. This knowledge has to be searched in some way to determine the desired solutions. The expert system needs to provide justification for specific conclusions or recommendations. It also needs to deal with uncertainty of input data as well as conclusions. Integrated in the reasoning process, the expert system needs a dialog structure for external information to be used in the course of some reasoning process. These issues are not specific applicable to diagnostic expert systems but to expert
systems in general. This chapter will give an overview of these issues in the context of failure diagnosis for an automobile.

3.2 Knowledge Representation

Failure diagnostic knowledge is contained in the knowledge base. A number of different techniques are used to store the knowledge within the knowledge base. This is called the knowledge representation methodology.

3.2.1 Rule Based Representation

The most common form of representing knowledge is in facts and production rules. This type of expert system is called rule-based systems. A fact represents a basic unit of knowledge. Rules are placed in the knowledge base to manipulate the facts. The rules are expressed in a simple IF-THEN format with AND's and OR's to handle more complicated situations. Rules can be thought of as:

  IF these conditions are met
  THEN take these actions

Conditions contain computer recognizable patterns that the inference engine tries to match with knowledge stored in the knowledge base. The actions can modify the knowledge base or perform arbitrary computations. For example, rules might be set up for diagnosing a failure in an automobile as follows:
IF engine_misfires
AND oily_deposits_on_sparkplug
THEN worn_pistonrings

Most other forms of knowledge representation incorporate some technique structured around the use of rules. Other techniques are usually used when one wants to reason about broader and deeper kinds of knowledge that can not be approached with production rules alone.

3.2.2 Semantic Nets

A semantic net is a formal graphic language for representing facts about entities in some world about which we wish to reason [Dym 1991]. Hierarchical relationships form the basis of the semantic net approach. Hierarchical relationships connect knowledge components (also called objects) which allows them to inherit information from each other. This reduces the need to duplicate information within the knowledge base. The link between objects can represent many types of relationships. For example, if the starter motor is one of the parts that the electrical system consist out of, the relationship between the electrical system and the starter motor can be described by a "HAS_A" link as follows: the electrical system "HAS_A" starter motor. Figure 3.1 shows a partial schematic net with the links representing the relationships between the objects.
Figure 3.1 Partial Semantic Net
3.2.3 Frame-Based Representation

Frame-based representation retains the fundamental notions of abstraction hierarchies and inheritance of properties. However, it packages the descriptive attributes associated with each class of instance into more compact local data structures variously called frames or schemas [Dym 1991]. A schema can be thought of as a collection of knowledge about a specific object, concept, or situation. For example, a frame may describe the ignition system, classes of the ignition system -- namely, distributor, condenser, etc. -- or even classes of the distributor. Schemas contain slots. Attributes of schemas and relations between schemas are represented in the slots.

More elaborate discussions on knowledge representation can be found in [Carrica 1989], [Dym 1991], [Edmunds 1988], [Fikes 1985], and [Jackson 1986].

3.3 Searching the Knowledge Space

An inference engine needs some method of controlling the diagnostic reasoning process. Two of the most common techniques for controlling the search strategies used by an inference engine are goal- and data-driven reasoning. In the following sections, the control techniques are discussed and then search strategies that can be controlled by either control technique, are discussed.
3.3.1 Data- and Goal-Driven Reasoning

There are two basic styles for using rules to define a direction of movement through a search space. They are data-driven reasoning and goal-driven reasoning.

Data-driven reasoning, also called forward chaining, uses data or basic ideas as a starting point to move towards a goal. We match the problem data against conditions. If the conditions are met we take the actions dictated. This process is repeated until the goal is reached. For example, assume that the starter relay is defective and we have the following rules to diagnose the failure:

Rule 1:
IF the automobile won't start
AND the battery is operative
THEN the starter system is suspect

Rule 2:
IF the starter system is suspect
AND jumping the starter relay causes the automobile to start
THEN the starter relay is defective

If the symptom automobile won't start is given, then a "trace" of the forward chaining would reveal steps that resemble the following sequence:

1. Searching for conditions of rules that might be satisfied.
2. Found condition: "automobile won't start" in rule 1.
3. No information for "battery is operative" -- ask user.
4. User says "battery operative".
5. Conclude "starter system is suspect".
6. Searching for conditions of rules that might be satisfied.
7. Found condition "starter system suspect" in rule 2.
8. No information for "jumping the starter relay causes the automobile to start" -- ask user.
9. User says "jumping the starter relay causes the automobile to start".
10. Conclude "the starter relay is defective".

Goal-driven reasoning, also called backward chaining, uses the goal or a hypothesis as a starting point. Backward chaining works back from the goal and finds the conditions that satisfy the action. If the conditions are not present, make them subgoals and find the conditions for the subgoals. Using the same symptom given and rules as in the previous example, then a "trace" of the backward chaining would reveal steps that resemble the following sequence:

1. Searching for a goal to pursue.
2. Found goal "starter relay defective" in rule 2.
3. No information for "starter system suspect".
4. Searching for conclusion "starter system suspect".
5. Found conclusion "starter system suspect" in rule 1.
6. No information on "battery operative" -- ask the user.
7. User says "battery operative".
8. No information for "jumping the starter relay causes the automobile to start" -- ask user.

9. User says "jumping the starter relay causes the automobile to start".

10. Conclude "the starter relay is defective".

3.3.2 Search Strategies

A search strategy is an approach for finding paths through the search space. Search strategies can be classified into two types. They are exhaustive and directed searches.

Exhaustive searches, also called weak methods of search, are those methods that simply take all possibilities into account. Exhaustive searches look at all possibilities until a solution is found. This is called a weak method because it lacks the power associated with knowledge-guided search.

Directed search, also called a strong method of search, incorporates domain knowledge within the search to make it more efficient.

3.4 Dialog Structure

When dealing with knowledge-intensive, problem-solving situations, questions arise in the pursuit of solutions. External information is to be used in the course of some reasoning processes. Questions are not asked ad hoc. They aim at acquiring the right
information in the right sequence at the right time. The following discussion outlines the steps of a fault diagnosis performed by a mechanic.

At the beginning of the diagnosis, the mechanic asks the non-expert to specify the symptoms observed. Each symptom needs to be fully characterized, i.e. if the automobile misfires, the mechanic asks, "How often?" Once the initial symptoms have been specified and fully characterized, the mechanic asks a number of standard questions. Each one of these questions aims at acquiring some highly discriminating item of information (such as mileage on an automobile).

The symptoms are then used to generate the most likely general hypothesis. The initial, general hypothesis is then successively refined to a terminal hypothesis. The questions raised aim at the most effective way of refining the hypothesis.

If the terminal hypothesis reached does not adequately explain the symptoms, the mechanic checks whether an alternative hypothesis can be identified.

It is very evident that the dialog structure is an integral part of the diagnostic process performed by a human expert, and should be incorporated intelligently into the design of an expert system. The expert system is more effective if the questions are put to the user in an intelligent order and are dependent upon domain structure, the strategies and heuristics employed.
3.5 Uncertainty

Human experts work in an uncertain environment. The degree of certainty or uncertainty about any decision in real life must be reflected in some way. For example, an expert will sometimes preface a diagnosis or decision with a qualifying statement reflecting his or her confidence in the decision. A mechanic may say, "We are 90 percent sure that your problem is caused by......." Sometimes, all information necessary for a confident conclusion is not available. Nonetheless, unless a particular item of information is critical, an expert can still attempt to reach a conclusion based on the limited information available and qualify the answer: Expert systems must be able to deal with uncertainty.

In an expert system the rules can be chained together. The certainty factors are factored together in some way to produce an overall degree of confidence in the final solution. Often a scale is used to build a certainty factor into the rule. Any scale (range of numbers) can be used: -1 to 1, 0 to 5, 0 to 100, etc.

There are two main issues to address in uncertainty, the reliability and completeness of information and the aggregation or combination of information from multiple sources. In order to combine uncertainty measures we have to discuss the probability theory in more depth.

Probability is a measure of certainty between 0 and 1. The extreme values denote impossibility and certainty. A definition of probability is given by [Hart 1986].

If a random experiment has N possible outcomes which are all equally likely and mutually exclusive, and n of these possibilities
has outcomes A then the probability of outcome A (P(A)) is n/N.

The only formal, logically correct statistical approaches available for uncertainty measures assume that probability outcomes are equally likely and mutually exclusive. This may, in practice, be difficult or impossible to ascertain.

The basis for combining uncertainty measures in most diagnostic systems is the conditional probability P(A/B), the probability of A given B. This brings us to the Bayesian theorem. Bayes theorem has been used extensively in expert systems development. In it simplest form it is:

\[ \text{Prob}(H/E) = \text{Prob}(E/H) \times \text{Prob}(H) / \text{Prob}(E), \]

where H is a hypothesis and E some evidence. For example, H could be the hypothesis that a particular failure is present, and E could be the symptoms which have been observed. The formula relates the prior probability \( \text{Prob}(H) \) with the posterior probability \( \text{Prob}(H/E) \), i.e. the new probability in the light of evidence. \( \text{Prob}(H) \) is the initial estimate without any information about E. \( \text{Prob}(H/E) \) is our new probability when we know that E is true. Our judgment is affected by knowledge about symptoms, i.e. event E [Hart 1986]. A more elaborate discussion on the idea can be found in [Dym 1991] and [Hart 1986].

The problems of using probability models are compounded by the fact that people do not understand the theory. People reason with words, not numbers. This may be why we find probability counter-intuitive, and in some cases difficult to understand [Hart 1986]. Although many people do not have a intuitive understanding of probability, simplification of formulae can cause gross errors in computations. Without the
mathematical precision inherent in the theory of probability, we may generate estimates of confidence levels that are contradictory or inflated in value. Expert systems must be able to deal with uncertainty and these problems should not preclude the knowledge engineer from using statistical methods, but simply caution him/her.

Another approach to uncertainty is the fuzzy set theory. The intent in fuzzy set theory is to allow subjective quantification of the imprecise or vague terminology that enters into our descriptive vocabulary. Discussions on this idea can be found in [Hart 1986] and [Edmunds 1988].

3.6 Explanation Facility

The explanation facility provides justification for specific conclusions or recommendations and provides the user with information to understand why certain questions are asked.

[Keravnou 1986] identifies three types of questions that need to be answered by an explanation facility. They are how, why, and why-not explanations.

*How explanations:* How was a particular conclusion accomplished?

*Why explanations:* Why was a particular conclusion tried to be concluded?

*Why-not explanations:* Why was a particular alternative conclusion not selected at the relevant decision point?
The three type of questions can easily be answered by the near-natural syntax of production rule systems. The near-natural language explanations are generated by stringing together, with a few connectives, the appropriate clauses and the names of any arguments contained within rule clauses. For example, if an automobile does not start and the headlights dim when the starter switch is operated, the solenoid might be defective. There are two methods to determine if the solenoid is defective. Depending upon whether a voltmeter is available, the voltmeter test will be performed; otherwise the noise test will be performed. The rules for doing the diagnosis are as follows:

\[
\begin{align*}
\text{IF} & \quad \text{not(auto}\_\text{start}) \\
\text{AND} & \quad \text{headlights}\_\text{dim}\_\text{when}\_\text{start} \\
\text{THEN} & \quad \text{do}\_\text{solenoid}\_\text{test} \\
\text{IF} & \quad \text{do}\_\text{solenoid}\_\text{test} \\
\text{AND} & \quad \text{have}\_\text{voltmeter} \\
\text{THEN} & \quad \text{do}\_\text{volt}\_\text{test} \\
\text{IF} & \quad \text{do}\_\text{solenoid}\_\text{test} \\
\text{AND} & \quad \text{not(have}\_\text{voltmeter}) \\
\text{THEN} & \quad \text{do}\_\text{noise}\_\text{test}
\end{align*}
\]

Consider that the expert system has concluded to do the solenoid test. In response to an automatic explanation inquiry from the user, the system might generate the following response:

You affirmed \text{not(auto}\_\text{start})
You affirmed *headlights_dim_when_start*

We concluded *do_solenoid_test*

We are attempting to determine whether to *do_volt_test* or *do_noise_test*

In order to do so, we need to know whether you *have_voltmeter*

Please confirm that you *have_voltmeter*

Some other forms of explanation are:

*Rule Traces.* Probably the simplest type of explanation is to trace the rules that are fired. At any stage of the diagnostic process, a list of the rules that were fired can be produced in order of execution.

*Rule Graphs.* A rule graph gives a network of the rule structure. It provides for understanding the structure of the rule set and for understanding how answers to previous questions led to a given conclusion.

*Frame Hierarchies.* A graphic display of frame hierarchies provides a way for the user to obtain an overview of the contents of a knowledge base. Most frame based systems have a graphic frame hierarchies display capability. This displays abstraction hierarchies and internals of frames.

*Knowledge-based Interactive Graphics.* Two-way interactive graphics, linked to a knowledge representation and reasoning system, have been called "knowledge-based interactive graphics" [Levitt 1987b]. This type of explanation can be very helpful in
model based diagnostic systems discussed in section 2.2.2, in instances where one wants to gather data continuously from sensors connected to an external operating system, to reason and explain about changes over time in the state of the system.
Chapter IV. BUILDING A DIAGNOSTIC CASE BASE

Chapter IV details a procedure for building a diagnostic case base for diagnostic reasoning in general and for specific use by CBR Express. Two techniques namely, Failure Mode, Effect and Criticality Analysis and Fault Tree Analysis are explained and used in order to show how they can be used to help acquire failure diagnostic knowledge. For demonstrating the techniques, a 1.6 liter 1981 model Volkswagen Vanagon is used as an example.

4.1 Knowledge Acquisition Defined

Knowledge acquisition is the collection and analysis of information from one or more domain experts and any other sources leading to the production of a number of documents which form the basis of a functioning knowledge base [Greenwell 1988].

A major problem in building expert systems is the task of obtaining knowledge. In recent
years, however, more knowledge engineers have realized the difficulties inherent in acquiring knowledge and several books on knowledge acquisition are now available: [Freiling 1985], [Greenwell 1988] and [Hart 1986].

4.2 Building a Diagnostic Case Base

Case-based reasoning in failure diagnosis is a process of retrieving previously known failures, represented in cases. Using symptoms as an initial input, a matching algorithm is employed to find all failures causing similar but not necessarily identical symptoms. Further reasoning about features associated with each matched failure takes then place to narrow the solution space to an exact or closest match. Thus any failure diagnostic case needs the following information:

1. A failure description. What falls and in what way?
2. Symptoms experienced as a result of the failure.
3. A test procedure consisting of features associated with the failure in order to determine the exact failure. This can be symptoms that need to be present or absent, or test actions that need to be performed in order to determine the exact failure.

With this information available one can construct a general case base that would need very little modification to be used by any case-based matching application package. The failure description forms the basis of the case. Initial matching is done on the symptoms experienced and refinement is done by confirming or denying features associated with matched cases. This chapter details two methodologies to help acquiring this failure
diagnostic knowledge. They are, Failure Mode, Effect and Criticality Analysis (FMECA) and Fault Tree Analysis (FTA) [Blanchard 1990], [Winland 1965], and [Grabinger 1990]. Both of these techniques are applied in the early stages of system design to influence the design. Most of the time these techniques are already performed by the time an expert system is to be developed. These analysis can be an excellent source of diagnostic knowledge. For demonstrating the techniques, a 1.6 liter, 1981 model Volkswagen Vanagon (VW) will be used as an example.

4.2.1 Failure Mode, Effect and Criticality Analysis

Failure Mode, Effect and Criticality Analysis (FMECA) basically identifies possible system failures, the effect of these failures, and the criticality in terms of safety and mission accomplishment. FMECA also helps in identifying special maintainability characteristics that are desirable in system design or unique maintenance procedures that should be followed in the field.

4.2.1.1 Analysis Procedure

The procedure for performing a FMECA is described in the following paragraphs. Table 4.1 shows a part of the FMECA performed on the electrical system of the Volkswagen Vanagon. Although the complete procedure is described (steps 1 to 7), only the part of FMECA that contributes towards failure diagnostic knowledge is performed in the example given in Table 4.1 (steps 1 to 3). Step 6, Criticality of Failure, may contribute
<table>
<thead>
<tr>
<th>Component Name</th>
<th>Failure Mode</th>
<th>Failure Effect</th>
<th>Case Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Battery</td>
<td>Discharged</td>
<td>Engine fails to turn, Engine turns slowly,</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Terminals loose.</td>
<td>Engine fails to turn</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Earth loose</td>
<td>Battery will not hold charge for long</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Internally defective.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Starter Solenoid</td>
<td>Internally defective.</td>
<td>Engine fails to turn</td>
<td>3</td>
</tr>
<tr>
<td>Starter Motor</td>
<td>Connections loose.</td>
<td>Engine fails to turn, Engine turns slowly</td>
<td>17</td>
</tr>
<tr>
<td></td>
<td>Starter brushes worn.</td>
<td>Engine turns slowly</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>Internally defective.</td>
<td>Engine fails to turn</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Pinion ring gear teeth worn.</td>
<td>Starter spins without turning the engine.</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>Starter mounting bolts loose.</td>
<td>Starter noisy.</td>
<td>24</td>
</tr>
<tr>
<td>Alternator</td>
<td>Internally defective.</td>
<td>Battery will not hold charge for long,</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Battery does not get charged, Ignition light stays on</td>
<td></td>
</tr>
<tr>
<td>Alternator Drivebelt</td>
<td>Broken.</td>
<td>Ignition light stays on, Engine overheats</td>
<td>32</td>
</tr>
<tr>
<td></td>
<td>Slipping.</td>
<td>Battery will not hold charge for long.</td>
<td>23</td>
</tr>
<tr>
<td>Voltage Stabilizer</td>
<td>Internally defective.</td>
<td>Instrument readings increase with engine speed</td>
<td>33</td>
</tr>
<tr>
<td>Fuel Sender Unit</td>
<td>Defective.</td>
<td>Fuel gauge gives no reading.</td>
<td>39</td>
</tr>
<tr>
<td>Fuel gauge</td>
<td>Defective.</td>
<td>Fuel gauge gives maximum reading all the time</td>
<td>40</td>
</tr>
<tr>
<td>Bulbs</td>
<td>Blown.</td>
<td>Light inoperative.</td>
<td>34</td>
</tr>
<tr>
<td>Horn</td>
<td>Internally defective.</td>
<td>No sound from horn</td>
<td>35</td>
</tr>
<tr>
<td>Wiper Motor</td>
<td>Defective.</td>
<td>Windscreen wipers inoperative.</td>
<td>41</td>
</tr>
<tr>
<td>Wiring</td>
<td>Open circuit.</td>
<td>No current.</td>
<td>38</td>
</tr>
<tr>
<td></td>
<td>Short circuit.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fuse</td>
<td>Blown.</td>
<td>No current.</td>
<td>36</td>
</tr>
</tbody>
</table>
towards failure diagnostic knowledge for some instances. However, for the example given in Table 4.1 it is assumed that the criticality of the failure does not contribute towards failure diagnostic knowledge.

1. *Item Identification.* Divide the system into a number of subsystems which can be more easily dealt with. Identify individual components for each subsystem that are likely to fail. Establish the level of detail for identifying individual components for potential failures. For instance, the starter might fail to turn the engine. If you have established that the starter motor is defective, would you want to know which component of the starter motor is defective? The fault diagnostic level for the example in Table 4.1 is dictated by the level at which components normally are replaced or repaired by a non-skilled owner. These components are listed in column 1 of Table 4.1.

2. *Failure mode identification.* Identify the failure modes for each component. How can the component fail? Failure modes may be classified as cracks, raptures, fractures, or short and open circuits etc. For example, the battery that is listed as a component in column 1 of Table 4.1 can have the following most likely failure modes: discharged, terminals loose, earth loose, internally defective. The failure modes of each component listed in column 1 are listed in column 2 of Table 4.1.

3. *Effects of failure.* Describe the possible effects as a result of each identified failure mode. The failure may cause secondary failures with their own effects. For example, the failure mode battery discharged can have the following effects: engine fails to turn, engine turns slowly. The effects of each failure mode are listed in column 3 of Table 4.1.
4. **Cause of failure.** The anticipated cause of the failure should be described. Typical causes might include abnormal equipment stresses during operation, normal wear-out, or operator faults etc.

5. **Probability of occurrence.** Probabilities of the occurrence of each component failure may be entered. Initially, they may be estimated from rates that have been developed from experienced. This rates can be updated as failure data are collected. Through statistical means the component failure rates can then be used to calculate higher level failure rates or system failure rate.

6. **Criticality of failure.** Failures may be classified in terms of criticality depending upon the defined failure effects. Criticality may be rated in several ways. The Society of Automotive Engineers (SAE) in Aerospace Recommended Practice 926 categorizes criticality of failure modes as follows:

   Category 1 : Failure resulting in potential loss of life.
   Category 2 : Failure resulting in potential mission failure.
   Category 3 : Failure resulting in delay or loss of operational availability.
   Category 4 : Failure resulting in excessive unscheduled maintenance.

7. **Preventive or Corrective measures.** Possible preventive or corrective measures need to be described to reduce the probability of failure occurrence or minimize the effects of the failure.

The FMECA process is especially applicable when a case base is build from scratch
because it takes all failure possibilities into account. As one can recall from the discussion in section 4.2 we need three items of information in order to build a case. They are, (1) a failure description (2) symptoms experienced (3) a test procedure. From Table 4.1 we can get the first two items of information we need. The failure mode identified will form the failure description. Symptoms experienced can be described by using the effects of each failure mode. The next step is to establish the third item of information, a test procedure for each failure mode to be used for determining the failure. We know what the failure is and we know what the effects of the failure are. By making use of this information a test procedure is constructed.

A test procedure is made up out of features that are contained in different "AND" and "OR" structures. Features are either effects identified by the FMECA or test actions that need to be performed. The following is a test procedure to determine if the starter solenoid is defective:

\[
\begin{align*}
\text{IF} & \quad \text{the engine fails to turn} & \text{..........................} & \text{..................} (1) \\
\text{AND} & \quad \text{the headlights dim when the starter switch is operated} & \text{..................} & \text{........} (2) \\
\text{AND} & \quad \text{you do not hear a clicking noise when the starter switch is operated} & \text{.........} & \text{....... (3) } \\
\text{THEN} & \quad \text{the starter solenoid is internally defective}
\end{align*}
\]

Feature (1) is an effect identified in the partial FMECA performed (Table 4.1 column 3), with features (2) and (3) as test actions to be performed. For example, a expert system will instruct the user to, switch on the headlights, operate the starter switch, watch if the headlights dim, and report the results. Once the test procedure is established a "genetic" case base can be constructed (See Table 4.2). With incorporation of uncertainty, which
<table>
<thead>
<tr>
<th>Failure description</th>
<th>Battery discharged.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Symptoms:</td>
<td>Automobile won't start. Starter turns engine slowly. Starter fails to turn engine. Lights inoperative.</td>
</tr>
<tr>
<td>Test procedure:</td>
<td>IF the engine does not turn normally AND the headlights dim after a few seconds when switched on. THEN the battery is in a discharged state.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Failure description</th>
<th>Battery terminals loose.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Symptoms:</td>
<td>Automobile won't start. Starter fails to turn engine. Battery will not hold charge for long.</td>
</tr>
<tr>
<td>Test Procedure:</td>
<td>IF the engine does not turn normally AND the headlights do not dim when the starter switch operated AND the battery terminals loose THEN loose terminal connections do not relay enough current from and/or to the battery</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Failure description</th>
<th>Battery earth cable loose.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Symptoms:</td>
<td>Automobile won't start. Starter fails to turn engine.</td>
</tr>
<tr>
<td>Test Procedure:</td>
<td>IF the engine does not turn at all AND lights inoperative AND the battery earth cable loose THEN the loose earth cable causes an open circuit.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Failure description</th>
<th>Solenoid defective.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Symptoms:</td>
<td>Automobile won't start.</td>
</tr>
<tr>
<td>Test procedure:</td>
<td>IF the engine does not turn normally AND the headlights dim when the starter switch is operated AND you do nor hear a clicking noise when the starter switch is operated THEN the starter solenoid is defective</td>
</tr>
</tbody>
</table>
Table 4.2 (Cont.)

<table>
<thead>
<tr>
<th>Failure description:</th>
<th>Starter brushes worn.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Symptoms:</strong></td>
<td><strong>Starter turns engine slowly. Automobile won't start.</strong></td>
</tr>
<tr>
<td><strong>Test procedure:</strong></td>
<td>IF the automobile won't start</td>
</tr>
<tr>
<td></td>
<td>AND the engine turns slowly</td>
</tr>
<tr>
<td></td>
<td>AND the headlights do not dim after a few seconds when switched on</td>
</tr>
<tr>
<td></td>
<td>AND no corroded or loose starter motor connections</td>
</tr>
<tr>
<td></td>
<td>THEN the starter brushes are worn</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Failure description:</th>
<th>Starter motor defective.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Symptoms:</strong></td>
<td><strong>Automobile won't start, starter fails to turn engine.</strong></td>
</tr>
<tr>
<td><strong>Test procedure:</strong></td>
<td>IF the Automobile won't start</td>
</tr>
<tr>
<td></td>
<td>AND the engine does not turn normally</td>
</tr>
<tr>
<td></td>
<td>AND the headlights dim when the starter switch is operated</td>
</tr>
<tr>
<td></td>
<td>AND you hear a clicking noise when the starter switch is operated</td>
</tr>
<tr>
<td></td>
<td>AND there is no corroded or loose starter motor connections</td>
</tr>
<tr>
<td></td>
<td>AND the starter does not spin without turning the engine</td>
</tr>
<tr>
<td></td>
<td>THEN the starter motor is internally defective.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Failure description:</th>
<th>No power to starter motor.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Symptoms:</strong></td>
<td><strong>Automobile won't start, Sartor fails to turn engine.</strong></td>
</tr>
<tr>
<td><strong>Test procedure:</strong></td>
<td>IF the automobile won't start</td>
</tr>
<tr>
<td></td>
<td>AND the engine does not turn normally</td>
</tr>
<tr>
<td></td>
<td>AND the battery terminals not loose or corroded</td>
</tr>
<tr>
<td></td>
<td>AND the battery earth cable is not loose</td>
</tr>
<tr>
<td></td>
<td>AND the headlights do not dim when the starter switch is operated</td>
</tr>
<tr>
<td></td>
<td>THEN it is an open circuit failure. Power is not reaching the starter motor.</td>
</tr>
</tbody>
</table>
will be discussed later, Table 4.2 can easily be transformed into a case base according to the software package to be used. This will be demonstrated in chapter 6 after the CBR Express reasoning is discussed in more detail.

4.2.2 Fault Tree Analysis

Fault Tree Analysis is primarily used to analyze the safety of systems but can also be very helpful in acquiring failure diagnostic knowledge. Fault tree analysis is an analytic technique for improving the potential success of a system by identifying and interrelating the most likely causes for failure. The fault tree is developed by showing failure events and connecting causes to the events by logic gates (AND and OR connectors) [Winland 1965] and [Grabinger 1990].

4.2.2.1 Analysis Procedure

The method for building a fault tree is described in the following paragraphs. The symbols commonly used to draw fault trees are shown in Figure 4.1. An example of a fault tree analysis is given in Appendix B with Figure 4.2 showing a part of the fault tree in Appendix B.

*Selecting the top event.* The selection of the top event is the first step in the process. The top event is a undesirable event that could occur. The expansion of the top event will lead to all the failures that might cause the undesirable event. In the example given in
OR gate. A logical inclusive OR relation. Output A exist if any of B1, B2, .... Bn, or any combination thereof, exist.

AND gate. A logical AND relation. Output A exist if and only if all of B1, B2, .... Bn, exist simultaneously.

Identification of a particular event. When contained in the sequence, usually describes the output or input of an AND or an OR gate. Applied to a gate, indicates a limiting condition or restriction that must be satisfied.

An event, usually a malfunction, described in terms of a specific circuit or component. ** Note that for the fault tree example given, the number in the bottom of each circle is the case number in Appendix A.

An event not developed further because of lack of information or of sufficient consequences. Could also be used to indicate further investigation is intended when additional becomes information available.

Figure 4.1 Fault Tree Symbols
Appendix A the top event "Automobile won't start" leads to 21 failures. Figure 4.2 shows a part of the fault tree that leads to eight failures.

*Building the tree.* The contributory events that could cause the top event are then drawn below the top event. As the tree is developed downward into "branches", two or more contributory events are separated by "gates." The two principle gates used with fault trees are OR and AND gates. If an OR gate (Fig. 4.1) is used, the presence of any of the contributory events will cause the event above to take place. If an AND gate is used, all the contributory events connected to that gate must be present to cause the event above it. Each contributory event is studied to determine the circumstances under which it will occur and the factors that will cause it. As the tree develops, progression down into branches indicates causes and moving up indicates effects. The process is continued down each branch until all available information has been used. The bottom level of each completed branch should be a failure. These are generally marked by a circle (Note that the number in the bottom of each circle of the fault tree is the case number in Appendix A).

If we look at Figure 4.2, starting at the event "Automobile won't start" moving down in the tree indicates causes. If the automobile won't start and the engine turns normal, it can be caused by an empty fuel tank, faulty plugs, or voltage that is not reaching the plugs. In expanding the event "Voltage not reaching the plugs", one asks the question, "What can cause the voltage not to reach the plugs?". Each answer to the question is a failure or an event that needs to be expanded further. One keeps on expanding the events and the branches will usually end in a failure.
Fault tree analysis is particularly effective for expanding a case base. The method focuses on the occurrence of one event, it indicates relationships that can cause that event but eliminate extraneous effort that might result into other events. For example, if some undesirable event occurs and the failure can not be identified by the expert system the case base need to be expanded. The undesirable event will then form the top event of a fault tree analysis. The similar cases in the case base can be of help in establishing the part of the fault tree with known failures. This supports the case-based reasoning theory of creating new cases with the assistance of known cases. Trying to establish an initial case base with fault tree analysis can result in duplication of effort. For example, in developing a fault tree for the event "Automobile won't start" one can determine that faulty spark plugs can cause the automobile not to start, but developing a fault tree for event "Automobile misfires" can result in the same failure. This duplication of effort gets eliminated by the FMECA process which begin by exploring the components and determining the effects of each faulty component.

Each circle in the bottom of the fault tree which contain a failure gives us our first item of information, the failure description. Moving up in the tree indicates effects of the failure. Many of these effects are not noticeably by the user of the vehicle. These effects should be screened to determine the ones that can be experienced by an automobile user to form the second item of information, symptoms experienced. The advantage of Fault Tree Analysis for developing a case base is that it more directly represents the logic involved in the test procedures. The logic gates can be fairly directly translated into a test procedure. For example, using the partial fault tree in Figure 4.2 the following test procedure for a defective coil can be constructed:
IF the automobile won't start
AND the engine turns normally
AND voltage not reaching the plugs
AND voltage not reaching the distributor
AND voltage not reaching the condenser
AND voltage is reaching the coil
THEN the coil is defective

The same conclusion could have been made by the following test procedure:

IF the automobile won't start
AND voltage not reaching the condenser
AND voltage is reaching the coil
THEN the coil is defective

The first and longer test procedure consist out of the complete branch in the tree in Figure 4.2. The second and shorter test procedure consist out of the top event and only a part of the branch. The test procedure consisting out of the complete branch help to narrow down the search space. For example, assume matching is done against the symptom "Automobile won't start". If voltage was reaching the plugs, conformation of this feature discards all the failures underneath the event "voltage not reaching plugs". The failure "coil defective" would not have been discarded if the second test procedure was used. This will still be in content for matching against the symptom "Automobile won't start" although the event "voltage not reaching plugs" has been denied (See Appendix A by using case numbers given in fault tree.)
Fault tree analysis focuses on the possibility of a undesirable event, indicates the relationships that can cause that even but eliminate extraneous effort that may result in other events. It also includes all of the contributory factors to that event. Conversely, the FMECA focuses on a failed component and identify undesirable events resulting out of the failure. This makes the FMECA more desirable for building a case base from scratch because it takes all failure possibilities into account. However, the FTA is more desirable for expanding a case base because it determines the new failure by focusing on the symptoms. Both the techniques are an excellent source of diagnostic knowledge and should be used in such a way to complement each other in building and expanding a case base.

4.3 Incorporation of Uncertainty

Case-based reasoning is a technique of comparing a presented case to a library of stared cases with known solutions. To do this, the features of the presented case are matched against corresponding features of the stored cases. How certain are we that a matched case is similar to the stored case? The answer depends on the software package used. Depending on the matching algorithms and matching scale that the software uses, it will come up with a certainty factor of how close the presented case matches the stored case. Matching done by CBR Express is discussed in depth in chapter 6.

In matching the features of the presented case against the features of the stored cases the question of how the features contribute towards the match certainty arises. Is one feature more important than another? This issue needs to be addressed after the test procedure
is established. The test procedure consist of the features that matching will be done on. Both the following test procedures consist out of three features each:

Procedure 1:

IF the engine fails to turn
AND the headlights dim when the starter switch is operated
AND you do not hear a clicking noise when the starter switch is operated
THEN the starter solenoid is defective

Procedure 2:

IF the engine fails to turn
AND the headlights dim when the starter switch is operated
AND no voltage reading across the starter side of the solenoid
THEN the starter solenoid is defective

How does each feature contribute to the conclusion? Are they all equally important or is one feature more important than the others? In procedure 1, the owner is asked to listen for a clicking noise. Certainly this feature will not contribute as much as the other features to the conclusion. This is because the probability of the owner correctly confirming this feature is much lower than with any of the other features. The importance of a feature can be expressed in a weight contribution towards the conclusion. Once again the exact method of weight assignment to the features depends on the software used. An easy way to do a rough estimate, is to assign weights according to a percentage scale. For example, feature 1 contributes 40%, feature 2 contributes 40%, and feature 3 contributes 20%. These rough estimates can then later be processed according
to the software package used.

Another issue that needs to be addressed is how certain the conclusion is. Given the three features, are you definitely sure the conclusion is true? This issue should not be mis-identified with the match certainty. Remember the match certainty depends on how close the presented case matches the stored case. Comparing the two test procedures, surely procedure 2 is more reliable than procedure 1.

These issues can be combined with statistical methods. The most commonly method used in expert systems is the Bayesian theorem discussed in section 3.4. Uncertainty in CBR Express is discussed in chapter 6.

### 4.4 Repair Actions

Repair actions may or may not be included in the case base. Although repair actions are associated with diagnosis, they do not contribute directly to the diagnostic process. Suggested repair actions for the Volkswagen Vanagon will be limited to repair actions that can be done by a non-skilled owner. For example, the repair action on the starter solenoid will be: "The solenoid must be replaced. The solenoid is secured to the starter motor which is located at the rear right-hand side of the vehicle. The starter motor is secured to the clutch housing from the front of the vehicle."; but the repair action for worn piston rings will be: "The piston rings are most probably worn and will have to be removed and stripped for detailed inspection by an expert." See Appendix A for repair actions.
4.5 Variations in Diagnosis

This section deals with the different scenarios that one can experience in fault diagnosis.

A single failure can cause multiple symptoms. For example, worn pistonrings can cause loss of power and excessive usage of oil.

A single symptom can be caused by multiple failures. We saw that in developing the fault tree. The single symptom "Automobile won't start" can be caused by 21 failures (See App. B).

A test procedure consist of multiple features in order to determining a failure. The features can be either symptoms that need to be present or absent, or test actions that need to be performed. We saw the multiple features in constructing the test procedures (Table 4.2).

Multiple test procedures can determine a single failure with equal or different levels of confidence. For an example see section 4.3 for the two test procedures that determine if the starter solenoid is defective.

Multiple features can contribute equally or with different weights to a single test procedure. This was discussed in section 4.3.

A single feature can contribute equally or with different weights to multiple test procedures. See Table 4.2 for serval test procedures that have the feature "engine does
not turn normal".

A single feature can be in multiple test procedures but contribute different weights for each test procedure.

These are issues that need to be taken into account when a software package is chosen. How does the software package manage these issues? CBR Express's managing of these issues are discussed in chapter 5.
Chapter V. CBR EXPRESS REASONING

Chapter V discusses and explains CBR Express reasoning and capabilities by using the Volkswagen Vanagon diagnostic case base developed. It also shows how CBR Express incorporates methodologies discussed in previous chapters.

5.1 General Description

CBR Express is a case base matching application of ART-IM, the Automated Reasoning Tool for information Management from Inference Corporation. It is designed to run on any IBM-compatible personal computer. It requires a hard drive, a mouse and a VGA display. The minimum configuration is a 286 processor with four megabytes of memory, but a 386 with eight megabytes is recommended. CBR Express runs under Microsoft Windows 3.0 and DOS 3.1 or better.

Figure 5.1 shows that CBR Express is composed of four software packages operating...
Figure 5.1 Software Interaction
together to produce a case base matching application. Each contributes as follows: (1) a
graphic user interface written in Toolbook from Asymetrix Corporation, (2) multiple PC
databases provided by db-Vista., (3) a case-matching search mechanism that is part of
ART-IM, (4) all these programs operate under Microsoft Windows. All functions are
integrated to provide a case-base matching application. The CBR Express package
include the ART-IM inference engine, a runtime Toolbook that does not permit editing,
and db-Vista databases.

CBR Express lets the user write a description of a case to search for, and locates the case
or cases that are most similar to the description. After the initial search a further dialog
takes place through questions about matched cases in order to narrow down the
possibilities to one best case (See Figure 5.2). The cases can be divided into a case
description, questions, and actions.

The case description is a critical paragraph of text that forms the basis for the first search.
Questions are used to refine the presented cases to narrow down the possibilities to one
best match. Actions are defined for each case in order to make a conclusion or give a
solution to the problem associated with the case.

5.2 CBR Express Knowledge Representation Strategy

CBR Express makes use of the frame-based representation discussed in section 3.1.3.
Each case is represented as an ART-IM object (a schema) and features of the case are
represented by the schema slots. The case description, questions and actions are features
Figure 5.2 CBR Express Reasoning.
of the case that are represented by the schema slots as follows:

```
(defschema stored case
  (feature1 value1)
  (feature2 value2)
  (feature3 value3)
  ..........
  (featureN valueN))
```

Table 5.1 shows cases represented by schemas.

To start a failure diagnosis with CBR Express a description of the symptoms experienced are entered which are then constructed into a presented schema by CBR Express. CBR Express will compare the presented schema to stored schemas to find the best matches. Further refinement takes place by answering questions associated with the matched schemas, with the answers to the questions also constructed into the represented schema. New matches can then be retrieved by comparing the refined schema to existing schemas.

5.3 CBR Express Matching

A typical usage of CBR Express reasoning follows the sequence of events shown below:

1. Build a case that specifies what you know about the case or cases you would like to retrieve (symptoms experiencing).
Table 5.1  Case Represented In Schemas

<table>
<thead>
<tr>
<th>(Defschema case18</th>
</tr>
</thead>
<tbody>
<tr>
<td>(number-key case18)</td>
</tr>
<tr>
<td>(title &quot;Incorrect gearshift adjustment&quot;)</td>
</tr>
<tr>
<td>(description &quot;Transmission jumps out of gear&quot;)</td>
</tr>
<tr>
<td>(question11 &quot;yes&quot;)</td>
</tr>
<tr>
<td>(question13 &quot;no&quot;)</td>
</tr>
<tr>
<td>(action38))</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>(Defschema question11</th>
</tr>
</thead>
<tbody>
<tr>
<td>(number-key question11)</td>
</tr>
<tr>
<td>(title &quot;Does the transmission jump out of gear?&quot;)</td>
</tr>
<tr>
<td>(match 10)</td>
</tr>
<tr>
<td>(mismatch 5)</td>
</tr>
<tr>
<td>(type yes_or_no))</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>(Defschema question13</th>
</tr>
</thead>
<tbody>
<tr>
<td>(number-key question13)</td>
</tr>
<tr>
<td>(title &quot;Is the gear lever alignment plate correctly adjusted?&quot;)</td>
</tr>
<tr>
<td>(text &quot;Slide up the rubber boot around the gear lever. Check that the two holes in the gear lever plate are aligned with the two holes directly below in the mounting plate&quot;)</td>
</tr>
<tr>
<td>(match 10)</td>
</tr>
<tr>
<td>(mismatch 5)</td>
</tr>
<tr>
<td>(type yes_or_no))</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>(Defschema action38</th>
</tr>
</thead>
<tbody>
<tr>
<td>(number-key action38)</td>
</tr>
<tr>
<td>(title &quot;Incorrect gearshaft lever plate adjustment&quot;)</td>
</tr>
<tr>
<td>(text &quot;Slacken the two retaining bolts or screws, align the four holes then tighten the bolts or screws&quot;)</td>
</tr>
</tbody>
</table>
2. The presented case is matched to existing cases and best matched cases in the case base are retrieved.

3. Refine the presented case and repeat the process from step 2 until the desired case or cases are retrieved.

Thus, as one can see from the reasoning process, matching is an integral part of CBR Express reasoning. To do the matching, the features of the search case are each individually scored against corresponding features of the stored cases.

A description of experienced symptoms is given, then CBR Express runs an initial search on this description and returns the five closest cases and list them in order of matched scores. Searching is done by ART-IM's forward-chaining rule system. Scoring is done by giving a number between 0 and 100 that shows how close the case matched the search description. After the questions associated with the matched cases are answered, CBR Express finds the five best matched cases to the combined description and questions. Matching is done by the case-based reasoning engine in ART-IM. In ART-IM the score range is -1 to 1 with CBR Express mapping this range into a match score of 0 to 100.

5.3.1 Match Score Derivation

To determine a match score, the features of each search case are individually scored against corresponding features of the stored cases. Each case's match score is computed based on how closely the features of the presented case matches the features of an individual case. Features, unless otherwise specified, contribute equally to the score for a
case. The weight contribution of each feature can be specified by assigning a match or mismatch weight to a feature. See Table 5.2 for an example. Column 1 of Table 5.2 gives the match and mismatch weight. Column 2 gives the features on which matching is done and column 3 gives the desired value for each feature. CBR Express has a default assignment of 10 and 0 for match and mismatch weights for the description weight (Table 5.2 feature 1) which cannot be changed. Any of the other feature's weights can be assigned any weight between 0 and 120 with CBR Express assigning default weights of 10 and 5 for match and mismatch weights. In Table 5.2 features 2 and 5 are more important than other features and are assigned the weights 40 and 20 respectively. The total of the weights assigned does not have to equal any specific match total. Any combination of weights can be specified. The percentage contribution of a feature can be determined by dividing the feature match weight by the total match weight. Given the assignment of weights in Table 5.2, the feature "heavy knocking noise" contributes to the case's total score as follows:

\[
\text{Contribution} = \frac{\text{Feature match weight}}{\text{Total match weight}} = \frac{40}{90} = 44\%
\]

The calculation of the percentage contribution has nothing to do with the match score derivation but only gives one an idea of how much does the feature contribute towards the match score. Remember the total match weight can be any number as long as each feature is assigned a weight between 0 and 120. There is no specific reason for the limit of 120 except for keeping some control for not having the user assign any weight.
<table>
<thead>
<tr>
<th>Weight Match Mismatch</th>
<th>Feature</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 0</td>
<td>1. Description</td>
<td>Knock, thump noise in engine</td>
</tr>
<tr>
<td>40 5</td>
<td>2. Question 1: Is there a regular heavy knocking noise present?</td>
<td>yes</td>
</tr>
<tr>
<td>10 5</td>
<td>3. Question 2: Is the noise less or worse under weight?</td>
<td>less</td>
</tr>
<tr>
<td>10 0</td>
<td>4. Question 3: Give a description of the spark plug heads.</td>
<td>wet, oily</td>
</tr>
<tr>
<td>20 5</td>
<td>5. Question 4: What is the lowest cylinder pressure reading (kPa)?</td>
<td>1.8 range: 0 to 2</td>
</tr>
<tr>
<td>90</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
If a search feature exactly matches a stored feature, the raw score of the stored case is incremented by the match weight of the question. The raw score is the sum of all feature scores for all features of the search case. For features that may result in partial matches (such as the description string) the raw score is incremented by some fraction of the feature's defined match weight, depending on how close the match is. It is also possible to define a mismatch weight for the feature. In this case, failure to match a feature of the search case results in decrementing the stored case's raw score. For example, a presented case is matched to the stored case in Table 5.2. For the moment assume that no partial matches take place. The feature match weight is either the match weight or the mismatch weight depending on if the answer is correct or incorrect. If the first four features match (answers correct) and the fifth not (answer incorrect) the raw score will be as follows:

\[
\text{Raw score} = 10 + 40 + 10 + 10 - 5 \\
= 65
\]

The raw scores of each case cannot be directly compared, so they are normalized to determine the match score. Ranking is then done on the normalized score. Normalizing is done by dividing a case's matching score by the maximum score for that case. The match score will be as follows:

\[
\text{Match score} = \frac{\text{Raw score}}{\text{Total score}} = \frac{10 + 40 + 10 + 10 - 5}{90} = \frac{65}{90} = 0.72
\]

If all the answers were correct the match score will be:

\[
\text{Match score} = \frac{\text{Raw score}}{\text{Total score}} = \frac{10 + 40 + 10 + 10 + 20}{90} = \frac{90}{90} = 1
\]
The ART-IM score range of -1 to 1 has to be mapped into a score of 0 to 100. This is done as follows:

If ART-IM score is negative: match score = 0
If ART-IM score is positive: match score = ART-IM score * 100

Thus, match score = 0.72 * 100 = 72
and, match score = 1 * 100 = 100

It is also possible to give a question an absolute score. This question will absolutely confirm or disqualify a case. For example, to determine if the coil connections are loose the following questions need to be answered:

Does the automobile start? No
Does the starter turn the engine normally? Yes
Is voltage reaching the plugs? No
Are there any loose connections on the coil? Yes

If the last question is answered correctly it absolutely confirms the case "loose coil connections". If the question is answered incorrectly it absolutely disqualifies the case as a contending case.

5.3.2 Feature Weight Derivation

I will continue to use the example given in Table 5.2 to explain the different feature
weight derivations and will refer to it as the stored case. For features that may result in partial matches, the raw score is incremented by some fraction of the feature's defined weight, depending on how close the match is. The feature weight derivation depends upon the match-type used. Features on which matching is done in CBR Express are the case description and questions. CBR Express supports four types of answers to questions, namely, yes or no, numeric, text, and list answers. Numeric questions have answers that may be positive or negative integers and floating-point numbers. Text questions accommodate text input of unrestricted length. List answers are selected from a scrolling list of legal answers. The following discussion describes in more detail the techniques used in determining the different feature match weights. Remember that if a stored case does not have a feature found on the presented case, the weight for the feature is set to the mismatch weight.

*Description match scoring.* The description gets processed by ART-IM's text-preprocessor before matching is done. Text-preprocessing is done to improve the quality of text feature matching by removing characters that represent "noise". The text-preprocessor removes word separators, converts the text to upper case, removes ignored words, replaces synonyms with basic words, and strips-away word suffixes. For example, suppose a presented case description contained the following text:

"I heard knocking- and thumping noises in the engine !"

The text-preprocessor will process the description as follows:

1. Remove word separators:

   "I heard knocking and thumping noises in the engine"

2. Convert to upper case:

   "I HEARD KNOCKING AND THUMPING NOISES IN THE ENGINE"
3. Remove ignored words:

"HEARD KNOCKING THUMPING NOISES ENGINE"

4. Remove synonyms:

"HEAR KNOCKING THUMPING NOISES ENGINE"

5. Strip-away suffixes:

"HEAR KNOCK THUMP NOISE ENGINE"

The default preprocessor has several default values for separators, ignored words and synonyms.

The remaining text is then broken up into trigrams, which are three-character fragments of the string. For example, the processed text "HEAR KNOCK THUMP NOISE ENGINE" would generate the following set of trigrams:


The trigrams of the search description are compared to the trigrams of each stored case description. The raw score of each case is then incremented by a fraction of the description weight for each trigram that the search description and the case description have in common. Absolute scoring does not apply to description matching. The formula for description scoring is as follows:

\[
\text{Description weight} = \frac{(t_x - t_m)}{t_x} \text{ mismatch weight} + \frac{t_m}{t_x} \text{ match weight}
\]
Where:
\[ tm = \text{the number of trigrams in common between the presented case and the stored case} \]
\[ tx = \text{the number of trigrams in the presented case} \]

If the presented case description is given and a search is conducted a match against the stored case (Table 5.2) will result in the following match score:

Presented case: 23 trigrams
Stored case: 19 trigrams
Trigrams in common: 19

Description weight = \((23-19) * (0) / 23 + 19 * 10 / 23\)
\[ = 8.26 \]

Match score (ART-IM) = \(8.26/90\)
\[ = 0.092 \]

Mapping the score for CBR Express:

If score negative: Match score = 0
else Match score = fraction * 100

Match score = 0.092 * 100
\[ = 9 \]

Thus CBR Express will present a match score of 9 after the initial search.

Yes/No Questions and List Questions Scoring. Yes/No questions and list questions get processed by a string matching algorithm. Either an answer on the presented case is an exact match of the answer of a stored case, or it is not. If the answer is correct, then the
stored case's raw score will be incremented by the match weight of the question. If the answer is incorrect the raw score will be decremented by the mismatch weight of the question. Absolute scoring applies to yes/no and list questions. The formula for string matching is as follows:

If the answer of the presented case and the stored case are equal:

\[ \text{Question weight} = \text{match weight} \]

If the answer of the presented case and the stored case are not equal:

\[ \text{Question weight} = \text{mismatch weight} \]

For example, if the first question of the stored case is answered "yes" the question weight equals 40 and if question 2 is answered "worse" the question weight equals -5.

**Text Questions Scoring.** Word matching is the algorithm for scoring text questions. In word matching the answer also gets processed by the text-preprocessor as discussed in description scoring. The answer string is preprocessed to remove "noise" words. The remaining text is then kept in word format. The raw score for each case is then incremented by a fraction of the question weight for each word that the search answer and the case answer have in common. Absolute scoring does not apply to text questions. The formula for text question scoring is as follows:

\[ \text{Question weight} = \frac{(wx - wm)}{wx} \cdot \text{mismatch weight} + \frac{wm}{wx} \cdot \text{match weight} \]

Where:
- \(wm\) = the number of words in common between the presented case and the stored case
- \(wx\) = the number of words in the presented case
For example, if question 3 of the stored case is answered "oily deposits" the question weight will be:

Stored case: 2 words
Presented case: 2 words
Words in common: 1

\[
\text{Question weight} = \left[ (2 - 1) \times \frac{0}{2} \right] + \left[ \frac{10}{2} \right] = 5
\]

**Numeric Question Scoring.** One specifies a desired number and a legal range for presented numbers. Number matching awards score points based on how near the search number is to the number in the stored case by taking the legal range into account. If the presented number is outside the range it is a total mismatch. The formula for numeric scoring is as follows:

\[
\text{Question weight} = \frac{|\text{cvalue} - \text{pvalue}|}{\text{mdev}} \cdot (\text{match - mismatch})
\]

Where:
- match = stored case's match weight for the feature
- cvalue = stored case value for question
- pvalue = presented case value for the question
- mdev = match-deviation, 10% of legal range.
- mismatch = stored case's mismatch-weight for the question

When \(|\text{cvalue} - \text{pvalue}| / \text{mdev}\) is greater than 1, the feature weight is the complete mismatch weight.

For example, if question 4 of the stored case is answered 1.75 kPa, the question weight
will be:

Legal range: 0 to 2
Stored case: 1.8
Presented case: 1.75
Match-deviation (10% of legal range): 0.2

\[
\text{Question weight} = 20 - \left( |1.8 - 1.75| / 0.2 \right) * [20 - (-5)]
\]
\[
= 13.75
\]

If another search is conducted after the questions is answered as in the examples, the match score for the presented case against the stored case will be as follows (See Table 5.3):

\[
\text{Match score (ART-IM)} = \frac{(8.26 + 40 - 5 + 5 + 13.75)}{90} = 62.01 / 90
\]
\[
= 0.689
\]

\[
\text{Match score (CBR Express)} = 0.689 * 100
\]
\[
= 69
\]

CBR Express rounds the match score to the closest integer.
<table>
<thead>
<tr>
<th>Match Weight Contribution</th>
<th>Feature</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>8.26</td>
<td>1. Description</td>
<td>Hear knock, thump noise in engine.</td>
</tr>
<tr>
<td>40</td>
<td>2. Question 1: Is there a regular heavy knocking noise present?</td>
<td>yes</td>
</tr>
<tr>
<td>-5</td>
<td>3. Question 2: Is the noise less or worse under weight?</td>
<td>worse</td>
</tr>
<tr>
<td>5</td>
<td>4. Question 3: Give a description of the spark plug heads.</td>
<td>oily deposits</td>
</tr>
<tr>
<td>13.75</td>
<td>5. Question 4: What is the lowest cylinder pressure reading (kPa)?</td>
<td>1.75</td>
</tr>
<tr>
<td>62.01</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
5.4 CBR Express Explanation

CBR Express provides a browse facility that can be used on any question or action. For example, the question "Is there a voltage reading across the solenoid?" can be browsed to get advise and reasons for why the question should be answered. A browse on the above question would provide the following response: "The solenoid contact can be checked by putting a voltmeter or bulb across the main cable connection on the starter side of the solenoid and earth. When the starter switch is operated, there should be no reading or lighted bulb to prove that the solenoid is defective."

After the initial search on the search description, the best matching cases are displayed with their match scores. The user can see which cases are the most promising and can browse text describing these cases. Any matched case's action can be browsed for further information. For example, assume the best match is, "the starter motor mounting bolts are loose". A browse on this action will provide the following: "The starter motor mounting bolts must be fastened. The loose bolts cause the starter motor pinion ring gear teeth and the flywheel ring gear teeth to intersect at a wrong angle which causes wear. If the teeth are too worn, the noise will continue and the starter motor will have to be removed for detailed inspection."

Toolbook makes it possible to provide graphics explanation to any browse. To provide this feature one needs a development copy of Toolbook. The CBR Express package only comes with a runtime copy of Toolbook. The graphic explanation can be very helpful in providing additional information. For example, a wiring diagram with illustrated test points can be very helpful in determining electric failures. Toolbook also provides a
graphic animation capability.

5.5 Building the CBR Express Case Base

Now that we know more about CBR Express reasoning, we can return to the building of a diagnostic case base discussed in chapter 4. We need to organize the information derived in the previous chapter (Table 4.2) according to the software package to be used. Thus, for building a case base for CBR Express, a case description, questions, and actions need to be defined for each case. See Appendix A for a printout of the case base.

The case description is a critical paragraph of text that forms the basis for the first search. The object is to write a sentence or short paragraph that describes the symptoms of the problem that can be experienced by the vehicle owner. The symptoms given in Table 4.2 forms the case description. These symptoms have to be written in the same format the vehicle owner would be explaining the symptoms to a mechanic when the vehicle is taken for repair. For example, the case description for a defective solenoid will be as follows: "Automobile won't start, Starter fails to turn the engine."

The questions are added to a case to confirm a failure. The test procedure in Table 4.2 form the basis of the questions. For example, the test procedure for identifying a defective solenoid was constructed as follows:

If the starter does not turn the engine
AND the headlights dim when the starter switch is operated
AND no voltage reading across the starter side of the solenoid
THEN  the starter solenoid is defective

This test procedure has to be reorganized in questions with desired answers as follows:

Question1: Does the automobile start ? ; no

Question2: Do the headlights dim when the starter switch is operated ? ; yes

Question3: Is there a voltage reading across the starter side of the solenoid ? ; no

Any of the four types of questions discussed can be used with weight contributions specified as discussed if necessary. Explanations should also be provided for each question. For example, an explanation for question 2 will be as follows: "Switch the headlights on and while they are switched on, operate the starter switch. When the lights dim, it confirms that power is reaching the starter motor."

Actions are attached to each case in order to make a conclusion or give a solution to the problem. The conclusion in the test procedure in Table 4.2 forms the basis of the action. For example, the action for a defective starter solenoid will be as follows: "The starter solenoid is defective. The solenoid will have to be replaced. The solenoid is secured to the starter motor which is located at the rear right-hand side of the vehicle. The starter motor is secured to the clutch housing from the front of the vehicle."

5.6 CBR Express Managing of Variations in Diagnosis

CBR Express can determine a failure from any combination of symptoms given. The
failure description, of the stored cases, consist of all the symptoms that can be experienced by the vehicle owner. The initial match can be done on single, multiple, or any combination of symptoms. CBR Express will match multiple failures to the symptoms given. Thus CBR Express covers all failure versus symptom scenarios discussed in chapter 4. For example, Case 2 in Appendix A "Battery discharged" can have the following symptoms: automobile won't start, starter turns engine slowly, starter fails to turn engine, lights inoperative. If a diagnosis is conducted by using CBR Express any combination of these symptoms can be entered. The vehicle owner might enter the symptoms "automobile won't start and the lights are inoperative". The symptoms will then be matched against all failures. The failure descriptions of the stored cases that best matches the symptoms given will be retrieved.

Multiple test procedures for determining a single failure can be constructed. For example, if two different test procedures determine the same failure, CBR Express can manage it as follows. Two cases need to be constructed, each with their own test procedure made up out of questions, but with the same action. From the symptoms as input, CBR Express will come up with two matches. Refinement is then done by answering questions that contribute to both the test procedures. After refinement CBR Express gives a match score for both cases, but when the actions are browsed only one action is given and the highest score is presented. For example, the following two cases were constructed in order to determine if the solenoid is defective (The case number given corresponds with the case number in Appendix A):

Case 3
Title: "Solenoid defective (H1)."
Description: "Automobile won't start."

Questions: "Does the automobile start?" : "No"

"Does the starter motor turn the engine normally?" : "No"

"Do the headlights dim when the starter switch is operated?" : "Yes"

"Do you hear a clicking noise when the starter switch is operated?" : "No"

Action: "The starter solenoid is defective."

Case 16

Title: "Solenoid defective (H2)."

Description: "Automobile won't start. Starter fails to turn engine."

Questions: "Does the automobile start?" : "No"

"Does the starter motor turn the engine normally?" : "No"

"Do the headlights dim when the starter switch is operated?" : "Yes"

"Is there a voltage reading across the solenoid?" : "No"

Action: "The starter solenoid is defective."

Different weight contributions of multiple features for a single test procedure can be specified by giving a match weight to each feature (discussed in section 5.3.1). For example, case 21 in Appendix A consist of the following features with the one feature contributing more than the other:

Case 21

Title: "Worn big-end bearings"

Description: "Knocking noise, thumping noise, in engine"

Questions: "Is there a regular heavy knocking noise present?" : "Yes"
Match weight = 70  Mismatch weight = 5
"Is the noise less or worse under load ?" : "less"
Match weight = 10  Mismatch weight = 0

Action: "Worn big-end bearings."

Different weight contribution by a single feature in multiple test procedures can not be done by CBR Express. When a feature (question) is defined, the match weight is specified and this match weight applies throughout all the test procedures that it is used in. This problem can be overcome by defining multiple features that are exactly the same, but have different weight contributions. The inconvenience associated with this is that after matching is done the same question might have to be answered several times, each time for a different test procedure. For example, case 22 in Appendix A uses the exact same question, "Is the noise less or worse under load ?", as in case 21 but have a different weight contribution. Two questions had to be defined each with a different weight contribution.

Case22

Title: "Worn main bearings"

Description: "Knocking noise, thumping noise, rumbling noise, in engine"

Questions: "Is there a rumbling and knocking noise present ?" : "Yes"

Match weight = 70  Mismatch weight = 5
"Is the noise less or worse under load ?" : "worse"
Match weight = 20  Mismatch weight = 0

Action: "Worn main bearings."
CBR Express does not give a confidence level on the conclusion. The match score that is given, is a confidence level on how close the presented case matches the stored case. Thus CBR Express can not give one test procedure a more reliable conclusion than another.

5.7 Summary of CBR Express Reasoning

Figure 5.3 gives a comprehensive outlay of CBR Express reasoning. Both the building and searching of the case-base is done through the user interface. To build a case-base one needs to define a failure description, questions that represent a test procedure, and an action that states the failure and recommend a repair action. Cases are stored in the case base in db-Vista databases.

Searching is done by giving a description of the symptoms experienced. After the initial search, refinement is done through answering questions about the matched cases. The search and refinement is then repeated until the desired case or cases are retrieved. Matching is done by a case matching mechanism from ART-IM, with all the functions operating under Microsoft Windows.
Figure 5.3 CBR Express Functioning
Chapter VI. SAMPLE DIAGNOSTIC CONSULTATIONS

In chapter VI sample diagnostic consultations by using CBR Express is performed. The figures indicate an illustration of the computer screen display as they would appear during a consultation. The chapter will familiarize the reader on how an actual diagnosis is performed by CBR Express.

6.1 Diagnostic Consultation Number One

If the spark plugs are faulty, the following consultation would take place. The consultation with CBR Express begins by entering the symptoms experienced by the automobile owner. Assume the symptom experienced by the automobile owner is "Automobile won't start" for this sample consultation. Figure 6.1 shows the matching cases with associated questions after the initial search on the description "Automobile won't start". The next step is to answer the questions. The questions may be answered in any order, and it is not necessary to answer them all. The questions are scanned and only
### Search

**Description:**

Automobile won't start

<table>
<thead>
<tr>
<th>Questions about this Problem</th>
<th>Answers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Does the starter motor turn the engine normally?</td>
<td>Not Answered</td>
</tr>
<tr>
<td>Are there any corroded or loose starter motor connections?</td>
<td>Not Answered</td>
</tr>
<tr>
<td>Is the cylinder pressure low?</td>
<td>Not Answered</td>
</tr>
<tr>
<td>Does the automobile start?</td>
<td>Not Answered</td>
</tr>
<tr>
<td>Is there moisture in the distributor cap?</td>
<td>Not Answered</td>
</tr>
<tr>
<td>Is voltage reaching the plug?</td>
<td>Not Answered</td>
</tr>
<tr>
<td>Is the gas tank empty?</td>
<td>Not Answered</td>
</tr>
</tbody>
</table>

### Matching Cases:

- 34 Starter connections loose or corroded
- 34 Low cylinder compressions
- 34 Moisture in HT circuit
- 34 Spark plug gaps faulty
- 34 Empty fuel tank

Figure 6.1. Sample Consultation
the questions that does not require the performance of any test actions are answered. After scanning the questions in Figure 6.1 three questions were answered as follows:

Does the starter motor turn the engine normally?; Yes
Does the automobile start?; No
Is the gas tank empty?; No

During the second CBR Express finds the five best cases that have the best match to the combined description and questions. Figure 6.2 shows the result after the second search. As before, CBR Express present a list of questions associated with the matched cases. The automobile owner continues to answer questions and search until one of the cases shows an acceptably high score, or until all questions are answered. A score of 100 is a perfect match but any score above 90 is a good match.

If a question is not understood well, CBR Express provides a means to browse additional information about the question. The matched cases can also be browsed to provide information about the case. Figure 6.3 shows a browse on the question "Is voltage reaching the plugs?" and a browse on the case "Spark plug gaps faulty".

The consultation is continued by answering the question "Is voltage reaching the plugs" positive and by conducting another search. Figure 6.4 shows the results after the search is conducted. CBR Express gives the operator the choice of showing either of the case titles or case actions. Figures 6.1 to 6.3 shows the case titles with Figure 6.4 showing the case actions. The action "The spark plugs are wet, dirty, or wrongly gaped" gives a match score of 94 which confirms that it is the failure. Figure 6.5 shows a browse on this action.
### Search

**Description:**
Automobile won't start

**Questions about this Problem:**

<table>
<thead>
<tr>
<th>Question</th>
<th>Answers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Is there moisture in the distributor cap?</td>
<td>Not Answered</td>
</tr>
<tr>
<td>Is voltage reaching the plug?</td>
<td>Not Answered</td>
</tr>
<tr>
<td>Is voltage reaching the distributor?</td>
<td>Not Answered</td>
</tr>
<tr>
<td>Are there any loose connections on the coil?</td>
<td>Not Answered</td>
</tr>
<tr>
<td>Does the starter spin without turning the engine?</td>
<td>Not Answered</td>
</tr>
<tr>
<td>Does the starter motor turn the engine normally?</td>
<td>Yes</td>
</tr>
<tr>
<td>Does the automobile start?</td>
<td>No</td>
</tr>
</tbody>
</table>

**Matching Cases:**

- 61 Low cylinder compressions
- 61 Moisture in HT circuit
- 61 Spark plug gaps faulty
- 59 Loose coil connections.
- 53 Pinion or flywheel ring gear teeth broken or worn (H1).

---

**Figure 6.2.** Sample Consultation
### Search

**Description:**
Automobile won't start

<table>
<thead>
<tr>
<th>Browsing Question:</th>
<th>Answers:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Is voltage reaching the plug?</td>
<td>Not Answered</td>
</tr>
</tbody>
</table>

**Disconnect each plug lead in turn at the spark plug end, and hold the end of the cable with rubber or an insulated tool about 6 mm away from the cylinder block. Spin the engine on the starter motor. Sparking between the end of the cable and the block should be fairly strong with a regular blue spark to prove that voltage is present.**

<table>
<thead>
<tr>
<th>Browsing Case:</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Description:</strong> Automobile won't start</td>
</tr>
<tr>
<td><strong>Questions:</strong></td>
</tr>
<tr>
<td>Does the starter motor turn the engine normally? Yes</td>
</tr>
<tr>
<td>Is voltage reaching the plug? Yes</td>
</tr>
<tr>
<td><strong>Actions:</strong></td>
</tr>
<tr>
<td>The spark plugs are wet, dirty or wrongly gaped.</td>
</tr>
</tbody>
</table>

---

Figure 6.3. Sample Consultation
### Search

**Description:**
Automobile won't start

<table>
<thead>
<tr>
<th>Questions about this Problem</th>
<th>Answers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Is the cylinder pressure low?</td>
<td>Not Answered</td>
</tr>
<tr>
<td>Is there moisture in the distributor cap?</td>
<td>Not Answered</td>
</tr>
<tr>
<td>Does the starter spin without turning the engine?</td>
<td>Not Answered</td>
</tr>
<tr>
<td>Is it difficult to start the engine?</td>
<td>Not Answered</td>
</tr>
<tr>
<td>Is the fuel pump faulty?</td>
<td>Not Answered</td>
</tr>
<tr>
<td>Is voltage reaching the plug?</td>
<td>Yes</td>
</tr>
<tr>
<td>Does the starter motor turn the engine normally?</td>
<td>Yes</td>
</tr>
</tbody>
</table>

**Recommended Actions:**
- 94 The spark plugs are wet, dirty or wrongly gapped.
- 57 The cylinder compressions are too low
- 57 Moisture in distributor cap.
- 51 The pinion or flywheel ring gear teeth are broken or badly worn.
- 47 The fuel pump is faulty.

Figure 6.4. Sample Consultation
### Search

**Description:**
Automobile won't start

<table>
<thead>
<tr>
<th>Questions about this Problem</th>
<th>Answers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Is the cylinder pressure low?</td>
<td>Not Answered</td>
</tr>
<tr>
<td>Is there moisture in the distributor cap?</td>
<td>Not Answered</td>
</tr>
<tr>
<td>Does the starter spin without turning the engine?</td>
<td>Not Answered</td>
</tr>
<tr>
<td>Is it difficult to start the engine?</td>
<td>Not Answered</td>
</tr>
<tr>
<td>Is the fuel pump faulty?</td>
<td>Not Answered</td>
</tr>
<tr>
<td>Is voltage reaching the plug?</td>
<td>Yes</td>
</tr>
<tr>
<td>Does the starter motor turn the engine normally?</td>
<td>Yes</td>
</tr>
</tbody>
</table>

**Browsing Action:**
Remove the spark plugs, clean and regap them.

Figure 6.5. Sample Consultation
6.2 Diagnostic Consultation Number Two

If there is air in the clutch hydraulic system, the following consultation would take place. Figure 6.6 shows the matched cases with associated questions after the initial search on the symptom "Difficulty in engaging gears" was conducted. One of the questions instruct the automobile owner to bleed the clutch system and report if the malfunction is corrected. Figure 6.7 shows a browse on this question. Assume the automobile owner bled the clutch system as instructed in Figure 6.7 and reported that the malfunction is corrected. After two more questions are answered as indicated in Figure 6.8 another search is conducted. Figure 6.8 shows the result after the search is conducted. The action "Air in the clutch system" gets a perfect match score of 100.
Search

Description:
Difficulty in engaging gears

Questions about this Problem:

<table>
<thead>
<tr>
<th>Question</th>
<th>Answer</th>
</tr>
</thead>
<tbody>
<tr>
<td>In which way does the clutch malfunction?</td>
<td>Not Answered</td>
</tr>
<tr>
<td>Are there any clutch hydraulic fluid leaks?</td>
<td>Not Answered</td>
</tr>
<tr>
<td>Are the clutch master cylinder correctly adjusted?</td>
<td>Not Answered</td>
</tr>
<tr>
<td>Is the brake fluid level under the minimum mark?</td>
<td>Not Answered</td>
</tr>
<tr>
<td>Bleed the clutch system - is the malfunction corrected?</td>
<td>Not Answered</td>
</tr>
</tbody>
</table>

Recommended Actions:

1. Clutch hydraulic leak.
2. Clutch master cylinder incorrectly adjusted.
3. Empty brake fluid reservoir.
4. Air in the clutch system.
5. The clutch is internally faulty.

Figure 6.6. Sample Consultation
Description:
Difficulty in engaging gears

Browsing Question:
From under the rear of the vehicle, wipe clean the area around the bleed screw on the slave cylinder and remove the rubber dust cover. Connect one end of a bleed tube to the bleed screw, and insert the other end of the tube in the jar containing sufficient clean hydraulic fluid to keep the end of the tube submerged. Open the bleed screw half a turn and have your assistant depress the clutch pedal and then slowly release it. Continue this procedure until clean hydraulic fluid.

Matching Cases:
51 Clutch hydraulic leak.
51 Clutch master cylinder adjustment incorrect (H1).
24 Empty brake fluid reservoir (H2).
21 Air in clutch hydraulic system.
17 Clutch faulty (H1)

Figure 6.7. Sample Consultation
### Search

**Description:**

Difficulty in engaging gears

**Questions about this Problem:**

<table>
<thead>
<tr>
<th>Question</th>
<th>Answer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Does the brake pedal feel spongy or travel excessively?</td>
<td>Not Answered</td>
</tr>
<tr>
<td>Are there any brake fluid leaks?</td>
<td>Not Answered</td>
</tr>
<tr>
<td>Bleed the brake system. Is the problem corrected?</td>
<td>Not Answered</td>
</tr>
<tr>
<td>Is the master cylinder pushrod correctly adjusted?</td>
<td>Not Answered</td>
</tr>
<tr>
<td>Are there any clutch hydraulic fluid leaks?</td>
<td>No</td>
</tr>
<tr>
<td>Is the brake fluid level under the minimum mark?</td>
<td>No</td>
</tr>
<tr>
<td>Bleed the clutch system - is the malfunction corrected?</td>
<td>Yes</td>
</tr>
</tbody>
</table>

**Matching Cases:**

- 100 Air in clutch hydraulic system.
- 36 Clutch master cylinder adjustment incorrect (H1).
- 18 Air in brake system.
- 16 Clutch hydraulic leak.
- 12 Faulty master cylinder.

---

Figure 6.8. Sample Consultation
Chapter VII. CONCLUSION

7.1 Concluding notes on CBR Express

A significant diagnostic case-base was developed for a 1.6 liter, 1981 model Volkswagen Vanagon in order to demonstrate and evaluate the appropriateness of CBR Express for failure diagnosis. The systematic approach discussed in chapter 4 was used to build the case base. This type of case base development makes the cases easier to verify and update.

The CBR Express case-base matching inference method is well suited for failure diagnosis. CBR Express is menu driven in both the maintenance and search modes, which make it an easy tool to use for those not familiar with computers and computer programming. However, all of the artificial intelligence features of ART-IM are available for use in expanding or customizing a CBR Express application. The CBR Express maintenance mode proves easy to use for expanding the system incrementally by adding knowledge to the system without repeated software updates performed by knowledge
engineers. The manuals make the package complete by giving a step-by-step introduction tutorial to CBR Express with easy to use user's guide and reference manual.

Complex diagnosis can not be efficiently accomplished without the graphical explanation facility. This necessitates a development copy of Toolbook which does not form part of the CBR Express package.

Overall, CBR Express provides an excellent case-base matching application.

7.2 Conclusion

Failure diagnosis is an expensive and time consuming task. It has become more critical because of increasing equipment complexity and rapid personnel turnover. Failure diagnostic expert systems offer the opportunity for improving the overall effectiveness of diagnosis. Failure diagnostic expert systems are always available for diagnosing failures, they are consistent, and comprehensive.

It takes a long time for someone to acquire expertise in failure diagnosis. Rapid personnel turnover makes it difficult in keeping experienced people and also keeping people from reaching a desired level of expertise. The few experienced people are not always available or/and are very costly. An expert system is always available. Experienced people can make mistakes or may forget an important point. Apart from hardware failures, and provided that the knowledge is correctly formulated, the failure diagnosis done by the expert system will be constantly correct. An expert can only draw
upon his own knowledge and experience. An expert system can encapsulate the knowledge of more than one expert, so that its diagnosis decision making is at least as good as any of the individual contributors.

This project investigated failure diagnosis through case-based reasoning; case-based reasoning being a specific type of expert systems. It was demonstrated how a diagnostic case base can be built and expanded in an effective manner. It is essential to use structured techniques for building a case base. Using the techniques discussed in chapter 4 for building a case base result in less extraneous effort and makes it easier to verify and update.

It was also shown that CBR Express is an ideally suited case-based matching application for failure diagnosis. The use of case-based reasoning for failure diagnosis not only provides an effective method of diagnosis, but also provides an easy way of expanding the diagnostic knowledge. One learns by experience and this knowledge gained over time can be added to the case base incrementally without major software updates.

A failure diagnostic expert system can not do the impossible or extraordinary but provide the means to increase system availability and decrease repair costs.
REFERENCES


[Searls 1989] D. Searls, J. Clark, D. Corpron, and P. Matuzek,

Appendix A: CASE BASE PRINTOUT
Cases Printout

BEGIN CASE Case1
  TITLE
    "Fuel rating."
  DESCRIPTION
    "Pre-ignition"
  QUESTIONS
    Question25 : "Yes"
    Question26 : "Yes"
  ACTIONS
    Action37
END CASE

BEGIN CASE Case2
  TITLE
    "Battery discharged (H1)."
  DESCRIPTION
    "Automobile won't start. Starter turns engine slowly. Starter fails to turn engine.
    Lights inoperative."
  QUESTIONS
    Question2 : "No"
    Question43 : "No"  (SCORING : -)
    Question3 : "Yes"
  ACTIONS
    Action1
END CASE

BEGIN CASE Case3
  TITLE
    "Solenoid defective (H1)."
  DESCRIPTION
    "Automobile won't start."
  QUESTIONS
    Question2 : "No"
    Question43 : "No"  (SCORING : -)
    Question4 : "Yes"
    Question5 : "No"
  ACTIONS
    Action3
END CASE

BEGIN CASE Case4
  TITLE
    "Battery terminals loose."
END CASE
DESCRIPTION
"Automobile won't start. Starter fails to turn engine. Battery will not hold charge for long."

QUESTIONS
Question2 : "No" (SCORING : -)
Question43 : "No" (SCORING : -)
Question6 : "Yes" (SCORING : -)

ACTIONS
Action4

END CASE

BEGIN CASE Case5

TITLE
"Battery earth cable loose."

DESCRIPTION
"Automobile won't start. Starter fails to turn engine."

QUESTIONS
Question2 : "No" (SCORING : -)
Question43 : "No" (SCORING : -)
Question7 : "Yes" (SCORING : -)

ACTIONS
Action5

END CASE

BEGIN CASE Case6

TITLE
"No power to starter motor."

DESCRIPTION
"Automobile won't start, starter fails to turn engine."

QUESTIONS
Question2 : "No"
Question6 : "No"
Question7 : "No"
Question4 : "No" (SCORING : -)

ACTIONS
Action2

END CASE

BEGIN CASE Case7

TITLE
"Starter motor defective."

DESCRIPTION
"Automobile won't start, starter fails to turn engine."

QUESTIONS
Question3 : "No"
Question4 : "Yes"
Question5 : "Yes"
Question15 : "No"
Question23 : "No"
BEGIN CASE Case8
TITLE
"Starter brushes worn or sticking."
DESCRIPTION
"Starter turns engine slowly. Automobile won't start."
QUESTIONS
Question15 : "No"
Question3 : "No"
Question30 : "Yes"
END CASE

BEGIN CASE Case9
TITLE
"Alternator defective (H2)."
DESCRIPTION
"Battery will not hold charge for long. Battery does not get charged. Ignition light stays on."
QUESTIONS
Question34 : "No"
Question31 : "Yes"
END CASE

BEGIN CASE Case10
TITLE
"Transmission input shaft bearings worn."
DESCRIPTION
"Transmission noisy in neutral."
QUESTIONS
Question8 : "Yes"
END CASE

BEGIN CASE Case11
TITLE
"Transmission and/or differential internally defective"
DESCRIPTION
"Transmission noisy only when moving, in all gears."
QUESTIONS
Question9 : "Yes"
BEGIN CASE Case12
  TITLE
    "Worn damaged or chipped gear teeth."
  DESCRIPTION
    "Transmission noisy in only one gear."
  QUESTIONS
    Question10 : "Yes"
  ACTIONS
    Action9
END CASE

BEGIN CASE Case13
  TITLE
    "Transmission internally defective."
  DESCRIPTION
    "Transmission jumps out of gear."
  QUESTIONS
    Question11 : "Yes"
    Question13 : "Yes"
  ACTIONS
    Action10
END CASE

BEGIN CASE Case14
  TITLE
    "Worn synchro rings."
  DESCRIPTION
    "Ineffective synchromesh."
  QUESTIONS
    Question12 : "Yes"
  ACTIONS
    Action11
END CASE

BEGIN CASE Case15
  TITLE
    "Battery discharged (H2)."
  DESCRIPTION
    "Automobile won't start, starter turns engine slowly, starter fails to turn engine, lights inoperative."
  QUESTIONS
    Question2 : "No"
    Question14 : "<9-volt"
  ACTIONS
    Action1
END CASE

BEGIN CASE Case16
  TITLE
  "Solenoid defective (H2)."
  DESCRIPTION
  "Automobile won't start. Starter fails to turn engine."
  QUESTIONS
  Question2 : "No" (SCORING : -)
  Question43 : "No" (SCORING : +)
  Question16 : "No" (SCORING : +)
  ACTIONS
  Action3
END CASE

BEGIN CASE Case17
  TITLE
  "Starter connections loose or corroded."
  DESCRIPTION
  "Automobile won't start. Starter turns engine slowly. Starter fails to turn engine."
  QUESTIONS
  Question15 : "Yes" (SCORING : -)
  ACTIONS
  Action12
END CASE

BEGIN CASE Case18
  TITLE
  "Incorrect gearshift adjustment"
  DESCRIPTION
  "Transmission jumps out of gear"
  QUESTIONS
  Question11 : "Yes"
  Question13 : "No"
  ACTIONS
  Action38
END CASE

BEGIN CASE Case19
  TITLE
  "Pinion or flywheel ring gear teeth broken or worn (H2)."
  DESCRIPTION
  "Starter noisy."
  QUESTIONS
  Question17 : "No" (SCORING : -)
  ACTIONS
  Action19
END CASE
BEGIN CASE Case20
  TITLE
    "Low cylinder compressions"
  DESCRIPTION
    "Automobile won't start"
  QUESTIONS
    Question43 : "Yes" (SCORING : -)
    Question44 : "Yes"
  ACTIONS
    Action39
END CASE

BEGIN CASE Case21
  TITLE
    "Worn big-end bearings"
  DESCRIPTION
    "Knocking noise, thumping noise, in engine"
  QUESTIONS
    Question19 : "Yes"
    Question20 : "less"
  ACTIONS
    Action15
END CASE

BEGIN CASE Case22
  TITLE
    "Worn main bearings"
  DESCRIPTION
    "Knocking noise, thumping noise, rumbling noise, in engine"
  QUESTIONS
    Question21 : "Yes"
    Question27 : "worse"
  ACTIONS
    Action16
END CASE

BEGIN CASE Case23
  TITLE
    "Alternator drivebelt slipping"
  DESCRIPTION
    "Battery will not hold charge for long."
  QUESTIONS
    Question22 : ">15mm"
  ACTIONS
    Action18
END CASE
BEGIN CASE Case24
  TITLE
    "Pinion or flywheel ring gear teeth broken or worn (H1)."
  DESCRIPTION
    "Starter spins but does not turn engine. Starter noisy. Automobile won't start."
  QUESTIONS
    Question2 : "No"
    Question23 : "Yes"
  ACTIONS
    Action19
END CASE

BEGIN CASE Case25
  TITLE
    "Starter motor mounting bolts loose."
  DESCRIPTION
    "Starter noisy."
  QUESTIONS
    Question17 : "Yes"  (SCORING : -)
  ACTIONS
    Action13
END CASE

BEGIN CASE Case26
  TITLE
    "Alternator defective (H1)."
  DESCRIPTION
    "Battery will not hold charge for long, battery does not get charged."
  QUESTIONS
    Question22 : "<= 15mm"
    Question24 : "good"
    Question6 : "No"
  ACTIONS
    Action20
END CASE

BEGIN CASE Case27
  TITLE
    "Over-rich fuel mixture."
  DESCRIPTION
    "Engine misfires."
  QUESTIONS
    Question1 : "Yes"  (SCORING : -)
    Question68 : "Dry, black, sooty..."
    (FULL : "Dry, black, sooty deposits")
  ACTIONS
    Action21
END CASE
BEGIN CASE Case28
  TITLE
  "Spark plug oil fouling (H1)."
  DESCRIPTION
  "Engine misfires."
  QUESTIONS
  Question1 : "Yes" (SCORING : -)
  Question68 : "Wet, oily deposits"
  ACTIONS
  Action22
END CASE

BEGIN CASE Case29
  TITLE
  "Spark plug oil fouling (H2)."
  DESCRIPTION
  "Engine misfires."
  QUESTIONS
  Question28 : "Wet, oily"
  ACTIONS
  Action22
END CASE

BEGIN CASE Case30
  TITLE
  "Wear in balljoints."
  DESCRIPTION
  "Vibration in steering"
  QUESTIONS
  Question29 : "No"
  Question32 : "decrease"
  ACTIONS
  Action24
END CASE

BEGIN CASE Case31
  TITLE
  "Wheels out of balance."
  DESCRIPTION
  "Vibration in steering"
  QUESTIONS
  Question33 : "No"
  Question32 : "decrease"
  (FULL : "no noticeable change")
  ACTIONS
  Action17
END CASE
BEGIN CASE Case32
  TITLE
    "Alternator drivebelt broken."
  DESCRIPTION
    "Ignition light stays on."
  QUESTIONS
    Question34 : "Yes"
  ACTIONS
    Action25
END CASE

BEGIN CASE Case33
  TITLE
    "Voltage stabilizer faulty."
  DESCRIPTION
    "Instrument readings increase with engine speed."
  QUESTIONS
    Question35 : "Yes" (SCORING : -)
    Question36 : "Yes" (SCORING : -)
    Question39 : "No"
    Question40 : "Yes"
  ACTIONS
    Action26
END CASE

BEGIN CASE Case34
  TITLE
    "Blown bulb."
  DESCRIPTION
    "Lights inoperative."
  QUESTIONS
    Question36 : "Yes" (SCORING : -)
    Question39 : "No"
    Question40 : "Yes"
  ACTIONS
    Action27
END CASE

BEGIN CASE Case35
  TITLE
    "Horn faulty"
  DESCRIPTION
    "Horn inoperative"
  QUESTIONS
    Question39 : "No"
    Question37 : "> 10 volt"
    Question38 : "No" (SCORING : +)
  ACTIONS
    Action29
END CASE
BEGIN CASE Case36
  TITLE "Blown fuse"
  DESCRIPTION "Lights, horn, windscreen wipers, inoperative."
  QUESTIONS
    Question39 : "Yes"   (SCORING : +)
  ACTIONS
    Action30
END CASE

BEGIN CASE Case37
  TITLE "No power to horn"
  DESCRIPTION "Horn inoperative"
  QUESTIONS
    Question39 : "No"
    Question37 : "< 10 volt"  (SCORING : -)
  ACTIONS
    Action31
END CASE

BEGIN CASE Case38
  TITLE "Open circuit"
  DESCRIPTION "Windscreen wiper, fuel gauge inoperative"
  QUESTIONS
    Question40 : "No"   (SCORING : +)
  ACTIONS
    Action32
END CASE

BEGIN CASE Case39
  TITLE "Fuel sender unit faulty"
  DESCRIPTION "Fuel gauge inoperative, gives no reading."
  QUESTIONS
    Question40 : "Yes"
    Question41 : "Minimum"  (SCORING : -)
  ACTIONS
    Action33
END CASE

BEGIN CASE Case40
  TITLE "Fuel gauge defective"

DESCRIPTION
"Fuel gauge inoperative, gives no reading."

QUESTIONS
Question40 : "Yes"
Question41 : "Maximum" (SCORING : -)

ACTIONS
Action34

END CASE

BEGIN CASE Case41
TITLE
"Wiper motor defective"

DESCRIPTION
"Windscreen wipers inoperative"

QUESTIONS
Question39 : "No"
Question40 : "Yes"

ACTIONS
Action35

END CASE

BEGIN CASE Case42
TITLE
"Windscreen washer electric pump defective"

DESCRIPTION
"Windscreen washer defective"

QUESTIONS
Question42 : "No" (SCORING : -)
Question40 : "Yes"

ACTIONS
Action36

END CASE

BEGIN CASE Case43
TITLE
"Inlet manifold air leak"

DESCRIPTION
"Engine idles erratically and/or stalls."

QUESTIONS
Question46 : "Yes" (SCORING : -)
Question45 : "Yes"

ACTIONS
Action40

END CASE

BEGIN CASE Case44
TITLE
"Loose ventilation hoses"

DESCRIPTION
"Engine idles erratically"

QUESTIONS
Question46 : "Yes"  (SCORING : -)
Question47 : "Yes"

ACTIONS
Action41

END CASE

BEGIN CASE Case45

TITLE
"Uneven cylinder compression."

DESCRIPTION
"Engine idles erratically, engine misfires"

QUESTIONS
Question48 : "Yes"  (SCORING : -)
Question49 : "Yes"

ACTIONS
Action42

END CASE

BEGIN CASE Case46

TITLE
"Oil consumption"

DESCRIPTION
"Excessive oil consumption"

QUESTIONS
Question50 : "Yes"
Question51 : "No"  (SCORING : -)
Question52 : "Yes"

ACTIONS
Action43

END CASE

BEGIN CASE Case47

TITLE
"Broken piston ring."

DESCRIPTION
"Tapping, rattling or tickling noise"

QUESTIONS
Question53 : "Ticking noise"
Question54 : "Yes"

ACTIONS
Action44

END CASE

BEGIN CASE Case48

TITLE
"Worn valve gear."

DESCRIPTION
"Tapping, rattling noise."

QUESTIONS
Question55 : "Tapping noise"
Question54 : "No"

ACTIONS
Action45

END CASE

BEGIN CASE Case49
TITLE
"Piston slap."
DESCRIPTION
"Knocking or thumping noise"

QUESTIONS
Question56 : "Yes"
Question57 : "Yes"

ACTIONS
Action46

END CASE

BEGIN CASE Case50
TITLE
"Moisture in HT circuit."
DESCRIPTION
"Automobile won't start"

QUESTIONS
Question2 : "No" (SCORING : -)
Question58 : "No" (SCORING : -)

ACTIONS
Action47

END CASE

BEGIN CASE Case51
TITLE
"Spark plug gaps faulty"
DESCRIPTION
"Automobile won't start"

QUESTIONS
Question43 : "Yes" (SCORING : -)
Question59 : "Yes" (SCORING : -)

ACTIONS
Action48

END CASE

BEGIN CASE Case52
TITLE
"Distributor cap cracked."
DESCRIPTION
"Automobile won't start"
QUESTIONS
Question43 : "Yes" (SCORING : -)
Question59 : "No" (SCORING : -)
Question60 : "Yes" (SCORING : -)

ACTIONS
Action49
Action50
Action51

END CASE

BEGIN CASE Case53
TITLE
"Loose coil connections."
DESCRIPTION
"Automobile won't start"
QUESTIONS
Question2 : "No" (SCORING : -)
Question43 : "Yes" (SCORING : -)
Question59 : "No" (SCORING : -)
Question60 : "No" (SCORING : -)
Question62 : "Yes" (SCORING : +)

ACTIONS
Action52

END CASE

BEGIN CASE Case54
TITLE
"Points faulty"
DESCRIPTION
"Automobile won't start"
QUESTIONS
Question43 : "Yes" (SCORING : -)
Question59 : "No" (SCORING : -)
Question60 : "No" (SCORING : -)
Question62 : "No" (SCORING : -)
Question63 : "Yes" (SCORING : +)

ACTIONS
Action53

END CASE

BEGIN CASE Case55
TITLE
"Points faulty adjusted."
DESCRIPTION
"Automobile won't start"
QUESTIONS
Question43 : "Yes" (SCORING : -)
Question59 : "No" (SCORING : -)
Question60 : "No" (SCORING : -)
BEGIN CASE Case56
TITLE  "Open circuit before coil."
DESCRIPTION  "Automobile won't start"
QUESTIONS
  Question2 : "No"  (SCORING : -)
  Question43 : "Yes"  (SCORING : -)
  Question59 : "No"  (SCORING : -)
  Question60 : "No"  (SCORING : -)
  Question62 : "No"  (SCORING : -)
  Question61 : "No"  (SCORING : +)
END CASE

BEGIN CASE Case57
TITLE  "Condenser defective."
DESCRIPTION  "Automobile won't start"
QUESTIONS
  Question43 : "Yes"  (SCORING : -)
  Question60 : "No"  (SCORING : -)
  Question62 : "No"  (SCORING : -)
  Question61 : "Yes"  (SCORING : -)
  Question65 : "Yes"  (SCORING : +)
END CASE

BEGIN CASE Case58
TITLE  "Open circuit between coil and distributor."
DESCRIPTION  "Automobile won't start"
QUESTIONS
  Question43 : "Yes"  (SCORING : -)
  Question60 : "No"  (SCORING : -)
  Question62 : "No"  (SCORING : -)
  Question61 : "Yes"  (SCORING : -)
  Question65 : "No"  (SCORING : -)
END CASE
Question66 : "Yes"

ACTIONS
  Action57

END CASE

BEGIN CASE Case59
  TITLE
    "Defective coil."
  DESCRIPTION
    "Automobile won't start"
  QUESTIONS
    Question43 : "Yes" (SCORING : -)
    Question60 : "No" (SCORING : -)
    Question62 : "No" (SCORING : -)
    Question61 : "Yes" (SCORING : -)
    Question65 : "No" (SCORING : -)
    Question66 : "No"

ACTIONS
  Action58

END CASE

BEGIN CASE Case60
  TITLE
    "Ignition lead worn."
  DESCRIPTION
    "Engine misfires"
  QUESTIONS
    Question1 : "Yes" (SCORING : -)
    Question18 : "One weak spark" (SCORING : -)
    Question62 : "No" (SCORING : -)
    Question67 : "No" (SCORING : -)

ACTIONS
  Action59

END CASE

BEGIN CASE Case61
  TITLE
    "Tracking on distributor cap."
  DESCRIPTION
    "Engine misfires"
  QUESTIONS
    Question1 : "Yes" (SCORING : -)
    Question18 : "One weak spark" (SCORING : -)
    Question62 : "No" (SCORING : -)
    Question67 : "Yes" (SCORING : +)

ACTIONS
  Action60

END CASE
BEGIN CASE Case62
  TITLE
  "Ignition timing incorrect."
  DESCRIPTION
  "Engine misfires"
  QUESTIONS
  Question1 : "Yes"
  Question59 : "Yes"
  Question68 : "Grey-brown..."  (SCORING : -)
  (FULL : "Grey-brown deposits")
  ACTIONS
  Action61
END CASE

BEGIN CASE Case63
  TITLE
  "Wheel out of balance."
  DESCRIPTION
  "Vibration."
  QUESTIONS
  Question69 : "Yes"  (SCORING : -)
  Question70 : "Yes"  (SCORING : +)
  ACTIONS
  Action62
END CASE

BEGIN CASE Case64
  TITLE
  "Driveshaft faulty."
  DESCRIPTION
  "Vibration"
  QUESTIONS
  Question69 : "Yes"  (SCORING : -)
  Question71 : "Yes"  (SCORING : +)
  ACTIONS
  Action63
END CASE

BEGIN CASE Case65
  TITLE
  "Worn rear wheel bearings."
  DESCRIPTION
  "Vibration, noise"
  QUESTIONS
  Question69 : "Yes"
  Question73 : "No"  (SCORING : -)
  Question72 : "Yes"  (SCORING : +-)
  ACTIONS
  Action64
END CASE

BEGIN CASE Case66
    TITLE
        "Worn constant velocity joints."
    DESCRIPTION
        "Vibration, noise"
    QUESTIONS
        Question74 : "Yes"
        Question75 : "Yes" (SCORING : -)
        Question76 : "No" (SCORING : -)
        Question77 : "No" (SCORING : -)
        Question78 : "No" (SCORING : -)
    ACTIONS
        Action65
END CASE

BEGIN CASE Case67
    TITLE
        "Constant velocity retaining bolts loose"
    DESCRIPTION
        "Knock or clunk noise"
    QUESTIONS
        Question75 : "Yes"
        Question76 : "Yes" (SCORING : +)
    ACTIONS
        Action66
END CASE

BEGIN CASE Case68
    TITLE
        "Hub retaining bolt loose."
    DESCRIPTION
        "Knock or clunk noise"
    QUESTIONS
        Question75 : "Yes"
        Question76 : "Yes" (SCORING : +)
    ACTIONS
        Action67
END CASE

BEGIN CASE Case69
    TITLE
        "Loose wheel nuts."
    DESCRIPTION
        "Knock or clunk noise"
    QUESTIONS
        Question75 : "Yes"
        Question77 : "Yes" (SCORING : +)
BEGIN CASE Case70
TITLE
"Shock absorbers worn"
DESCRIPTION
"Excessive bouncing and pitching"
QUESTIONS
Question79 : "Yes" (SCORING : -)
Question80 : "Yes"
END CASE

BEGIN CASE Case71
TITLE
"Shock absorber mounting bushes worn."
DESCRIPTION
"Click cluck noise"
QUESTIONS
Question81 : "Yes"
Question82 : "Yes" (SCORING : +)
END CASE

BEGIN CASE Case72
TITLE
"Springs weak."
DESCRIPTION
"Excessive bouncing or pitching"
QUESTIONS
Question79 : "Yes" (SCORING : -)
Question80 : "No" (SCORING : -)
END CASE

BEGIN CASE Case73
TITLE
"Worn steering flexible couplings ?"
DESCRIPTION
"Free play in steering wheel"
QUESTIONS
Question83 : "Yes" (SCORING : -)
Question84 : "Free play in the..." (SCORING : +)
(FULL : "Free play in the flexible couplings")
ACTIONS
    Action72
END CASE

BEGIN CASE Case74
    TITLE
        "Worn relay gear."
    DESCRIPTION
        "Free play in steering wheel"
    QUESTIONS
        Question83 : "Yes"   (SCORING : -)
        Question84 : "Free play in the..."   (SCORING : +)
                   (FULL : "Free play in the relay gear")
    ACTIONS
        Action73
END CASE

BEGIN CASE Case75
    TITLE
        "Connecting shaft loose."
    DESCRIPTION
        "Free play in steering wheel"
    QUESTIONS
        Question83 : "Yes"   (SCORING : -)
        Question84 : "Free play in the..."   (SCORING : +)
                   (FULL : "Free play in the connecting shafts")
    ACTIONS
        Action74
END CASE

BEGIN CASE Case76
    TITLE
        "Steering box faulty."
    DESCRIPTION
        "Free play in steering wheel"
    QUESTIONS
        Question83 : "Yes"   (SCORING : -)
        Question84 : "Free play in the..."   (SCORING : +)
                   (FULL : "Free play in the steering box")
    ACTIONS
        Action75
END CASE

BEGIN CASE Case77
    TITLE
        "Wheel alignment faulty."
    DESCRIPTION
        "Vehicle wandering, excessive tyre wear, steering stiff and heavy"
    QUESTIONS
Question87 : "Yes"  
Question88 : "No"  
(SCORING : +)

END CASE

BEGIN CASE Case78
  TITLE
  "Bent steering column."
  DESCRIPTION
  "Steering stiff and heavy."
  QUESTIONS
  Question89 : "Yes"  
  Question90 : "Yes"  
  (SCORING : +)
  ACTIONS
  Action77
END CASE

BEGIN CASE Case79
  TITLE
  "Front hub bearings worn."
  DESCRIPTION
  "Vehicle difficult to steer in straight line, wandering."
  QUESTIONS
  Question87 : "Yes"  
  Question91 : "Worn front hub..."  
  (FULL : "Worn front hub bearings")
  ACTIONS
  Action78
END CASE

BEGIN CASE Case80
  TITLE
  "Ball joints worn."
  DESCRIPTION
  "Vehicle difficult to steer in straight line, wandering."
  QUESTIONS
  Question87 : "Yes"  
  Question91 : "Worn balljoints"
  ACTIONS
  Action79
END CASE

BEGIN CASE Case81
  TITLE
  "Wishbone mounting bushes worn."
  DESCRIPTION
  "Vehicle difficult to steer in strait line, wandering."
  QUESTIONS
BEGIN CASE Case82
TITLE
"Worn anti-roll bar mountings."
DESCRIPTION
"Excessive pitching and rolling."
QUESTIONS
Question79 : "Yes" (SCORING : +)
Question92 : "Worn anti-roll bar..." (FULL : "Worn anti-roll bar mountings")
ACTION
Action81
END CASE

BEGIN CASE Case83
TITLE
"Worn radius rod mountings."
DESCRIPTION
"Excessive pitching and rolling."
QUESTIONS
Question79 : "Yes"
Question92 : "Worn radius rod..." (SCORING : +)
(FULL : "Worn radius rod mountings")
ACTION
Action82
END CASE

BEGIN CASE Case84
TITLE
"Brake fluid leak."
DESCRIPTION
"Excessive brake pedal travel, spongy."
QUESTIONS
Question93 : "Yes" (SCORING : -)
Question94 : "Yes" (SCORING : +)
ACTION
Action83
END CASE

BEGIN CASE Case85
TITLE
"Empty brake fluid reservoir (H1)."
DESCRIPTION

"Excessive brake pedal travel, spongy."

QUESTIONS
Question93 : "Yes" (SCORING : -)
Question95 : "Yes"

ACTIONS
Action84

END CASE

BEGIN CASE Case86

TITLE
"Air in brake system."

DESCRIPTION
"Excessive brake travel, spongy."

QUESTIONS
Question93 : "Yes" (SCORING : -)
Question95 : "No" (SCORING : -)
Question94 : "No" (SCORING : -)
Question96 : "Yes" (SCORING : +)

ACTIONS
Action85

END CASE

BEGIN CASE Case87

TITLE
"Faulty adjusted master cylinder."

DESCRIPTION
"Excessive brake pedal travel, spongy."

QUESTIONS
Question93 : "Yes" (SCORING : -)
Question97 : "No" (SCORING : +)

ACTIONS
Action86

END CASE

BEGIN CASE Case88

TITLE
"Faulty master cylinder."

DESCRIPTION
"Excessive brake pedal travel, brakes spongy, brakes binding."

QUESTIONS
Question93 : "Yes" (SCORING : -)
Question97 : "Yes" (SCORING : -)
Question96 : "No" (SCORING : -)
Question95 : "No" (SCORING : -)
Question94 : "No" (SCORING : -)

ACTIONS
Action87

END CASE
BEGIN CASE Case89
   TITLE
       "Loose brake caliper retaining bolts."
   DESCRIPTION
       "Judder felt through brake pedal."
   QUESTIONS
       Question98 : "Yes" (SCORING : -)
       Question99 : "Yes" (SCORING : +)
   ACTIONS
       Action88
END CASE

BEGIN CASE Case90
   TITLE
       "Brake pads worn."
   DESCRIPTION
       "Judder felt through brake pedal, excessive pressure required to stop, brakes pull to one side."
   QUESTIONS
       Question100 : "Worn brake pads" (SCORING : -)
   ACTIONS
       Action89
END CASE

BEGIN CASE Case91
   TITLE
       "Brake disc worn."
   DESCRIPTION
       "Judder felt through brake pedal."
   QUESTIONS
       Question98 : "Yes" (SCORING : -)
       Question100 : "Worn brake pads..." (SCORING : +)
       (FULL : "Worn brake pads and brake disc.")
   ACTIONS
       Action90
END CASE

BEGIN CASE Case92
   TITLE
       "Brake linings worn."
   DESCRIPTION
       "Judder felt through brake pedal, excessive pressure required to stop, brakes pull to one side."
   QUESTIONS
       Question101 : "Worn brake shoe..." (SCORING : -)
       (FULL : "Worn brake shoe linings.")
   ACTIONS
       Action91
END CASE
BEGIN CASE Case93
  TITLE
  "Brake drum worn."
  DESCRIPTION
  "Judder felt through brake pedal."
  QUESTIONS
  Question98 : "Yes" (SCORING : -)
  Question101 : "Worn brake drum." (SCORING : -)
  ACTIONS
  Action92
END CASE

BEGIN CASE Case94
  TITLE
  "Faulty brake pressure regulator."
  DESCRIPTION
  "Rear wheels lock when braking."
  QUESTIONS
  Question102 : "Yes" (SCORING : -)
  ACTIONS
  Action93
END CASE

BEGIN CASE Case95
  TITLE
  "Handbrake incorrectly adjusted."
  DESCRIPTION
  "Handbrake does not brake."
  QUESTIONS
  Question103 : "No" (SCORING : -)
  Question104 : "No" (SCORING : -)
  Question105 : "No" (SCORING : +)
  ACTIONS
  Action94
END CASE

BEGIN CASE Case96
  TITLE
  "Handbrake cables broken."
  DESCRIPTION
  "Handbrake inoperative."
  QUESTIONS
  Question103 : "No" (SCORING : -)
  Question104 : "Yes" (SCORING : +)
  ACTIONS
  Action95
END CASE
BEGIN CASE Case97
    TITLE
        "Vacuum hose leak."
    DESCRIPTION
        "Excessive brake pedal pressure required to stop."
    QUESTIONS
        Question106 : "Yes"  (SCORING : -)
        Question107 : "Vacuum hose leak."  (SCORING : +)
    ACTIONS
        Action96
END CASE

BEGIN CASE Case98
    TITLE
        "Servo non-return valve faulty."
    DESCRIPTION
        "Excessive brake pedal pressure required to stop."
    QUESTIONS
        Question106 : "Yes"  (SCORING : -)
        Question107 : "Servo unit non..."  (SCORING : +)
            (FULL : "Servo unit non-return valve faulty.")
    ACTIONS
        Action97
END CASE

BEGIN CASE Case99
    TITLE
        "Servo air filter faulty."
    DESCRIPTION
        "Excessive brake pedal pressure required to stop."
    QUESTIONS
        Question106 : "Yes"  (SCORING : -)
        Question107 : "Servo air filter..."  (SCORING : +)
            (FULL : "Servo air filter faulty.")
    ACTIONS
        Action98
END CASE

BEGIN CASE Case100
    TITLE
        "Servo unit faulty."
    DESCRIPTION
        "Excessive brake pedal pressure required to stop."
    QUESTIONS
        Question106 : "Yes"  (SCORING : -)
        Question107 : "Servo unit faulty."  (SCORING : +)
    ACTIONS
        Action99
END CASE
BEGIN CASE Case101
  TITLE  "Empty brake fluid reservoir (H2)."
  DESCRIPTION "Clutch drag, gears don't engage properly."
  QUESTIONS
    Question108 : "Clutch drag."  (SCORING : -)
    Question95 : "Yes"  (SCORING : +)
  ACTIONS
    Action84
END CASE

BEGIN CASE Case102
  TITLE  "Clutch hydraulic leak."
  DESCRIPTION "Clutch drag, difficulty in engaging gears."
  QUESTIONS
    Question108 : "Clutch drag."  (SCORING : -)
    Question110 : "Yes"  (SCORING : +)
  ACTIONS
    Action100
END CASE

BEGIN CASE Case103
  TITLE  "Clutch master cylinder adjustment incorrect (H1)."
  DESCRIPTION "Clutch drag, difficulty in engaging gears."
  QUESTIONS
    Question108 : "Clutch drag."  (SCORING : -)
    Question111 : "No"  (SCORING : +)
  ACTIONS
    Action101
END CASE

BEGIN CASE Case104
  TITLE  "Air in clutch hydraulic system."
  DESCRIPTION "Clutch drag, difficulty in engaging gears."
  QUESTIONS
    Question108 : "Clutch drag."  (SCORING : -)
    Question111 : "Yes"  (SCORING : -)
    Question110 : "No"  (SCORING : -)
    Question95 : "No"  (SCORING : -)
    Question109 : "Yes"  (SCORING : +)
  ACTIONS
END CASE
END CASE

BEGIN CASE Case105
  TITLE
  "Clutch faulty (H1)"
  DESCRIPTION
  "Clutch drag, difficulty in engaging gears."
  QUESTIONS
  Question108 : "Clutch drag." (SCORING : -)
  Question111 : "Yes" (SCORING : -)
  Question110 : "No" (SCORING : -)
  Question95 : "No" (SCORING : -)
  Question109 : "No" (SCORING : -)
  ACTIONS
  Action103
END CASE

BEGIN CASE Case106
  TITLE
  "Engine/gearbox mountings worn."
  DESCRIPTION
  "Clutch judder, shudders when clutch released, clutch not smoothly taking up the drive."
  QUESTIONS
  Question108 : "Clutch judder." (SCORING : -)
  Question112 : "Yes" (SCORING : +)
  ACTIONS
  Action104
END CASE

BEGIN CASE Case107
  TITLE
  "Clutch faulty (H2)."
  DESCRIPTION
  "Clutch judder, shudders when clutch released, clutch not smoothly taking up the drive."
  QUESTIONS
  Question108 : "Clutch judder." (SCORING : -)
  Question112 : "No" (SCORING : +)
  ACTIONS
  Action103
END CASE

BEGIN CASE Case108
  TITLE
  "Clutch master cylinder adjustment incorrect (H2)."
  DESCRIPTION
  "Clutch slip."
QUESTIONS
Question108 : "Clutch slip." (SCORING : -)  
Question111 : "No" (SCORING : +)

ACTIONS
Action101

END CASE

BEGIN CASE Case109

TITLE
"Clutch faulty (H3)."

DESCRIPTION
"Clutch slip."

QUESTIONS
Question108 : "Clutch slip." (SCORING : -)  
Question111 : "Yes" (SCORING : -)

ACTIONS
Action103

END CASE

BEGIN CASE Case110

TITLE
"Worn clutch release bearing."

DESCRIPTION
"Clutch squeal, rumble noise."

QUESTIONS
Question108 : "Clutch squeal." (SCORING : -)

ACTIONS
Action105

END CASE

BEGIN CASE Case111

TITLE
"Faulty fuel pump."

DESCRIPTION
"Automobile difficult to start."

QUESTIONS
Question43 : "Yes" (SCORING : -)  
Question114 : "Yes" (SCORING : -)  
Question113 : "Yes" (SCORING : +)

ACTIONS
Action106

END CASE

BEGIN CASE Case112

TITLE
"Idle stabilizing unit faulty."

DESCRIPTION
"Poor performance, hesitation or erratic running."

QUESTIONS

Question46: "Yes" (SCORING: -)
Question115: "Idle stabilizer unit..." (SCORING: +)
(FULL: "Idle stabilizer unit faulty.")

ACTIONS
Action107

END CASE

BEGIN CASE Case113
TITLE
"Carburetor idle setting incorrect."
DESCRIPTION
"Poor performance, hesitation or erratic running."
QUESTIONS
Question46: "Yes" (SCORING: -)
Question115: "Carburetor idle..." (SCORING: +)
(FULL: "Carburetor idle speed incorrect.")

ACTIONS
Action108

END CASE

BEGIN CASE Case114
TITLE
"Fuel filter restricted"
DESCRIPTION
"Fuel starvation, stalls."
QUESTIONS
Question116: "Yes" (SCORING: -)
Question117: "Yes" (SCORING: +)

ACTIONS
Action109

END CASE

BEGIN CASE Case115
TITLE
"Carburetor worn."
DESCRIPTION
"Excessive fuel consumption."
QUESTIONS
Question118: "Yes" (SCORING: -)
Question119: "Yes" (SCORING: +)

ACTIONS
Action110

END CASE

BEGIN CASE Case116
TITLE
"Choked air cleaners."
DESCRIPTION
"Excessive fuel consumption."
BEGIN CASE Case117
TITLE "Carburetor component settings incorrect."
DESCRIPTION "Difficult to start, erratic running."
QUESTIONS
  Question121 : "Yes" (SCORING : -)
  Question115 : "No fault." (SCORING : -)
ACTIONS
  Action112
END CASE

BEGIN CASE Case118
TITLE "Loose spark plug."
DESCRIPTION "Noise in engine."
QUESTIONS
  Question122 : "Yes" (SCORING : -)
  Question123 : "Yes" (SCORING : +)
ACTIONS
  Action113
END CASE

BEGIN CASE Case119
TITLE "Carburetor retracting spring worn."
DESCRIPTION "Gas pedal won't return all the way."
QUESTIONS
  Question124 : "No" (SCORING : -)
  Question125 : "Yes" (SCORING : +)
ACTIONS
  Action114
END CASE

BEGIN CASE Case120
TITLE "Empty fuel tank."
DESCRIPTION "Automobile won't start."
QUESTIONS
Question2 : "No" (SCORING : -)
Question43 : "Yes" (SCORING : -)
Question126 : "Yes" (SCORING : +)

ACTIONS
Action115

END CASE
Questions Printout

BEGIN QUESTION Question1
TITLE
"Does the engine misfire ?"
WEIGHT
MATCH : 10
MISMATCH : 5
ANSWERS
TYPE : YES_OR_NO
END QUESTION

BEGIN QUESTION Question2
TITLE
"Does the automobile start ?"
WEIGHT
MATCH : 10
MISMATCH : 5
ANSWERS
TYPE : YES_OR_NO
END QUESTION

BEGIN QUESTION Question3
TITLE
"Do the headlights dim after a few seconds when switched on ?"
TEXT
"Switch on the headlights and watch if they dim in a few seconds. This is to determine
if the battery is discharged. The headlights will shine brighter immediately after switched on than after
a few seconds, if the battery is in a discharged state."
WEIGHT
MATCH : 10
MISMATCH : 5
ANSWERS
TYPE : YES_OR_NO
END QUESTION

BEGIN QUESTION Question4
TITLE
"Do the headlights dim when the starter switch is operated ?"
TEXT
"Switch the headlights on. While the headlights are switched on, operate the starter
switch. If the lights dim it confirms that power is reaching the starter motor."
WEIGHT
MATCH : 10
MISMATCH : 50
BEGIN QUESTION Question5
TITLE
"Do you hear a clicking noise when the starter switch is operated?"
TEXT
"A clicking noise confirms that the solenoid is operating."
WEIGHT
MATCH : 10
MISMATCH : 5
ANSWERS
TYPE : YES_OR_NO
END QUESTION

BEGIN QUESTION Question6
TITLE
"Are the battery terminals loose or corroded?"
TEXT
"The battery is located beneath the passenger seat. To gain access to the battery, move the seat fully forward, lift up the battery box lid and check if the battery terminals are loose or corroded. Corroded or loose connections can prevent sufficient current to be passed."
WEIGHT
MATCH : 10
MISMATCH : 5
ANSWERS
TYPE : YES_OR_NO
END QUESTION

BEGIN QUESTION Question7
TITLE
"Is the battery earth cable loose?"
TEXT
"The battery is located beneath the passenger seat. To gain access to the battery, move the seat fully forward and lift up the battery box lid. Check if the battery earth cable is loose. The loose earth cable can cause an open circuit."
WEIGHT
MATCH : 10
MISMATCH : 5
ANSWERS
TYPE : YES_OR_NO
END QUESTION

BEGIN QUESTION Question8
TITLE
"Is the transmission noisy only in neutral?"
WEIGHT
MATCH : 10
MISMATCH : 5
ANSWERS
TYPE : YES_OR_NO
END QUESTION

BEGIN QUESTION Question9
TITLE
"Is the transmission noisy only when moving, in all gears ?"
WEIGHT
MATCH : 10
MISMATCH : 5
ANSWERS
TYPE : YES_OR_NO
END QUESTION

BEGIN QUESTION Question10
TITLE
"Is the transmission noisy in only one gear ?"
WEIGHT
MATCH : 10
MISMATCH : 5
ANSWERS
TYPE : YES_OR_NO
END QUESTION

BEGIN QUESTION Question11
TITLE
"Does the transmission jump out of gear ?"
WEIGHT
MATCH : 10
MISMATCH : 5
ANSWERS
TYPE : YES_OR_NO
END QUESTION

BEGIN QUESTION Question12
TITLE
"Is the synchromesh ineffective ?"
WEIGHT
MATCH : 10
MISMATCH : 5
ANSWERS
TYPE : YES_OR_NO
END QUESTION

BEGIN QUESTION Question13
TITLE
"Is the gear lever alignment plate correctly adjusted ?"
TEXT
"Slide up the rubber boot around the gear lever. Check that the two holes in the gear lever plate are aligned with the two holes directly below in the mounting plate."

WEIGHT
MATCH : 10
MISMATCH : 5
ANSWERS
TYPE : YES_OR_NO
END QUESTION

BEGIN QUESTION Question14
TITLE
"What is the voltage measure of the battery?"

TEXT
"Take the voltage measure of the battery in order to determine the charged state of the battery. The battery is located beneath the passenger seat. To gain access to the battery, move the seat fully forward, lift up the battery box lid."

WEIGHT
MATCH : 10
MISMATCH : 5
ANSWERS
TYPE : LIST
LIST : "<9-volt" "> = 9-volt"
END QUESTION

BEGIN QUESTION Question15
TITLE
"Are there any corroded or loose starter motor connections?"

TEXT
"The starter motor is located at the rear right-hand side of the vehicle. The starter motor is secured to the clutch housing from the front of the vehicle. Corroded or loose starter motor connections can cause insufficient power to reach the starter motor."

WEIGHT
MATCH : 10
MISMATCH : 5
ANSWERS
TYPE : YES_OR_NO
END QUESTION

BEGIN QUESTION Question16
TITLE
"Is there a voltage reading across the solenoid?"

TEXT
"The solenoid contact can be checked by putting a voltmeter or bulb across the main cable connection on the starter side of the solenoid and earth. When the starter switch is operated, there should be no reading or lightened bulb to prove that the solenoid is defective. The solenoid is attached to the starter motor which is located at the rear right-hand side of the vehicle. The starter motor is secured to the clutch housing from the front of the vehicle."

WEIGHT
MATCH : 100
BEGIN QUESTION Question17
TITLE
"Are the starter motor mounting bolts loose?"
TEXT
"The starter motor is located at the rear right-hand side of the vehicle and secured to the clutch housing from the front of the vehicle. The loose bolts can cause the starter motor pinion ring gear teeth and the flywheel ring gear teeth to intersect at a wrong angle which causes wear."
WEIGHT
MATCH : 20
MISMATCH : 0
ANSWERS
TYPE : YES_OR_NO
END QUESTION

BEGIN QUESTION Question18
TITLE
"Is there a weak spark only at one or all spark plugs?"
TEXT
"Disconnect each plug lead in turn at the spark plug end, and hold the end of the cable with rubber or an insulated tool about 6 mm away from the cylinder block. Spin the engine on the starter motor. Sparking between the end of the cable and the block should be fairly strong with a regular blue spark to prove that voltage is present."
WEIGHT
MATCH : 10
MISMATCH : 5
ANSWERS
TYPE : LIST
LIST : "One weak spark" "Four weak sparks"
END QUESTION

BEGIN QUESTION Question19
TITLE
"Is there a regular heavy knocking noise present?"
WEIGHT
MATCH : 70
MISMATCH : 5
ANSWERS
TYPE : YES_OR_NO
END QUESTION

BEGIN QUESTION Question20
TITLE
"Is the noise less or worse under load (W10)?"
WEIGHT
MATCH : 10
MISMATCH : 0

ANSWERS
TYPE : LIST
LIST : "worse" "less"

END QUESTION

BEGIN QUESTION Question21
TITLE
"Is there a rumbling and knocking noise present?"

WEIGHT
MATCH : 70
MISMATCH : 5

ANSWERS
TYPE : YES_OR_NO

END QUESTION

BEGIN QUESTION Question22
TITLE
"How big is the drivebelt deflection?"

TEXT
"Measure the drivebelt deflection under moderate finger pressure midway between the pulleys."

WEIGHT
MATCH : 14
MISMATCH : 5

ANSWERS
TYPE : LIST
LIST : "> 15mm" "<= 15mm"

END QUESTION

BEGIN QUESTION Question23
TITLE
"Does the starter spin without turning the engine?"

TEXT
"If the starter motor turns the engine, the sound heard will be the same as when the engine turns before it starts under normal circumstances. If the starter spins without turning the engine, a high whining noise can be heard."

WEIGHT
MATCH : 14
MISMATCH : 5

ANSWERS
TYPE : YES_OR_NO

END QUESTION

BEGIN QUESTION Question24
TITLE
"What is the operating condition of the battery?"

WEIGHT
MATCH : 10
MISMATCH : 5
ANSWERS
TYPE : LIST
LIST : "good" "bad/unknown"
END QUESTION

BEGIN QUESTION Question25
TITLE
"Does the engine pre-ignite ?" 
WEIGHT
MATCH : 10
MISMATCH : 5
ANSWERS
TYPE : YES_OR_NO
END QUESTION

BEGIN QUESTION Question26
TITLE
"Is the ignition timing set correctly ?"
TEXT
"Start the engine, allow it to reach normal operating temperature and then switch off. Connect a stroboscopic timing light to the HT lead of No 1 cylinder (right-hand side of the engine nearest the flywheel) and make any other electrical connections according to timing light type by following the manufacturer's instructions. Connect a tachometer to the engine following the manufacturer's instructions for this instrument also. Disconnect the vacuum advance pipe from the distributor vacuum unit, start the engine again and allow it to idle. Check that the engine is idling at the specified speed for ignition timing in the owner's specifications."
WEIGHT
MATCH : 10
MISMATCH : 5
ANSWERS
TYPE : YES_OR_NO
END QUESTION

BEGIN QUESTION Question27
TITLE
"Is the noise less or worse under load ? (W20) "
WEIGHT
MATCH : 20
MISMATCH : 0
ANSWERS
TYPE : LIST
LIST : "less" "worse"
END QUESTION

BEGIN QUESTION Question28
TITLE
"Give a description of the spark plug head."
BEGIN QUESTION Question29
TITLE
"Are the steering column bolts loose?"
WEIGHT
MATCH : 10
MISMATCH : 5
ANSWERS
TYPE : YES_OR_NO
END QUESTION

BEGIN QUESTION Question30
TITLE
"Does the starter turn the engine slowly?"
WEIGHT
MATCH : 10
MISMATCH : 5
ANSWERS
TYPE : YES_OR_NO
END QUESTION

BEGIN QUESTION Question31
TITLE
"Does the ignition light stay on?"
TEXT
"When the ignition light stays on, the alternator drive belt is broken or the alternator is not charging the battery."
WEIGHT
MATCH : 10
MISMATCH : 5
ANSWERS
TYPE : YES_OR_NO
END QUESTION

BEGIN QUESTION Question32
TITLE
"Does the vibration increase or decrease under load?"
WEIGHT
MATCH : 10
MISMATCH : 0
ANSWERS
TYPE : LIST
LIST : "Increase" "decrease" "no noticeable change"
END QUESTION

BEGIN QUESTION Question33
  TITLE
    "Does the vibration increase proportional to speed?"
  WEIGHT
    MATCH : 60
    MIS MATCH : 5
  ANSWERS
    TYPE : YES_OR_NO
END QUESTION

BEGIN QUESTION Question34
  TITLE
    "Is the alternator drivebelt broken?"
  TEXT
    "The alternator drivebelt can be seen by opening the oil dipstick lid. The license
    number plate is secured to the lid."
  WEIGHT
    MATCH : 10
    MIS MATCH : 5
  ANSWERS
    TYPE : YES_OR_NO
END QUESTION

BEGIN QUESTION Question35
  TITLE
    "Do any instrument readings increase with engine speed?"
  TEXT
    "Any instrument reading increase with engine speed increase is caused by a faulty
    voltage stabilizer."
  WEIGHT
    MATCH : 10
    MIS MATCH : 5
  ANSWERS
    TYPE : YES_OR_NO
END QUESTION

BEGIN QUESTION Question36
  TITLE
    "Are any lights inoperative?"
  TEXT
    ""
  WEIGHT
    MATCH : 10
    MIS MATCH : 5
  ANSWERS
    TYPE : YES_OR_NO
END QUESTION
BEGIN QUESTION Question37
TITLE
"What is the potential at the horn terminals?"
TEXT
"The horn is located under the front of the vehicle to the right-hand side, bolted to
the frame. Check the potential at the horn terminals when the horn button is pushed. It should be
nearly 12 volts. This is done to determine if the horn gets power."
WEIGHT
MATCH : 10
MISMATCH : 5
ANSWERS
TYPE : LIST
LIST : "< 10 volt" "> 10 volt"
END QUESTION

BEGIN QUESTION Question38
TITLE
"Does the horn produce a noise when adjusting screw is turned?"
TEXT
"Chip the sealing compound which covers the adjusting screw on the back of the horn
away and adjust the screw clockwise 1/4 turn at a time. If this produces no noise the horn is defective."
WEIGHT
MATCH : 10
MISMATCH : 5
ANSWERS
TYPE : YES_OR_NO
END QUESTION

BEGIN QUESTION Question39
TITLE
"Is the fuse blown?"
TEXT
"The fusebox is situated below the facia on the left-hand side. To gain access to the
fuses simply lift off the transparent plastic cover. The fuse numbers are shown on the cover with
circuits they protect as follows:
1 - Left-hand tail light, parking light and side marker light.
2 - Right-hand tail light, parking light and side marker light, number plate lamps.
3 - Left-hand dipped beam.
4 - Right-hand dipped beam.
5 - Left-hand main beam, main beam warning lamp.
6 - Right-hand main beam.
7 - Not used (accessories).
8 - Interior lights, brake lights, cigarette lighter.
9 - Hazard flasher system.
10 - Windscreen wipers, windscreen washer pump, heated rear window.
11 - Direction indicators.
12 - Horn, reversing lights."
WEIGHT
BEGIN QUESTION Question40
  TITLE
  "Is there continuity in the wiring?"
  TEXT
  "Check the continuity by measuring the potential over the positive and negative wires closest to the faulty component. If it is a component that operates depending on a switch, make sure that the switch is in the operative position."
  WEIGHT
  MATCH : 4
  MISMATCH : 5
  ANSWERS
  TYPE : YES_OR_NO
END QUESTION

BEGIN QUESTION Question41
  TITLE
  "Does the fuel gauge give a maximum or minimum reading?"
  TEXT
  "The question distinguishes probable faults between the fuel gauge itself and the fuel sender unit."
  WEIGHT
  MATCH : 10
  MISMATCH : 5
  ANSWERS
  TYPE : LIST
  LIST : "Maximum" "Minimum"
END QUESTION

BEGIN QUESTION Question42
  TITLE
  "Can the electric water pump be heard when operated?"
  TEXT
  "The windshield washer reservoir and pump is located in the front left-hand side, inside the automobile. When operated the electric pump should be heard."
  WEIGHT
  MATCH : 10
  MISMATCH : 5
  ANSWERS
  TYPE : YES_OR_NO
END QUESTION

BEGIN QUESTION Question43
  TITLE
"Does the starter motor turn the engine normally?"

WEIGHT
MATCH : 10
MISMATCH : 5
ANSWERS
TYPE : YES_OR_NO
END QUESTION

BEGIN QUESTION Question44
TITLE
"Is the cylinder pressure low?"
TEXT
"The cylinder pressure can be measured by the spark plug pressure method. A device that has a pressure meter connected to a sensor replaces one spark plug at a time. By turning the ignition, the meter will register a pressure. The owner's specification provides pressure specifications."
WEIGHT
MATCH : 10
MISMATCH : 5
ANSWERS
TYPE : YES_OR_NO
END QUESTION

BEGIN QUESTION Question45
TITLE
"Does the inlet manifold have an air leak?"
TEXT
"While the engine is running, a whistling or wheezing noise should be heard close to the manifold."
WEIGHT
MATCH : 10
MISMATCH : 5
ANSWERS
TYPE : YES_OR_NO
END QUESTION

BEGIN QUESTION Question46
TITLE
"Does the engine idle erratically and/or stalls?"
WEIGHT
MATCH : 10
MISMATCH : 5
ANSWERS
TYPE : YES_OR_NO
END QUESTION

BEGIN QUESTION Question47
TITLE
"Are there any loose crankcase ventilation hoses?"
WEIGHT
BEGIN QUESTION Question48
TITLE
"Does the engine misfire and/or idle erratically?"
WEIGHT
MATCH : 10
MISMATCH : 5
ANSWERS
TYPE : YES_OR_NO
END QUESTION

BEGIN QUESTION Question49
TITLE
"Are the cylinder compression uneven?"
TEXT
"Test for uneven cylinder pressure. This can be done by the spark plug method. A device with a pressure meter connected to a sensor replaces one spark plug at a time. By turning the ignition, the meter will register a pressure reading."
WEIGHT
MATCH : 10
MISMATCH : 5
ANSWERS
TYPE : YES_OR_NO
END QUESTION

BEGIN QUESTION Question50
TITLE
"Is the oil consumption excessive?"
WEIGHT
MATCH : 10
MISMATCH : 5
ANSWERS
TYPE : YES_OR_NO
END QUESTION

BEGIN QUESTION Question51
TITLE
"Are there any evident oil leaks?"
TEXT
"The most common places for a oil leak are: rocker cover, pushrod tubes, and crankcase seals or oil seals."
WEIGHT
MATCH : 10
BEGIN QUESTION Question52
TITLE
"Does the exhaust fumes contain any trace of oil?"
WEIGHT
MATCH : 10
MISMATCH : 5
ANSWERS
TYPE : YES_OR_NO
END QUESTION

BEGIN QUESTION Question53
TITLE
"Do you hear a tickling noise in the engine?"
WEIGHT
MATCH : 10
MISMATCH : 5
ANSWERS
TYPE : YES_OR_NO
END QUESTION

BEGIN QUESTION Question54
TITLE
"Is one cylinder's compression evidently low?"
TEXT
"Test for one evidently low cylinder pressure. This can be done by the spark plug method. A device with a pressure meter connected to a sensor replaces one spark plug at a time. By turning the ignition, the meter will register a pressure reading."
WEIGHT
MATCH : 10
MISMATCH : 5
ANSWERS
TYPE : YES_OR_NO
END QUESTION

BEGIN QUESTION Question55
TITLE
"Do you hear a tapping or tickling noise in the engine?"
TEXT
"If it is a tapping noise it can be worn valve gear but if it is a tickling noise it can be a broken piston ring."
WEIGHT
MATCH : 10
MISMATCH : 5
ANSWERS
BEGIN QUESTION Question56
  TITLE
  "Do you hear a knocking and/or thumping noise in the engine?"
  WEIGHT
  MATCH : 10
  MISMATCH : 5
  ANSWERS
  TYPE : YES_OR_NO
END QUESTION

BEGIN QUESTION Question57
  TITLE
  "Is the noise more evident when the engine is cold?"
  WEIGHT
  MATCH : 10
  MISMATCH : 5
  ANSWERS
  TYPE : YES_OR_NO
END QUESTION

BEGIN QUESTION Question58
  TITLE
  "Is there moisture in the distributor cap?"
  TEXT
  "Remove the distributor cap and look for condensation in the distributor cap."
  WEIGHT
  MATCH : 10
  MISMATCH : 5
  ANSWERS
  TYPE : YES_OR_NO
END QUESTION

BEGIN QUESTION Question59
  TITLE
  "Is voltage reaching the plug?"
  TEXT
  "Disconnect each plug lead in turn at the spark plug end, and hold the end of the cable with rubber or an insulated tool about 6 mm away from the cylinder block. Spin the engine on the starter motor. Sparking between the end of the cable and the block should be fairly strong with a regular blue spark to prove that voltage is present."
  WEIGHT
  MATCH : 10
  MISMATCH : 5
  ANSWERS
  TYPE : YES_OR_NO
END QUESTION

BEGIN QUESTION Question60
    TITLE
        "Is voltage reaching the distributor?"
    TEXT
        "Take off the high tension lead from the center of the distributor cap and hold it with rubber or an insulated tool about 6 mm away from the cylinder block. Spin the engine on the starter motor. A rapid succession of blue sparks between the end of the lead and the block indicates that voltage is present."
    WEIGHT
        MATCH : 10
        MISMATCH : 5
    ANSWERS
        TYPE : YES_OR_NO
END QUESTION

BEGIN QUESTION Question61
    TITLE
        "Is voltage reaching the coil?"
    TEXT
        "Use a 12V voltmeter or a 12V bulb and two lengths of wire. With the ignition switched on and the points open, test between the low tension wire to the coil and earth."
    WEIGHT
        MATCH : 10
        MISMATCH : 5
    ANSWERS
        TYPE : YES_OR_NO
END QUESTION

BEGIN QUESTION Question62
    TITLE
        "Are there any loose connections on the coil?"
    WEIGHT
        MATCH : 10
        MISMATCH : 5
    ANSWERS
        TYPE : YES_OR_NO
END QUESTION

BEGIN QUESTION Question63
    TITLE
        "Are the contact breaker points rough, pitted or dirty?"
    TEXT
        "Remove the distributor cap. Lift off the rotor arm followed by the protective cover over the contact breaker assembly. Gently prise the contact breaker points open and examine the condition of their faces."
    WEIGHT
        MATCH : 10
BEGIN QUESTION Question64
  TITLE  
  "Are the contact breaker points gap adjusted correctly?"
  TEXT  
  "It is necessary to use a dwell meter. Remove the distributer cap, rotor arm and plastic cover from the distributer. Connect one lead of the dwell meter to the positive terminal on the ignition coil and the other lead to the negative terminal on the coil. Operate the starter switch and observe the reading on the dwell meter. The reading should be as stated in the owners specifications. If not, adjust the breaker assembly as necessary."
  WEIGHT
  MATCH : 10
  MISMATCH : 5
  ANSWERS
  TYPE : YES_OR_NO
END QUESTION

BEGIN QUESTION Question65
  TITLE  
  "Is there a voltage reading by bypassing the condenser?"
  TEXT  
  "Remove the distributer cap. Lift off the rotor arm followed by the protective cover over the contact breaker assembly. Take the condenser wire off the points assembly and with the points open test between the moving point and earth."
  WEIGHT
  MATCH : 10
  MISMATCH : 5
  ANSWERS
  TYPE : YES_OR_NO
END QUESTION

BEGIN QUESTION Question66
  TITLE  
  "Is there voltage between earth and distributer terminal of the coil?"
  TEXT  
  "With the ignition switched on, take a voltage reading between earth and the distributor terminal of the coil."
  WEIGHT
  MATCH : 10
  MISMATCH : 5
  ANSWERS
  TYPE : YES_OR_NO
END QUESTION

BEGIN QUESTION Question67
Is there any tracking on the distributor cap?

This can be recognized by a very thin black line running between two or more electrodes, or between an electrode and some other part of the distributor. These lines are paths which conduct electricity across the cap thus letting it run to earth.

What do the spark plugs look like?

A normal operating spark plug will have grey-brown deposits with a lightly coated core nose. Any one of the plugs with a different look should be mentioned.

Does the vehicle vibrate?

The wheels will have to be tested on a balance machine.

Are any of the wheels out of balance?
END QUESTION

BEGIN QUESTION Question71
TITLE
"Are the driveshafts bent or distorted?"
TEXT
"Jack up the rear of the car and support it on axle stands. A bent or distorted driveshaft can easily be detected by visual inspection while turning the wheels."

WEIGHT
MATCH : 10
MISMATCH : 5

ANSWERS
TYPE : YES_OR_NO
END QUESTION

BEGIN QUESTION Question72
TITLE
"Are any of the rear wheel bearings worn?"
TEXT
"Jack up the rear of the vehicle and securely support it on axle stands. Release the handbrake. Grasp the wheel at the 12 o'clock and 6 o'clock positions and try to rock it. Any excess movement here indicates wear in the rear wheel bearings or slackness in the wheel shaft retaining nut. Wear may also be accompanied by a rumbling sound or noticeable roughness when the wheel is turned."

WEIGHT
MATCH : 10
MISMATCH : 5

ANSWERS
TYPE : YES_OR_NO
END QUESTION

BEGIN QUESTION Question73
TITLE
"Is the wheel shaft retaining nut loose?"

WEIGHT
MATCH : 10
MISMATCH : 5

ANSWERS
TYPE : YES_OR_NO
END QUESTION

BEGIN QUESTION Question74
TITLE
"Does the vehicle vibrate from the back?"

WEIGHT
MATCH : 10
MISMATCH : 5

ANSWERS
TYPE : YES_OR_NO
END QUESTION

BEGIN QUESTION Question75
TITLE
"Do you hear a knock or clunk when accelerating or decelerating?"
WEIGHT
MATCH : 10
MISMATCH : 5
ANSWERS
TYPE : YES_OR_NO
END QUESTION

BEGIN QUESTION Question76
TITLE
"Are the velocity joint retaining bolts loose?"
WEIGHT
MATCH : 10
MISMATCH : 5
ANSWERS
TYPE : YES_OR_NO
END QUESTION

BEGIN QUESTION Question77
TITLE
"Are the wheel nuts loose?"
WEIGHT
MATCH : 10
MISMATCH : 5
ANSWERS
TYPE : YES_OR_NO
END QUESTION

BEGIN QUESTION Question78
TITLE
"Are the hub retaining nuts loose?"
WEIGHT
MATCH : 10
MISMATCH : 5
ANSWERS
TYPE : YES_OR_NO
END QUESTION

BEGIN QUESTION Question79
TITLE
"Is the vehicle bouncing and pitching excessively?"
WEIGHT
MATCH : 10
MISMATCH : 5
ANSWERS
TYPE : YES_OR_NO
END QUESTION

BEGIN QUESTION Question80
  TITLE
  "Are the shock absorbers worn ?"
  TEXT
  "Check for any sign of fluid leakage around the shock absorber body or for any
damage or deformation of the unit. The efficiency of the shock absorber may be checked by bouncing
the vehicle at each corner. Generally speaking the body will return to its normal position and stop after
being depressed. If it rises and returns on a rebound the shock absorber is probably worn."
  WEIGHT
  MATCH : 10
  MISMATCH : 5
  ANSWERS
  TYPE : YES_OR_NO
END QUESTION

BEGIN QUESTION Question81
  TITLE
  "Do you hear a click cluck noise from the suspension ?"
  WEIGHT
  MATCH : 10
  MISMATCH : 5
  ANSWERS
  TYPE : YES_OR_NO
END QUESTION

BEGIN QUESTION Question82
  TITLE
  "Are the shock absorber mounting bushes worn ?"
  TEXT
  "Examine the upper and lower shock absorber mountings for any sign of wear or
deterioration of the rubber bushes."
  WEIGHT
  MATCH : 10
  MISMATCH : 5
  ANSWERS
  TYPE : YES_OR_NO
END QUESTION

BEGIN QUESTION Question83
  TITLE
  "Is there excess free play felt in the steering wheel ?"
  WEIGHT
  MATCH : 10
  MISMATCH : 5
  ANSWERS
  TYPE : YES_OR_NO
END QUESTION

BEGIN QUESTION Question84
TITLE
"Inspect the steering components and report results."
TEXT
"With the vehicle standing on its wheels, have an assistant turn the steering wheel back and forth about one eighth of a turn each way while the steering gear components are viewed from below. There should be no lost movement between the steering wheel and the roadwheels. If this is not the case, closely observe the following items for free play: steering gear flexible couplings, relay gear, connecting shafts and connections, and steering box."
WEIGHT
MATCH : 10
MISMATCH : 5
ANSWERS
TYPE : LIST
LIST : "Free play in the flexible couplings" "Free play in the relay gear" "Free play in the connecting shafts" "Free play in the steering box"
END QUESTION

BEGIN QUESTION Question85
TITLE
"Has the oil usage increased since the noise started?"
WEIGHT
MATCH : 10
MISMATCH : 5
ANSWERS
TYPE : YES_OR_NO
END QUESTION

BEGIN QUESTION Question86
TITLE
"Is it difficult to start the vehicle only when it is cold?"
WEIGHT
MATCH : 10
MISMATCH : 5
ANSWERS
TYPE : YES_OR_NO
END QUESTION

BEGIN QUESTION Question87
TITLE
"Is it difficult to steer in a straight line - vehicle wandering?"
WEIGHT
MATCH : 10
MISMATCH : 5
ANSWERS
TYPE : YES_OR_NO
END QUESTION
BEGIN QUESTION Question88
   TITLE
   "Is the front wheel alignment correct?"
   TEXT
   "To check the alignment, a simple gauge can be made up from a length of tubing or bar and having a bolt and locknut at one end. Use the gauge to measure the distance between the two inner wheel rims at hub height and at the front of the wheels. Push the vehicle forward to rotate the wheels 180 degrees (half a turn) then measure the distance between the inner wheel rims at hub height, but this time at the rear of the wheels. The last measurement should be greater than the first by the amount stated in the owner specifications and represent the correct toe-in of the front wheels."
   WEIGHT
   MATCH : 10
   MISMATCH : 5
   ANSWERS
   TYPE : YES_OR_NO
END QUESTION

BEGIN QUESTION Question89
   TITLE
   "Is it stiff and heavy to steer?"
   WEIGHT
   MATCH : 10
   MISMATCH : 5
   ANSWERS
   TYPE : YES_OR_NO
END QUESTION

BEGIN QUESTION Question90
   TITLE
   "Is the steering column bent or distorted?"
   TEXT
   "Inspect the steering column closely. Any bent or distortion should be visually apparent."
   WEIGHT
   MATCH : 10
   MISMATCH : 5
   ANSWERS
   TYPE : YES_OR_NO
END QUESTION

BEGIN QUESTION Question91
   TITLE
   "Inspect front hub bearings and ball joints, then report results."
   TEXT
   "Jack up the front of the vehicle and securely support it on axle stands. Grasp the road wheel at the 12 o'clock and 6 o'clock positions and try to rock it. Very slight free play should be felt, but if the movement is appreciable it can be faulty ball joints or hub bearings. Continue rocking the wheel while an assistant depresses the footbrake. If the movement is eliminated or significantly reduced, it is
likely that the front hub bearings are worn. If the free play is still evident with the footbrake depressed, visually inspect the steering tie-rod balljoints and the steering knuckle ball joints. Visual movement will be obvious which will indicate worn balljoints. If the balljoints are not worn pay close attention to the upper wishbone mounting bushes, for they might be worn."

**WEIGHT**
MATCH : 10
MISMATCH : 5

**ANSWERS**
TYPE : LIST
LIST : "Worn front hub bearings" "Worn balljoints" "Upper wishbone mounting bushes"

**END QUESTION**

**BEGIN QUESTION Question92**

**TITLE**
"Check the anti-roll bar and radius rod mountings and report results."

**TEXT**
"Using a large screwdriver as a lever, check for wear in the anti-roll bar and radius rod mountings by levering against these components. Some movement is to be expected as the mountings are made of rubber, but excessive wear should be obvious."

**WEIGHT**
MATCH : 10
MISMATCH : 5

**ANSWERS**
TYPE : LIST
LIST : "Worn anti-roll bar mountings" "Worn radius rod mountings"

**END QUESTION**

**BEGIN QUESTION Question93**

**TITLE**
"Does the brake pedal feel spongy or travel excessively?"

**WEIGHT**
MATCH : 10
MISMATCH : 5

**ANSWERS**
TYPE : YES_OR_NO

**END QUESTION**

**BEGIN QUESTION Question94**

**TITLE**
"Are there any brake fluid leaks?"

**TEXT**
"The brake pipes must be examined carefully and methodically. They must be cleaned off and checked for evidence for new brake fluid after the brake pedal is depressed and released several times."

**WEIGHT**
MATCH : 10
MISMATCH : 5

**ANSWERS**
BEGIN QUESTION Question95
   TITLE
   "Is the brake fluid level under the minimum mark?"
   TEXT
   "Check the brake fluid level in the master cylinder reservoir located behind the
   instrument panel. To gain access, remove the instrument panel cover by lifting up at the two recesses in
   the rear of the cover. Disengage the cover at the front and lift off. Make sure that the level of fluid is
   between the MIN and MAX on the side of the reservoir."
   WEIGHT
   MATCH : 10
   MISMATCH : 5
   ANSWERS
   TYPE : YES_OR_NO
END QUESTION

BEGIN QUESTION Question96
   TITLE
   "Bleed the brake system. Is the problem corrected?"
   TEXT
   "The brake system should be bled in the following sequence: right-hand rear, left-
   hand rear, right-hand Freon, and last left-hand front. To bleed the system, first clean the area around
   the bleed screw on the brake caliper and fit a bleed tube. The front have two bleed screws on each
   brake caliper. The lower one is used for draining and the upper one is used for bleeding. Immerse the
   free end of the bleed tube in a jar and pour in sufficient brake fluid to keep the end of the tube
   submerged. Open the bleed screw half a turn and have your assistant depress the brake pedal to the
   floor and then slowly release it. Tighten the bleed screw at the end of each downstroke to prevent the
   expelled air and fluid from being drawn back into the system. Repeat the procedure, then top up the
   brake fluid level. Continue bleeding until clean brake fluid, free from bubbles, can be seen coming
   through the tube. Now tighten the bleed screw and remove the tube."
   WEIGHT
   MATCH : 10
   MISMATCH : 5
   ANSWERS
   TYPE : YES_OR_NO
END QUESTION

BEGIN QUESTION Question97
   TITLE
   "Is the master cylinder pushrod correctly adjusted?"
   TEXT
   "Measure the master cylinder pushrod length. The distance from the center of the
   clevis pin hole to the end of the pushrod should be equal to the dimension given in the owner
   specifications."
   WEIGHT
   MATCH : 10
   MISMATCH : 5
BEGIN QUESTION Question98
TITLE
"Does the brake pedal judder when braking?"
WEIGHT
MATCH : 10
MISMATCH : 5
END QUESTION

BEGIN QUESTION Question99
TITLE
"Are any of the brake calipers retaining bolts loose?"
WEIGHT
MATCH : 10
MISMATCH : 5
END QUESTION

BEGIN QUESTION Question100
TITLE
"Inspect the brake pads and brake disc and report results."
TEXT
"Jack up the front of the vehicle and support it on axle stands. Remove both front road wheels. Remove the brake pads retaining pins, lift off the spreader spring plate and then withdraw the brake pads one at a time from the caliper. Inspect the thickness of the brake pad friction material. If they are less than 2mm they must be renewed. With the pads removed, carefully inspect the surface of the brake disc. Concentric scores up to 0.4mm are acceptable."
WEIGHT
MATCH : 10
MISMATCH : 5
END QUESTION

BEGIN QUESTION Question101
TITLE
"Inspect the brake linings and brake drums and report results."
TEXT
"Two inspection holes are provided on each rear brake backplate and after removal of the plugs the lining thicknesses can be observed through the holes. To carry out a thorough inspection the brake drum must be removed. Jack up the rear of the vehicle and support it on axle stands. Remove both wheels and then release the handbrake. Undo the two small bolts securing the brake
drum to the rear wheel hub and withdraw the drum. Measure the brake shoe lining thickness. If the thickness of any of the linings are less than 2.5mm, all four shoes must be renewed. Examine the internal braking surface of the brake drum for scoring or cracks.

**WEIGHT**
MATCH : 10
MISMATCH : 5

**ANSWERS**
TYPE : LIST
LIST : "Worn brake shoe linings." "Worn brake drum."

END QUESTION

BEGIN QUESTION Question102
**TITLE**
"Do the rear wheels lock under normal breaking?"

**WEIGHT**
MATCH : 10
MISMATCH : 5

**ANSWERS**
TYPE : YES_OR_NO

END QUESTION

BEGIN QUESTION Question103
**TITLE**
"Does the handbrake function correctly?"

**WEIGHT**
MATCH : 10
MISMATCH : 5

**ANSWERS**
TYPE : YES_OR_NO

END QUESTION

BEGIN QUESTION Question104
**TITLE**
"Are any of the handbrake cables broken?"

**TEXT**
"The hand brake has one primary cable that stretches, underneath the vehicle, from the handbrake lever towards the back of the vehicle. The back end is attached to a equalizer from wear the two secondary cables are secured to the rear brakes."

**WEIGHT**
MATCH : 10
MISMATCH : 5

**ANSWERS**
TYPE : YES_OR_NO

END QUESTION

BEGIN QUESTION Question105
**TITLE**
"Is the handbrake adjusted correctly?"

**TEXT**
"Jack up the rear of the vehicle and support it on axle stands. Apply the handbrake to the second notch of the ratchet. From under the vehicle, turn the adjusting nut until the brake shoes are just dragging on the drums. The handbrake adjusting nut is on the back end of the primary handbrake cable secured to the equalizer."

WEIGHT
MATCH : 10
MISMATCH : 5

ANSWERS
TYPE : YES_OR_NO

END QUESTION

BEGIN QUESTION Question106
TITLE
"Is excessive brake pedal pressure required to stop vehicle?"

WEIGHT
MATCH : 10
MISMATCH : 5

ANSWERS
TYPE : YES_OR_NO

END QUESTION

BEGIN QUESTION Question107
TITLE
"Check the vacuum servo unit operation and report results."

TEXT
"With the engine switched off depress the footbrake several times and then hold it down. Start the engine and, as this is done, there should be a noticeable 'give' in the brake pedal. Allow the engine to run for at least two minutes and then switch it off. If the brake pedal is now depressed again, a slight hiss should be noticeable from the unit when the pedal is depressed. After about four or five applications no further hissing will be heard and the pedal will feel considerably firmer. If the servo does not function as describes, check the vacuum hose and all unions for leaks and check the operation of the no-return valve. To do this, disconnect the vacuum hose from the connector on the inlet manifold or air intake housing. Slacken the hose clamp and withdraw the non-return valve from the vacuum hose. Check that it is only possible to blow through the valve in the direction of the arrow stamped on the body. Check the servo air filters condition. If all these checks provide no fault, the servo unit is inoperative."

WEIGHT
MATCH : 10
MISMATCH : 5

ANSWERS
TYPE : LIST
LIST : "Servo unit faulty." "Servo unit non-return valve faulty." "Vacuum hose leak."

"Servo air filter faulty."

END QUESTION

BEGIN QUESTION Question108
TITLE
"In which way does the clutch malfunction?"

TEXT
"Clutch judder occurs when the clutch pedal released in first or reverse gears and the whole vehicle shudders as it moves backwards or forwards. Clutch drag can be confirmed by difficulty in engaging first or reverse gears from the rest, difficulty in changing gear and very sudden take up of clutch drive at the fully depressed end of the clutch pedal travel as the pedal is released. Clutch slip occurs when the engine speed increases on acceleration without a corresponding increase in road speed. A squealing or rumbling noise can clearly be heard when the clutch is depressed to confirm clutch squeal."

WEIGHT
MATCH : 10
MISMATCH : 5

ANSWERS
TYPE : LIST

END QUESTION

BEGIN QUESTION Question109
TITLE
"Bleed the clutch system - Is the malfunction corrected ?"

TEXT
"From under the rear of the vehicle wipe clean the area around the bleed screw on the slave cylinder and remove the rubber dust cover. Connect one end of a bleed tube to the bleed screw, and insert the other end of the tube in the jar containing sufficient clean hydraulic fluid to keep the end of the tube submerged. Open the bleed screw half a turn and have your assistant depress the clutch pedal and then slowly release it. Continue this procedure until clean hydraulic fluid, free from bubbles emerges from the tube. Tighten the bleed screw at the end of a downstroke."

WEIGHT
MATCH : 10
MISMATCH : 5

ANSWERS
TYPE : YES_OR_NO

END QUESTION

BEGIN QUESTION Question110
TITLE
"Are there any clutch hydraulic fluid leaks ?"

TEXT
"Check for leaks at the master and slave cylinders and the hydraulic fluid pipe. Fluid in one of the rubber dust covers fitted over the end of the master and slave cylinders is a sure sign of leaking rubber seals."

WEIGHT
MATCH : 10
MISMATCH : 5

ANSWERS
TYPE : YES_OR_NO

END QUESTION

BEGIN QUESTION Question111
TITLE
"Are the clutch master cylinder correctly adjusted ?"
TEXT
"Check the free play between the pushrod and the master cylinder piston. The free play should not be more than 0.5mm."
WEIGHT
MATCH : 10
MISMATCH : 5
ANSWERS
TYPE : YES_OR_NO
END QUESTION

BEGIN QUESTION Question112
TITLE
"Are any of the gearbox or engine mountings worn or loose ?"
WEIGHT
MATCH : 10
MISMATCH : 5
ANSWERS
TYPE : YES_OR_NO
END QUESTION

BEGIN QUESTION Question113
TITLE
"Is the fuel pump faulty ?"
TEXT
"The mechanical fuel pipe is situated on top of the crankcase adjacent to the distributor. Disconnect the outlet fuel pipe. Operate the starter switch. A strong jet of fuel should be ejected from the outlet. If not, the pump is faulty."
WEIGHT
MATCH : 10
MISMATCH : 5
ANSWERS
TYPE : YES_OR_NO
END QUESTION

BEGIN QUESTION Question114
TITLE
"Is it difficult to start the engine ?"
WEIGHT
MATCH : 10
MISMATCH : 5
ANSWERS
TYPE : YES_OR_NO
END QUESTION

BEGIN QUESTION Question115
TITLE
"Check carburetor idle settings/stabilizing unit and report results."
TEXT
"Connect a tachometer to the engine in accordance with the manufacturer's
instructions. Pull the connectors off the idle stabilizing unit and connect them together. Detach the crankcase ventilation hose and ensure that all electrical equipment on the vehicle is switched off. Start the engine and allow it to idle. If the idle speed is not from 800 to 900 rev/min, turn the idle adjusting screw as necessary until the idle speed between 800 and 900 rev/min is obtained. Switch off the engine, reconnect the plugs to the idle stabilizer unit and start the engine again. The idle speed should now have increased with 50 rev/min. If not, the idle stabilizing unit is faulty.

**WEIGHT**
- MATCH : 10
- MISMATCH : 5

**ANSWERS**
- TYPE : LIST
  - LIST : "Carburetor idle speed incorrect." "Idle stabilizer unit faulty." "No fault."

**END QUESTION**

**BEGIN QUESTION Question116**

**TITLE**
- "Does it feel like a fuel starvation problem ?"

**WEIGHT**
- MATCH : 10
- MISMATCH : 5

**ANSWERS**
- TYPE : YES_OR_NO

**END QUESTION**

**BEGIN QUESTION Question117**

**TITLE**
- "Is the fuel filter restricted ?"

**TEXT**
- "Inspect the fuel filter underneath the fuel tank. Any dirt or objects restricting the fuel filter will be visually obvious."

**WEIGHT**
- MATCH : 10
- MISMATCH : 5

**ANSWERS**
- TYPE : YES_OR_NO

**END QUESTION**

**BEGIN QUESTION Question118**

**TITLE**
- "is the fuel consumption excessive ?"

**WEIGHT**
- MATCH : 10
- MISMATCH : 5

**ANSWERS**
- TYPE : YES_OR_NO

**END QUESTION**

**BEGIN QUESTION Question119**

**TITLE**
"Any fuel leaking from the carburetor?"

TITLE
"Check for any fuel leakage from the carburetor while the throttle is operated."

TEXT

WEIGHT
MATCH : 10
MISMATCH : 5

ANSWERS
TYPE : YES OR NO

END QUESTION

BEGIN QUESTION Question120
TITLE
"Is the air cleaner choked?"

TEXT
"Inspect the air cleaner elements for any restrictions."

WEIGHT
MATCH : 10
MISMATCH : 5

ANSWERS
TYPE : YES OR NO

END QUESTION

BEGIN QUESTION Question121
TITLE
"Is the engine running erratically?"

WEIGHT
MATCH : 10
MISMATCH : 5

ANSWERS
TYPE : YES OR NO

END QUESTION

BEGIN QUESTION Question122
TITLE
"Is there an unusual noise in the engine?"

WEIGHT
MATCH : 10
MISMATCH : 5

ANSWERS
TYPE : YES OR NO

END QUESTION

BEGIN QUESTION Question123
TITLE
"Are any of the spark plugs loose?"

TEXT
"Pull on the spark plug leads. An unscrewed spark plug will be pulled out with ease."

WEIGHT
MATCH : 10
BEGIN QUESTION Question124
TITLE
"Does the gas pedal return all the way after depressed?"
TEXT
"If the gas pedal is pulled back by hand and the engine revolutions decrease, the pedal
does not return all the way."
WEIGHT
MATCH : 10
MISMATCH : 5
ANSWERS
TYPE : YES_OR_NO
END QUESTION

BEGIN QUESTION Question125
TITLE
"Is the carburetor retracting spring worn?"
TEXT
"Watch the carburetor accelerator linkage while an assistant depresses and releases
the gas pedal. Pull on the carburetor retracting spring to see if the accelerator linkage has retracted all
the way to the stop screw. If not, the spring is worn."
WEIGHT
MATCH : 10
MISMATCH : 5
ANSWERS
TYPE : YES_OR_NO
END QUESTION

BEGIN QUESTION Question126
TITLE
"Is the gas tank empty?"
WEIGHT
MATCH : 10
MISMATCH : 5
ANSWERS
TYPE : YES_OR_NO
END QUESTION
BEGIN ACTION Action1
    TITLE
    "The battery is in a discharged state."
    TEXT
    "The battery will have to be removed and charged. The battery is located beneath the passenger seat. To gain access to the battery, move the seat fully forward. Lift up the battery box lid and remove battery. Check battery water levels and fill up if necessary. Charge battery. If the battery does not charge or discharges without use, the battery is defective and must be replaced."
END ACTION

BEGIN ACTION Action2
    TITLE
    "It is a open circuit failure. Power is not reaching the starter motor."
    TEXT
    "Check wiring and connect breakage. If the breakage is not obvious, the automobile will have to be taken to a automotive electrician for repair."
END ACTION

BEGIN ACTION Action3
    TITLE
    "The starter solenoid is defective."
    TEXT
    "The solenoid must be replaced. The solenoid is secured to the starter motor which is located at the rear right-hand side of the vehicle. The starter motor is secured to the clutch housing from the front of the vehicle."
END ACTION

BEGIN ACTION Action4
    TITLE
    "Terminal connections do not relay enough current from and/or to the battery."
    TEXT
    "The battery is located beneath the passenger seat. To gain access to the battery, move the seat fully forward, lift up the battery box lid. Tighten loose terminal connections. For corroded connections, clean thoroughly and smear petroleum jelly around the connections to prevent further corrosion."
END ACTION

BEGIN ACTION Action5
    TITLE
    "The loose earth cable causes an open circuit."
    TEXT
    "The battery is located beneath the passenger seat. To gain access to the battery earth cable, move the seat fully forward and lift up the battery box lid. Fasten the earth cable."
BEGIN ACTION Action6
  TITLE  "The starter motor is internally defective."
  TEXT  "The starter motor must be replaced or removed for detail inspection. The starter motor is located at the rear right-hand side of the vehicle. The starter motor is secured to the clutch housing from the front of the vehicle."
END ACTION

BEGIN ACTION Action7
  TITLE  "The transmission input shaft bearings are worn."
  TEXT  "The transmission will have to be removed and stripped for detailed inspection."
END ACTION

BEGIN ACTION Action8
  TITLE  "The transmission and/or differential is internally faulty."
  TEXT  "The transmission will have to be removed for detailed inspection. It can be one of the following failures:
  Pinion shaft bearings are worn,
  differential bearings are worn,
  wear, damage or incorrect adjustment of differential crownwheel and pinion teeth."
END ACTION

BEGIN ACTION Action9
  TITLE  "The gear teeth are worn, damaged or chipped."
  TEXT  "The transmission will have to be removed and stripped for gears to be replaced."
END ACTION

BEGIN ACTION Action10
  TITLE  "The transmission is internally faulty."
  TEXT  "The transmission will have to be removed and stripped for detail inspection. It can be one of the following failures:
  Worn synchro units,
  worn shift rod detent or weak springs,
  Worn selector forks."
END ACTION

BEGIN ACTION Action11
 TITLE  "Worn synchro rings."
 TEXT  "The transmission will have to be removed for the synchro rings to be inspected and replaced."
 END ACTION

BEGIN ACTION Action12
 TITLE  "Corroded and/or loose starter motor connections do not relay enough current."
 TEXT  "Secure loose connections. Clean corroded connections and smear petroleum jelly around connections to prevent corrosion."
 END ACTION

BEGIN ACTION Action13
 TITLE  "The starter motor mounting bolts are loose."
 TEXT  "The starter motor mounting bolts must be fastened. The loose bolts cause the starter motor pinion ring gear teeth and the flywheel ring gear teeth to intersect at a wrong angle which causes wear. If the teeth have already been worn to much the noise will continue and the starter motor will have to be removed for detail inspection."
 END ACTION

BEGIN ACTION Action14
 TITLE  "Failure 1"
 END ACTION

BEGIN ACTION Action15
 TITLE  "Worn big-end bearings."
 TEXT  "The big-end bearings are most probably worn. The engine will have to be stripped for detailed inspection."
 END ACTION

BEGIN ACTION Action16
 TITLE  "Worn main bearings."
 TEXT  "The main bearings are most probably worn. The engine will have to be stripped for detailed inspection."
 END ACTION

BEGIN ACTION Action17
 TITLE  "Wheels out of balance"
END ACTION

BEGIN ACTION Action18
  TITLE
  "The alternator drivebelt is most probably slipping."
  TEXT
  "Adjust the belt tension. If the tensioning bracket adjustment is already on maximum, the belt must be replaced."
END ACTION

BEGIN ACTION Action19
  TITLE
  "The pinion or flywheel ring gear teeth are broken or badly worn."
  TEXT
  "The starter motor will have to be removed for detailed inspection. The starter motor is located at the rear right-hand side of the vehicle and secured to the clutch housing from the front of the vehicle."
END ACTION

BEGIN ACTION Action20
  TITLE
  "The alternator is defective."
  TEXT
  "The alternator will have to be removed for detailed inspection."
END ACTION

BEGIN ACTION Action21
  TITLE
  "Over-rich fuel mixture."
  TEXT
  "The carburetor mixture needs to be set correctly. The spark plugs can be reused after cleaning."
END ACTION

BEGIN ACTION Action22
  TITLE
  "Engine internally defective most probably worn piston rings."
  TEXT
  "The engine will have to be removed and stripped for detailed inspection. It can be worn piston rings or valve guides; The failure sometimes occurs (temporarily) during running-in period. Plugs can be re-used after thorough cleaning."
END ACTION

BEGIN ACTION Action23
  TITLE
  "Steering column bolts loose"
END ACTION
BEGIN ACTION Action24
  TITLE
    "Wear in steering balljoints."
END ACTION

BEGIN ACTION Action25
  TITLE
    "The alternator drivebelt is broken."
  TEXT
    "Replace the alternator drivebelt."
END ACTION

BEGIN ACTION Action26
  TITLE
    "The voltage stabilizer is defective."
  TEXT
    "The voltage stabilizer must be replaced. It is located on the back of the instrument panel, attached to the speedometer."
END ACTION

BEGIN ACTION Action27
  TITLE
    "The bulb is blown."
  TEXT
    "Replace the bulb."
END ACTION

BEGIN ACTION Action28
  TITLE
    "The starter brushes worn or sticking."
  TEXT
    "The starter motor must be replaced or removed for detailed inspection. The starter motor is located at the rear right-hand side of the vehicle. The starter motor is secured to the clutch housing from the front of the vehicle."
END ACTION

BEGIN ACTION Action29
  TITLE
    "The horn is defective."
  TEXT
    "The horn is defective and must be replaced. The horn is located under the front of the vehicle towards the right-hand side, bolted to the frame."
END ACTION

BEGIN ACTION Action30
  TITLE
    "The fuse is blown."
  TEXT
    "The fuse must be replaced. The fuse numbers are shown on the fuse cover and
information on the circuits they protect is given in the owner specifications."
END ACTION

BEGIN ACTION Action31
  TITLE
  "Not sufficient or no power is reaching the horn."
  TEXT
  "Check the earth circuit, testing from the horn earth terminal, then from the flexible coupling on the steering column. Finally prise out the horn button, disconnect the wire from it, and check continuity back to the horn earth terminal. The horn button contacts may be dirty or bent. Check these and clean if necessary. Check the potential at the positive terminal. It should be nearly 12 volts."
END ACTION

BEGIN ACTION Action32
  TITLE
  "It is an open circuit failure."
  TEXT
  "Check for discontinuity in the wiring."
END ACTION

BEGIN ACTION Action33
  TITLE
  "The fuel sender unit is faulty."
  TEXT
  "The fuel sender unit must be replaced."
END ACTION

BEGIN ACTION Action34
  TITLE
  "The fuel gauge is defective."
  TEXT
  "Replace the fuel gauge."
END ACTION

BEGIN ACTION Action35
  TITLE
  "The windscreen wiper motor is defective."
  TEXT
  "The windscreen wiper motor must be replaced."
END ACTION

BEGIN ACTION Action36
  TITLE
  "The windscreen washer electric pump is defective."
  TEXT
  "The electric pump must be replaced."
END ACTION

BEGIN ACTION Action37

"The fuel octane rating is too low."
"Use fuel with a higher octane rating."

"Incorrect gearshift lever plate adjustment."
"Slacken the two retaining bolts or screws, align the four holes then tighten the bolts or screws."

"The cylinder compressions are too low"
"The engine will have to be stripped for detailed inspection."

"The intake manifold air leak causes engine to idle erratically."
"Secure the intake manifold"

"The crankcase ventilation hoses are loose."
"Secure the loose hoses. The loose crankcase ventilation hoses can cause the engine to idle erratically."

"Uneven cylinder pressure causes engine to misfire or/and idle erratically"
"The engine will have to be removed for detailed inspection"

"The fault can be any of: worn pistons, worn cylinder bores, or worn piston rings"
"The engine will have to be removed and stripped for detailed inspection."
BEGIN ACTION Action44
  TITLE
  "A piston ring is most probably broken."
  TEXT
  "The engine will have to be stripped for detailed inspection."
END ACTION

BEGIN ACTION Action45
  TITLE
  "The valve gear are most probably worn."
  TEXT
  "The engine will have to be stripped for detailed inspection."
END ACTION

BEGIN ACTION Action46
  TITLE
  "The noise is most probably caused by piston slap."
  TEXT
  "The engine will have to be stripped for detailed inspection."
END ACTION

BEGIN ACTION Action47
  TITLE
  "Moisture in distributer cap."
  TEXT
  "Dry the cap with a rag and also wipe over the leads."
END ACTION

BEGIN ACTION Action48
  TITLE
  "The spark plugs are wet, dirty or wrongly gaped."
  TEXT
  "Remove the spark plugs, clean and regap them."
END ACTION

BEGIN ACTION Action49
  TITLE
  "The distributer cap might be cracked."
  TEXT
  "Inspect the distributer cap very closely and replace if cracked."
END ACTION

BEGIN ACTION Action50
  TITLE
  "The roter arm might be faulty."
  TEXT
  "Remove the roter arm from the distributer and inspect the roter arm. The metal tip should not be damaged. If damaged, replace the roter arm."
END ACTION

BEGIN ACTION Action51
  TITLE
  "The carbon brush might not make good contact."
  TEXT
  "The carbon brush in the top of the distributor cap is not making good contact with
the spring on the roter arm. Check to see if they make contact and correct if not."
END ACTION

BEGIN ACTION Action52
  TITLE
  "Open circuit failure by the coil."
  TEXT
  "Loose coil connection cause an open circuit failure. Secure loose connections."
END ACTION

BEGIN ACTION Action53
  TITLE
  "Contact breaker points faulty."
  TEXT
  "Replace the contact breaker points."
END ACTION

BEGIN ACTION Action54
  TITLE
  "Open circuit between the ignition switch and coil."
  TEXT
  "Check connection on ignition switch and secure loose connections. If the breakage
can't be located, the vehicle will have to be taken for expert repair."
END ACTION

BEGIN ACTION Action55
  TITLE
  "Contact breaker points incorrectly adjusted."
  TEXT
  "Slacken the screw securing the contact breaker assembly to the distributor baseplate.
Engage a screwdriver between the slot in the breaker assembly and the two adjacent pips on the
baseplate, then move the assembly as necessary to obtain the correct setting."
END ACTION

BEGIN ACTION Action56
  TITLE
  "The condenser is defective."
  TEXT
  "Fit a new condenser."
END ACTION

BEGIN ACTION Action57
TITLE
"Open circuit failure between the coil and distributor."

TEXT
"Replace the wire between the coil and distributor."

END ACTION

BEGIN ACTION Action58
TITLE
"The coil is defective."

TEXT
"Replace the coil."

END ACTION

BEGIN ACTION Action59
TITLE
"The ignition lead is damaged."

TEXT
"Replace the ignition lead."

END ACTION

BEGIN ACTION Action60
TITLE
"Tracking takes place on the distributor cap."

TEXT
"The tracking lines are paths which conduct electricity across the gap thus letting it run to earth. Replace the distributor cap."

END ACTION

BEGIN ACTION Action61
TITLE
"The ignition timing is set incorrectly."

TEXT
"Adjust the ignition timing correctly."

END ACTION

BEGIN ACTION Action62
TITLE
"The wheels are out of balance."

TEXT
"Balance the wheels."

END ACTION

BEGIN ACTION Action63
TITLE
"The driveshaft is faulty."

TEXT
"The driveshaft will have to be repaired by an expert."

END ACTION
BEGIN ACTION Action64
  TITLE
  "Rear wheel bearings are worn."
  TEXT
  "The bearings will have to be removed for detailed inspection."
END ACTION

BEGIN ACTION Action65
  TITLE
  "The constant velocity joints are worn."
  TEXT
  "The constant velocity joints will have to be removed for detailed inspection."
END ACTION

BEGIN ACTION Action66
  TITLE
  "The constant velocity joint retaining bolts are loose."
  TEXT
  "Secure the bolts."
END ACTION

BEGIN ACTION Action67
  TITLE
  "The hub retaining nut is loose."
  TEXT
  "Secure the nut and replace the hub spline."
END ACTION

BEGIN ACTION Action68
  TITLE
  "The wheel nuts are loose."
  TEXT
  "Secure the wheel nuts."
END ACTION

BEGIN ACTION Action69
  TITLE
  "The shock absorbers are worn."
  TEXT
  "Replace the shock absorbers."
END ACTION

BEGIN ACTION Action70
  TITLE
  "The shock absorber mounting bushes are worn."
  TEXT
  "Replace the mounting bushes."
END ACTION
BEGIN ACTION Action71
    TITLE
        "The coil springs are most probably worn."
    TEXT
        "Replace the coil springs."
END ACTION

BEGIN ACTION Action72
    TITLE
        "Worn flexible coupling."
    TEXT
        "Replace the flexible coupling."
END ACTION

BEGIN ACTION Action73
    TITLE
        "The relay gear is worn."
    TEXT
        "The relay gear will have to be removed for detailed inspection."
END ACTION

BEGIN ACTION Action74
    TITLE
        "Loose connecting shaft."
    TEXT
        "Secure the connecting shaft."
END ACTION

BEGIN ACTION Action75
    TITLE
        "The steering box is faulty."
    TEXT
        "The steering box will have to be striped for detailed inspection."
END ACTION

BEGIN ACTION Action76
    TITLE
        "The front wheel alignment is incorrect."
    TEXT
        "Set the wheel alignment."
END ACTION

BEGIN ACTION Action77
    TITLE
        "Steering column bent or distorted."
    TEXT
        "The steering colm will have to be removed and inspected by an expert."
END ACTION
BEGIN ACTION Action78
    TITLE "Worn front hub bearings."
    TEXT "Replace hub bearings."
END ACTION

BEGIN ACTION Action79
    TITLE "The balljoists are worn."
    TEXT "Replace balljoists."
END ACTION

BEGIN ACTION Action80
    TITLE "The upper wishbone mounting bushes are worn."
    TEXT "Replace the mounting bushes."
END ACTION

BEGIN ACTION Action81
    TITLE "The anti-roll bar mountings are worn."
    TEXT "Renew worn mountings."
END ACTION

BEGIN ACTION Action82
    TITLE "The radius rod mountings are worn."
    TEXT "Renew the worn mountings."
END ACTION

BEGIN ACTION Action83
    TITLE "Brake fluid leak."
    TEXT "Replace the section of the brake fluid pipe that leaks."
END ACTION

BEGIN ACTION Action84
    TITLE "Empty brake fluid reservoir."
    TEXT "Fill the reservoir to the MAX mark. There might be air in the brake system. If the problem is not corrected, the brake system will have to be bled. There are a number of one man, do-it-yourself, brake bleeding kits currently available from motor accessory shops. Always follow the
instructions supplied with the kit. Bleeding should be done in the following sequence: right-hand rear, left-hand rear, right-hand front, and last left-hand front.

END ACTION

BEGIN ACTION Action85
  TITLE
  "Air in the brake system."
END ACTION

BEGIN ACTION Action86
  TITLE
  "Incorrect adjusted master cylinder pushrod."
  TEXT
  "Adjust by slackening the locknut and turning the pushrod."
END ACTION

BEGIN ACTION Action87
  TITLE
  "The master cylinder is faulty."
  TEXT
  "The master cylinder will have to be stripped for detailed inspection."
END ACTION

BEGIN ACTION Action88
  TITLE
  "The brake caliper retaining bolts are loose."
  TEXT
  "Secure the bolts."
END ACTION

BEGIN ACTION Action89
  TITLE
  "The brake pads are worn."
  TEXT
  "Renew the brake pads."
END ACTION

BEGIN ACTION Action90
  TITLE
  "The brake disc is worn."
  TEXT
  "The disc must be skimmed or preferably renewed."
END ACTION

BEGIN ACTION Action91
  TITLE
  "The brake shoe linings are worn."
  TEXT
  "Renew the brake shoes."
END ACTION

BEGIN ACTION Action92
TITLE
"The brake drum is worn."
TEXT
"The brake drum must be skimmed."
END ACTION

BEGIN ACTION Action93
TITLE
"The brake pressure regulator is faulty."
TEXT
"The regulator must be removed for detailed inspection."
END ACTION

BEGIN ACTION Action94
TITLE
"Handbrake incorrectly adjusted."
END ACTION

BEGIN ACTION Action95
TITLE
"Handbrake cable broken."
TEXT
"Renew handbrake cable."
END ACTION

BEGIN ACTION Action96
TITLE
"The vacuum hose has a leak."
TEXT
"Renew the vacuum hose."
END ACTION

BEGIN ACTION Action97
TITLE
"The servo unit non-return valve is faulty."
TEXT
"Replace the valve."
END ACTION

BEGIN ACTION Action98
TITLE
"The servo air filter is faulty."
TEXT
"Replace the air filter."
END ACTION
BEGIN ACTION Action99
  TITLE
  "The servo unit is faulty."
  TEXT
  "Replace the servo unit."
END ACTION

BEGIN ACTION Action100
  TITLE
  "Clutch hydraulic leak."
  TEXT
  "If the master or slave cylinder is leaking, it will have to be removed to replace the rubber seals. Replace the hydraulic fluid pipe if any leak is detected from it."
END ACTION

BEGIN ACTION Action101
  TITLE
  "Clutch master cylinder incorrectly adjusted."
  TEXT
  "Adjust the free play between the pushrod and the master cylinder piston to just a noticeable freeplay (less than 0.5mm). Adjustment is carried out by slackening the locknut and turning the pushrod in the desired direction to increase or decrease the freeplay."
END ACTION

BEGIN ACTION Action102
  TITLE
  "Air in the clutch system."
END ACTION

BEGIN ACTION Action103
  TITLE
  "The clutch is internally faulty."
  TEXT
  "The clutch will have to be removed for detailed inspection."
END ACTION

BEGIN ACTION Action104
  TITLE
  "Gearbox/engine mountings worn or loose."
  TEXT
  "Renew the worn mountings and secure mountings."
END ACTION

BEGIN ACTION Action105
  TITLE
  "The clutch release bearing is worn."
  TEXT
  "Renew the clutch release bearing."
END ACTION
BEGIN ACTION Action106
  TITLE  "The fuel pump is faulty."
  TEXT   "Replace the fuel pump."
END ACTION

BEGIN ACTION Action107
  TITLE  "The idle stabilizing unit is faulty."
  TEXT   "Replace the stabilizing unit."
END ACTION

BEGIN ACTION Action108
  TITLE  "Carburetor idle speed adjustment incorrect."
END ACTION

BEGIN ACTION Action109
  TITLE  "Fuel filter restricted."
  TEXT   "Replace the fuel filter."
END ACTION

BEGIN ACTION Action110
  TITLE  "Worn carburetor."
  TEXT   "The carburetor will have to be stripped for detail inspection."
END ACTION

BEGIN ACTION Action111
  TITLE  "The air cleaner is choked."
  TEXT   "Remove any obstacles in the air cleaner and replace the air filter element if necessary."
END ACTION

BEGIN ACTION Action112
  TITLE  "The carburetor component settings incorrect."
  TEXT   "The carburetor component settings need to be adjusted by an expert."
END ACTION
BEGIN ACTION Action113
    TITLE
      "Loose spark plug."
    TEXT
      "Secure the spark plug."
END ACTION

BEGIN ACTION Action114
    TITLE
      "The carburetor retracting spring is worn."
    TEXT
      "Renew the spring and lubricate the accelerator linkages."
END ACTION

BEGIN ACTION Action115
    TITLE
      "The fuel tank is empty."
    TEXT
      "Fill the fuel tank."
END ACTION
Appendix B: FAULT TREE ANALYSIS
Figure B.2 Fault Tree Analysis
Figure B.3 Fault Tree Analysis

1. Engine faulty
2. Fuel system faulty
3. Voltage not reaching plugs
4. Distributor components faulty
   - Distributor cap wet
   - Carbon brush faulty
   - Faulty rotor arm
   - Cracked distributor cap
   - Condenser defective
   - Loose coil connections
Figure B.4 Fault Tree analysis

- Engine does not turn normal
- Battery discharged
- Power not reaching starter motor
- Solenoid faulty
- Battery terminals loose
- Battery earth cable loose
- Open circuit
- Starter connections loose
Engine does not turn normal

Battery discharged 2

Starter motor assembly faulty

Starter motor pinion worn 24
Starter motor internally faulty
Starter brushes worn 8
Solenoid faulty 3
Battery terminals loose 4

Figure B.5 Fault Tree Analysis