FAILURE DIAGNOSTIC EXPERT SYSTEMS:
A CASE STUDY IN FAULT DIAGNOSIS
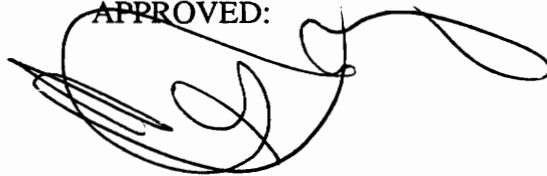
by

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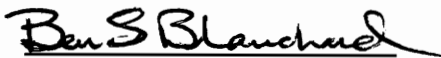in partial fulfillment of the requirements for the degree of

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APPROVED:

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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.

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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 discused 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, entitiled 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.
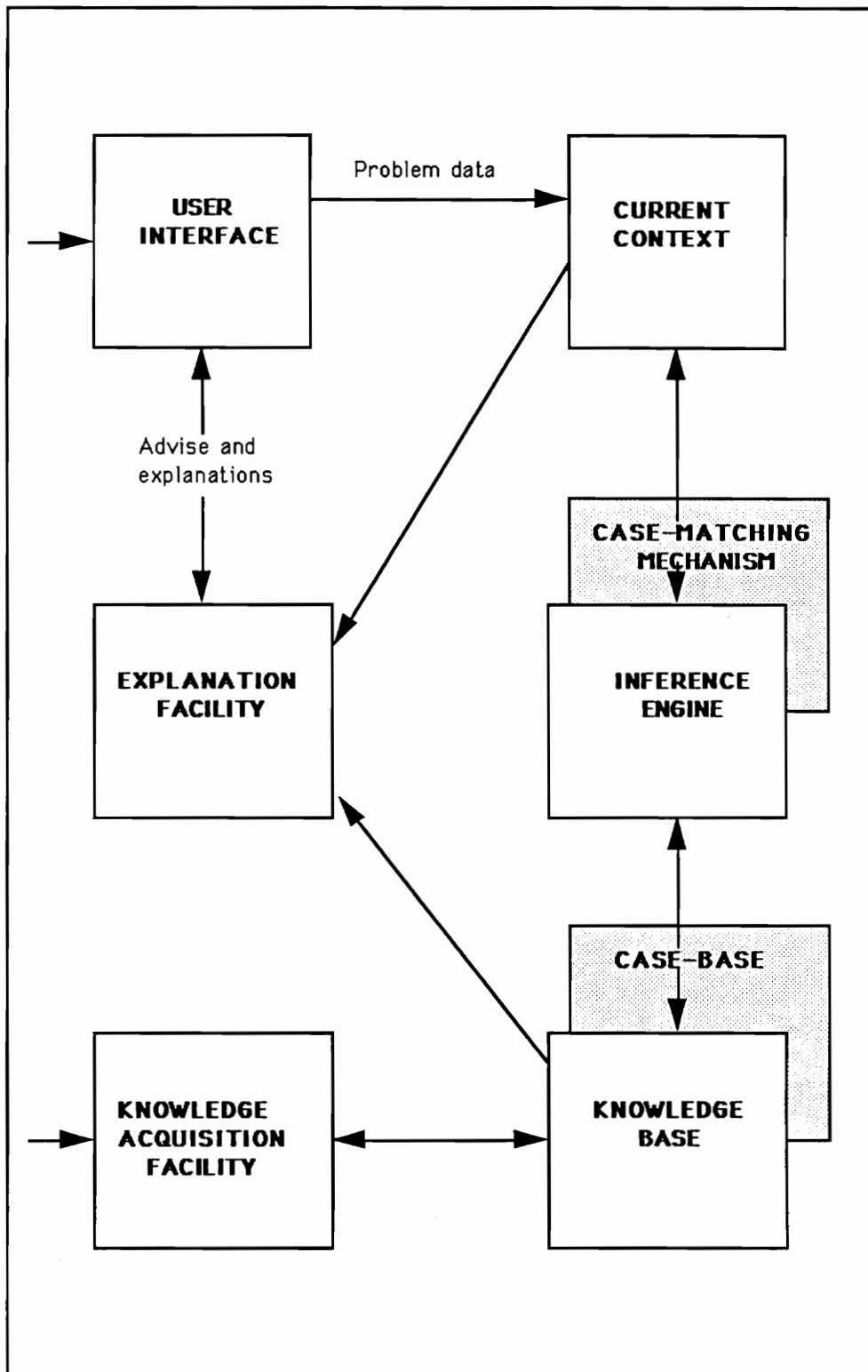
FIGURE 2.1   Architecture of Expert Systems Versus the
Architecture of Case-Base Reasoning

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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 pistonrings. Undersize pistonrings 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 [Winlund 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.
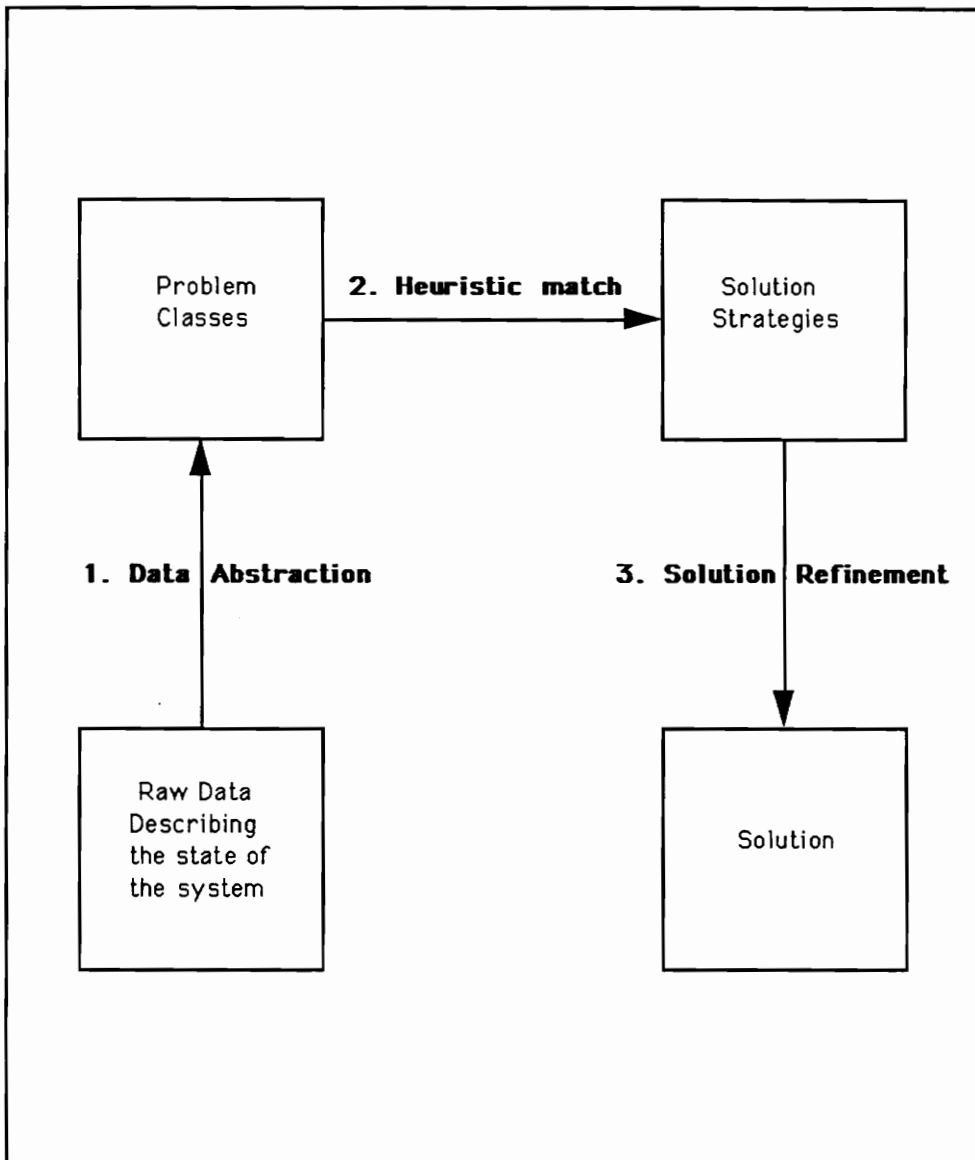
Figure 2.2 Heuristic Classification

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
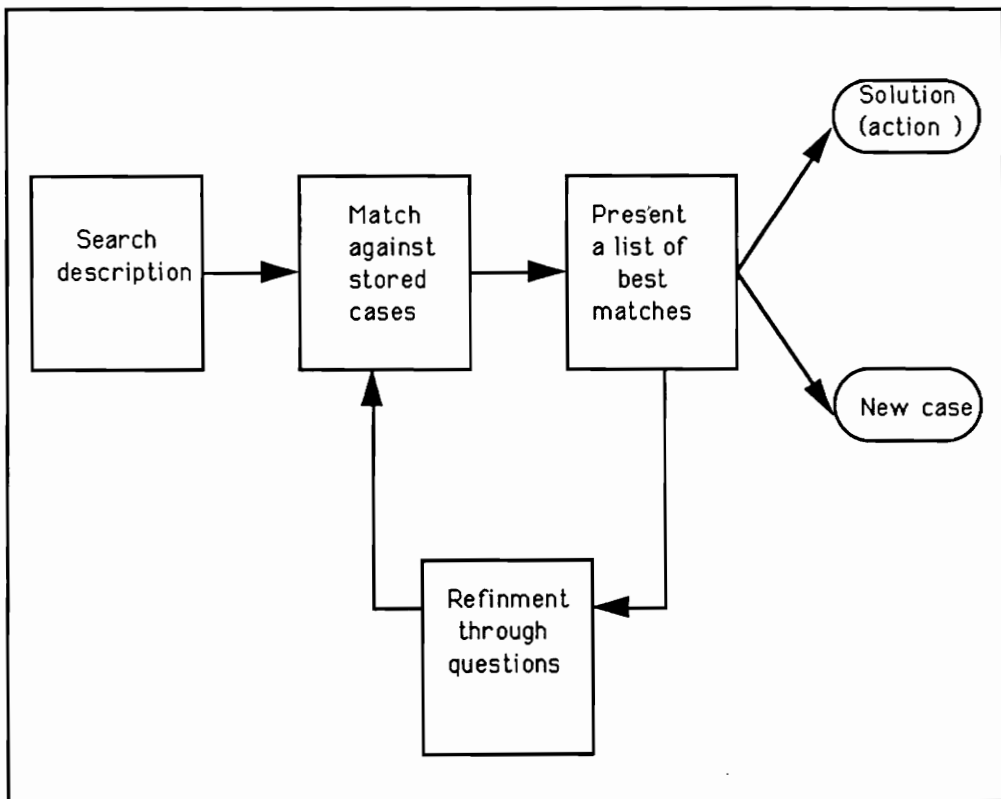
Figure 2.3 CBR Express Reasoning.

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.
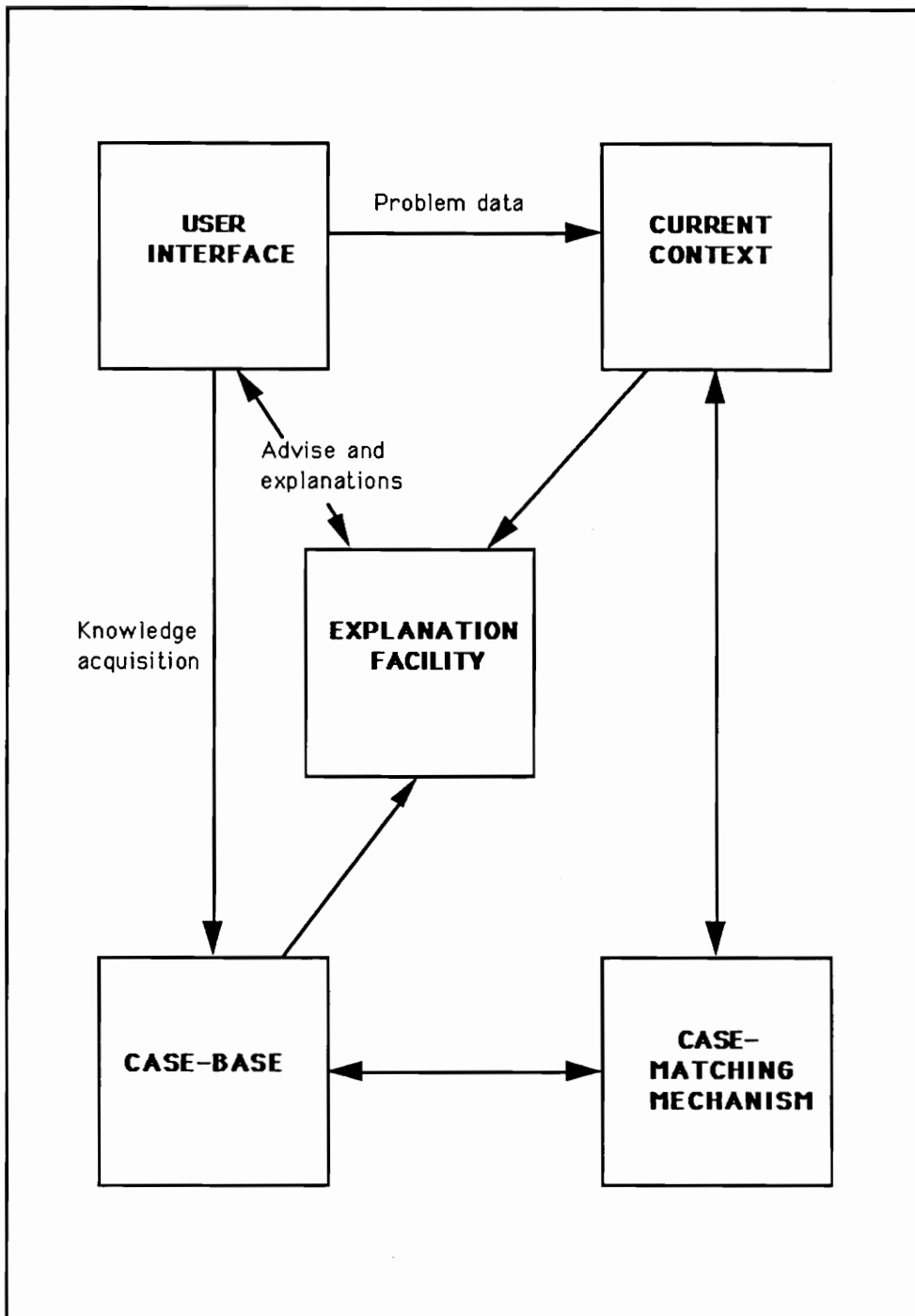
Figure 2.4 CBR Express Architecture

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 a 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.
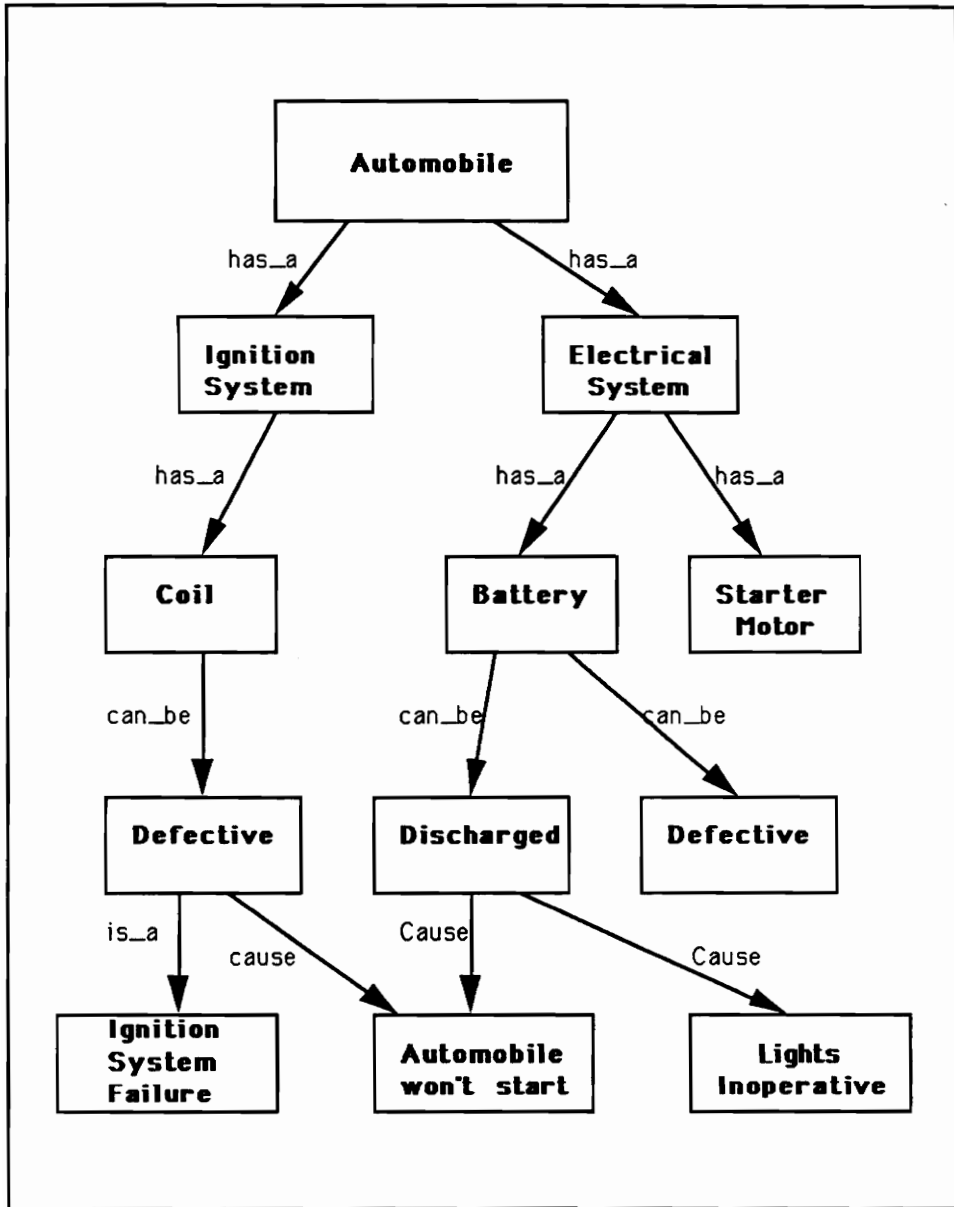
Figure 3.1   Partial Semantic Net

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, distributer, condenser, etc. -- or even classes of the distributer. 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:

Prob(H/E) = Prob(E/H) * Prob(H) / 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 Prob(H) with the posterior probability Prob(H/E), i.e. the new probability in the light of evidence. Prob(H) is the initial estimate without any information about E. 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:

IF   not(auto_start)

AND   headlights_dim_when_start

THEN   do_solenoid_test

IF   do_solenoid_test

AND   have_voltmeter

THEN   do_volt_test

IF   do_solenoid_test

AND   not(have_voltmeter)

THEN   do_noise_test

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 *not(auto_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].

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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 fails 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

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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 technique 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 4.1. Partial FMECA

Component Name	Failure Mode	Failure Effect	Case Number Appendix A
Battery	Discharged.	Engine fails to turn. Engine turns slowly.	2
	Terminals loose.	Engine fails to turn. Battery will not hold charge for long.	4
	Earth loose.	Engine fails to turn.	5
	Internally defective.	Engine fails to turn. Battery will not hold charge for long. Engine turns slowly.	
Starter Solenoid	Internally defective.	Engine fails to turn.	3
Starter Motor	Connections loose.	Engine fails to turn. Engine turns slowly.	17
	Starter brushes worn.	Engine turns slowly.	8
	Internally defective.	Engine fails to turn.	7
	Pinion ring gear teeth worn.	Starter spins without turning the engine.	24
	Starter mounting bolts loose.	Starter noisy.	25
Alternator	Internally defective.	Battery will not hold charge for long. Battery does not get charged. Ignition light stays on.	9
Alternator Drivebelt	Broken.	Ignition light stays on. Engine overheats.	32
	Slipping.	Battery will not hold charge for long.	23
Voltage Stabilizer	Internally defective.	Instrument readings increase with engine speed.	33
Fuel Sender Unit	Defective.	Fuel gauge gives no reading.	39
Fuel gauge	Defective.	Fuel gauge gives maximum reading all the time.	40
Bulbs	Blown.	Light inoperative.	34
Horn	Internally defective.	No sound from horn.	35
Wiper Motor	Defective.	Windscreen wipers inoperative.	41
Wiring	Open circuit. Short circuit.	No current. No current.	38
Fuse	Blown.	No current.	36

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:

IF   the engine fails to turn .... (1)
AND the headlights dim when the starter switch is operated .... (2)
AND you do not hear a clicking noise when the starter switch is operated .... (3)
THEN the starter solenoid is internally defective

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 4.2 General Case Base

Failure description:
Battery discharged.
Symptoms:
Automobile won't start. Starter turns engine slowly. Starter fails to turn engine. Lights inoperative.
Test procedure:
IF   the engine does not turn normaly
AND   the headlights dim after a few seconds when switched on.
THEN the battery is in a discharged state."
Failure description:
Battery terminals loose.
Symptoms:
Automobile won't start. Starter fails to turn engine. Battery will not hold charge for long.
Test Procedure:
IF   the engine does not turn normaly
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
Failure description:
Battery earth cable loose.
Symptoms:
Automobile won't start. Starter fails to turn engine.
Test Procedure:
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.
Failure description:
Solenoid defective.
Symptoms:
Automobile won't start.
Test procedure:
IF   the engine does not turn normaly
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

Table 4.2 (Cont.)

Failure description:
Starter brushes worn.
Symptoms:
Starter turns engine slowly. Automobile won't start.
Test procedure:
IF the automobile wont start
AND the engine turns slowly
AND the headlights do not dim after a few seconds when switched on
AND no corroded or loose starter motor connections
THEN the starter brushes are worn
Failure description:
Starter motor defective.
Symptoms:
Automobile won't start, starter fails to turn engine.
Test procedure:
IF the Automobile won't start
AND the engine does not turn normaly
AND the headlights dim when the starter switch is operated
AND you hear a clicking noise when the starter switch is operated
AND there is no corroded or loose starter motor connections
AND the starter does not spin without turning the engine
THEN the starter motor is internally defective.
Failure description:
No power to starter motor.
Symptoms:
Automobile won't start, Sartor fails to turn engine.
Test procedure:
IF the automobile won't start
AND the engine does not turn normaly
AND the battery terminals not loose or corroded
AND the battery earth cable is not loose
AND the headlights do not dim when the starter switch is operated
THEN It is an open circuit failure. Power is not reaching the starter motor.

will be discused 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
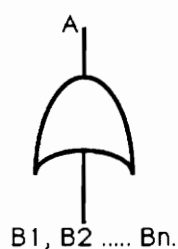
OR gate. A logical inclusive OR relation.
Output A exist if any of B1, B2, ... Bn,
or any combination thereof, exist.
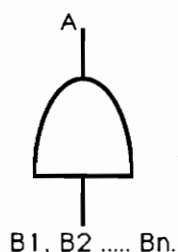
AND gate. A logical AND relation.
Output A exist if and only if all of
B1, B2, ... Bn, exist simultaneously.

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.
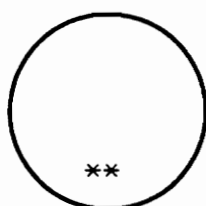
An event, usually a malfunction, described
in terms of a specific circuit or component.
** Note that for the fault tree example given,
the number in the bottom of each circle is the
case number in Appendix A.
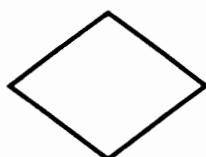
An event not developed further because
of lack of information or of sufficient
consequences. Could also be used to
indicate further investigation is intended
when additional becomes information available.

Figure 4.1 Fault Tree Symbols
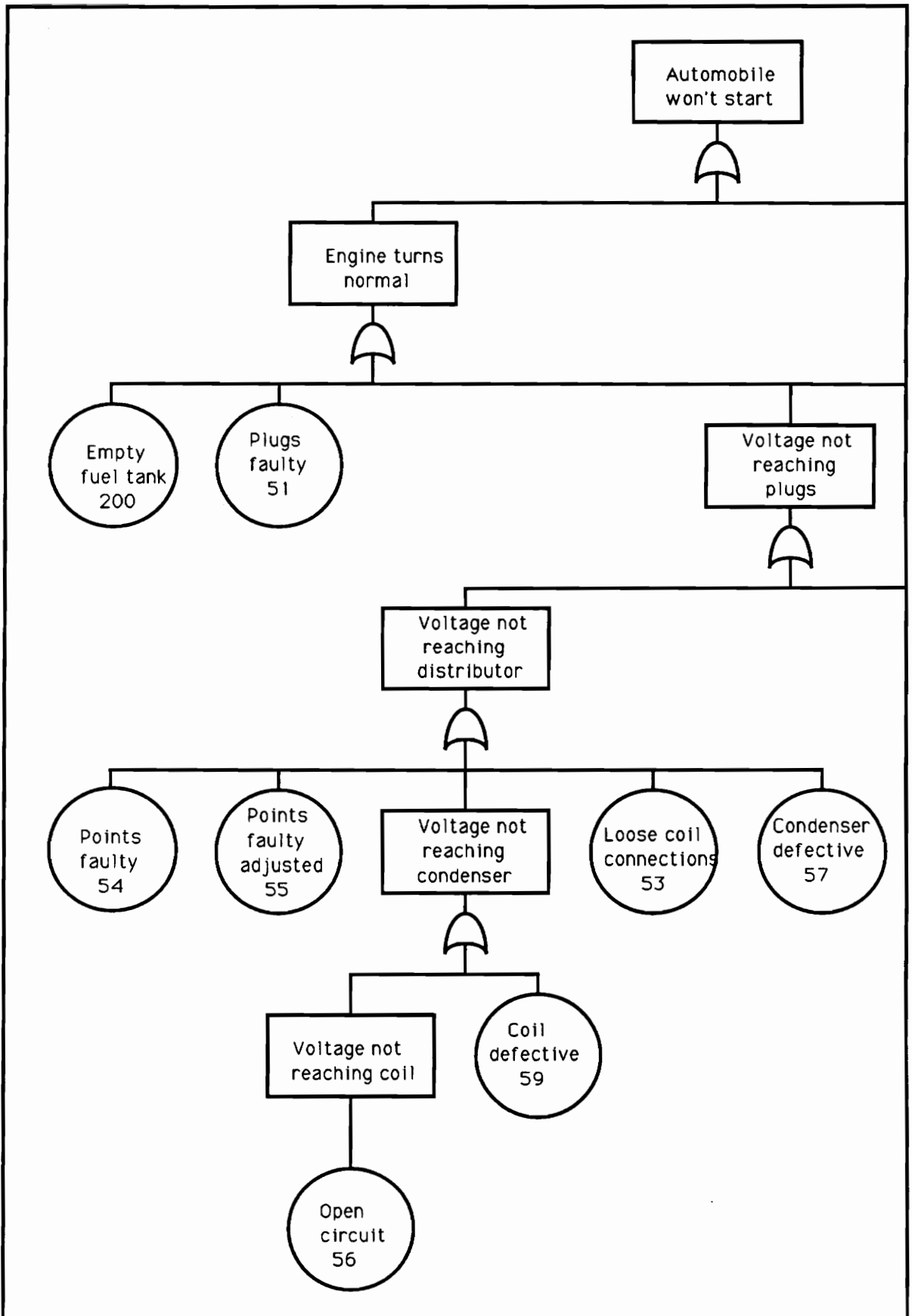
Figure 4.2 Partial Fault Tree Analysis

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 normaly

AND voltage not reaching the plugs

AND voltage not reaching the distributer

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 discused 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
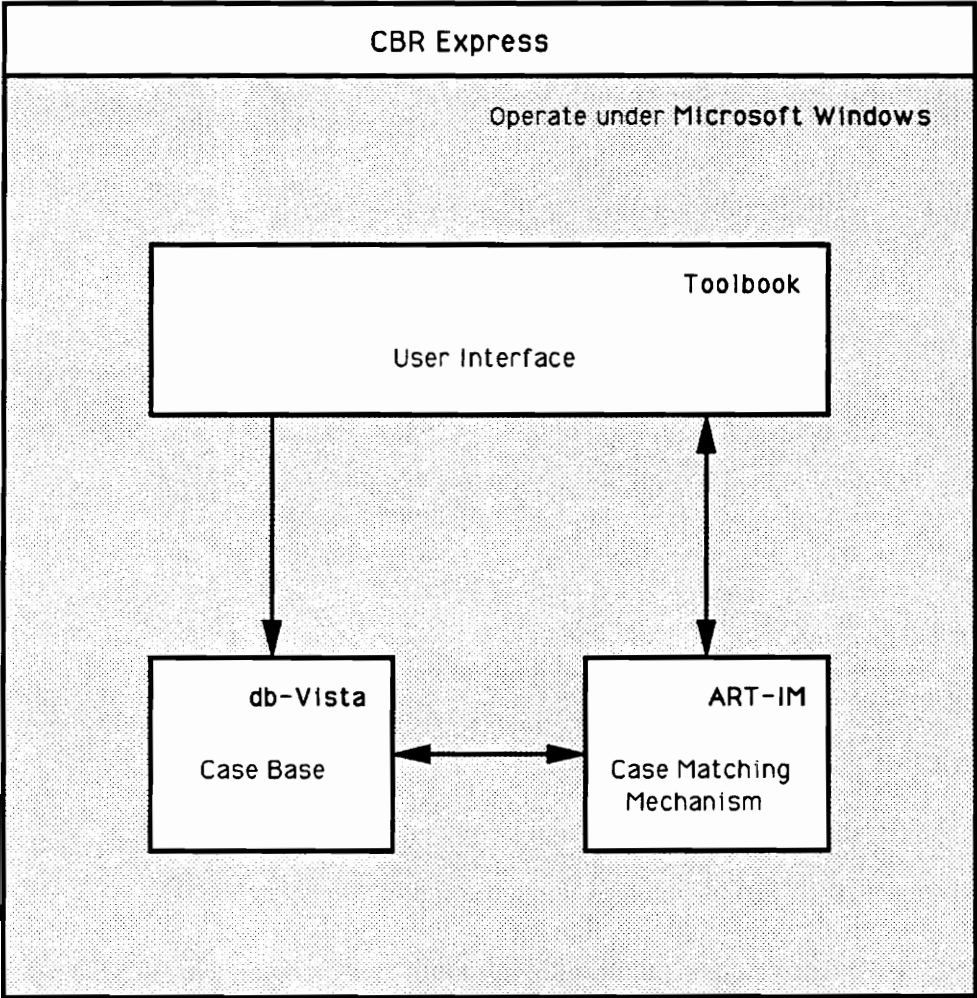
Figure 5.1 Software Interaction

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
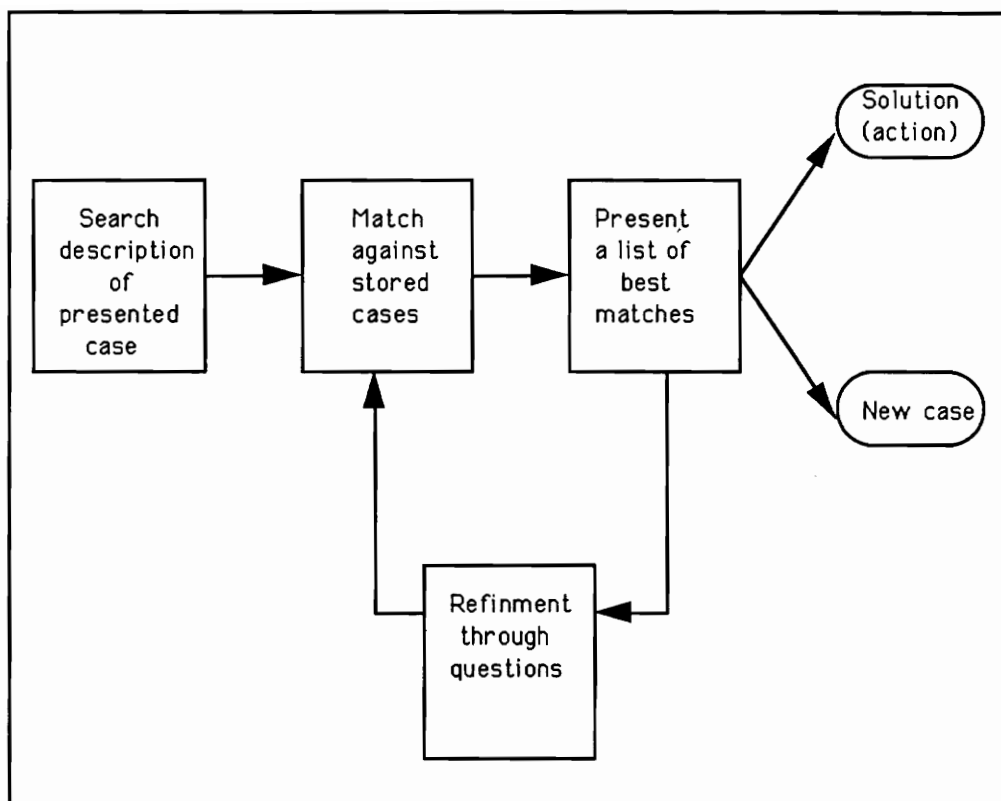
Figure 5.2 CBR Express Reasoning.

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

```
(Defschema case18
    (number-key case18)
    (title "Incorrect gearshift adjustment")
    (description "Transmission jumps out of gear")
    (question11 "yes")
    (question13 "no")
    (action38))

(Defschema question11
    (number-key question11)
    (title "Does the transmission jump out of gear ?")
    (match 10)
    (mismatch 5)
    (type yes_or_no))

(Defschema question13
    (number-key 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")
    (match 10)
    (mismatch 5)
    (type yes_or_no))

(Defschema action38
    (number-key action38)
    (tilte "Incorrect gearshift lever plate adjustment"
    (text "Slacken the two retaining bolts or screws, align the four holes then tighten the bolts or
     screws"))
```

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 can not 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 5.2 Stored Case Weight Contribution

Weight Match	Mismatch	Feature	Value
10	0	1. Description	Knock, thump noise in engine.
40	5	2. Question 1: Is there a regular heavy knocking noise present ?	yes
10	5	3. Question 2: Is the noise less or worse under weight ?	less
10	0	4. Question 3: Give a description of the spark plug heads.	wet, oily
20 —— 90	5	5. Question 4: What is the lowest cylinder pressure reading (kPa) ?	1.8 range: 0 to 2

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:

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 normilized 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:

"HEA", "EAR", "ARK", "RKN", "KNO", "NOC", "OCK", "CKT", "KTH", "THU", "HUM", "UMP", "MPN", "PNO", "NOI", "OIS", "ISE", "SEE", "EEN", "ENG", "NGI", "GIN", "INE".   .

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:

$$\text{Description weight} = \frac{(tx - tm)}{tx} \text{ mismatch weight} + \frac{tm}{tx} \text{ match weight}$$

.

Where:

tm = the number of trigrams in common between the presented case and the
     stored case

tx = 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:

    Question weight = match weight

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

    Question weight = 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:

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

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

Question weight = [(2 - 1) * 0 / 2] + [10 / 2]
                = 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:

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

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 lcvalue - pvalue l / 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

Question weight = 20 - [| 1.8 - 1.75 | / 0.2] * [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):

Match score (ART-IM) = (8.26 + 40 - 5 + 5 + 13.75) / 90 = 62.01 / 90

= 0.689

Match score (CBR Express) = 0.689 * 100

= 69

CBR Express rounds the match score to the closest integer.

Table 5.3 Stored Case Weight Contribution

Match Weight Contribution	Feature	Value
8.26	1. Description	Hear knock, thump noise in engine.
40	2. Question 1: Is there a regular heavy knocking noise present ?	yes
-5	3. Question 2: Is the noise less or worse under weight ?	worse
5	4. Question 3: Give a description of the spark plug heads.	oily deposits
13.75 ———— 62.01	5. Question 4: What is the lowest cylinder pressure reading (kPa) ?	1.75

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 there 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.
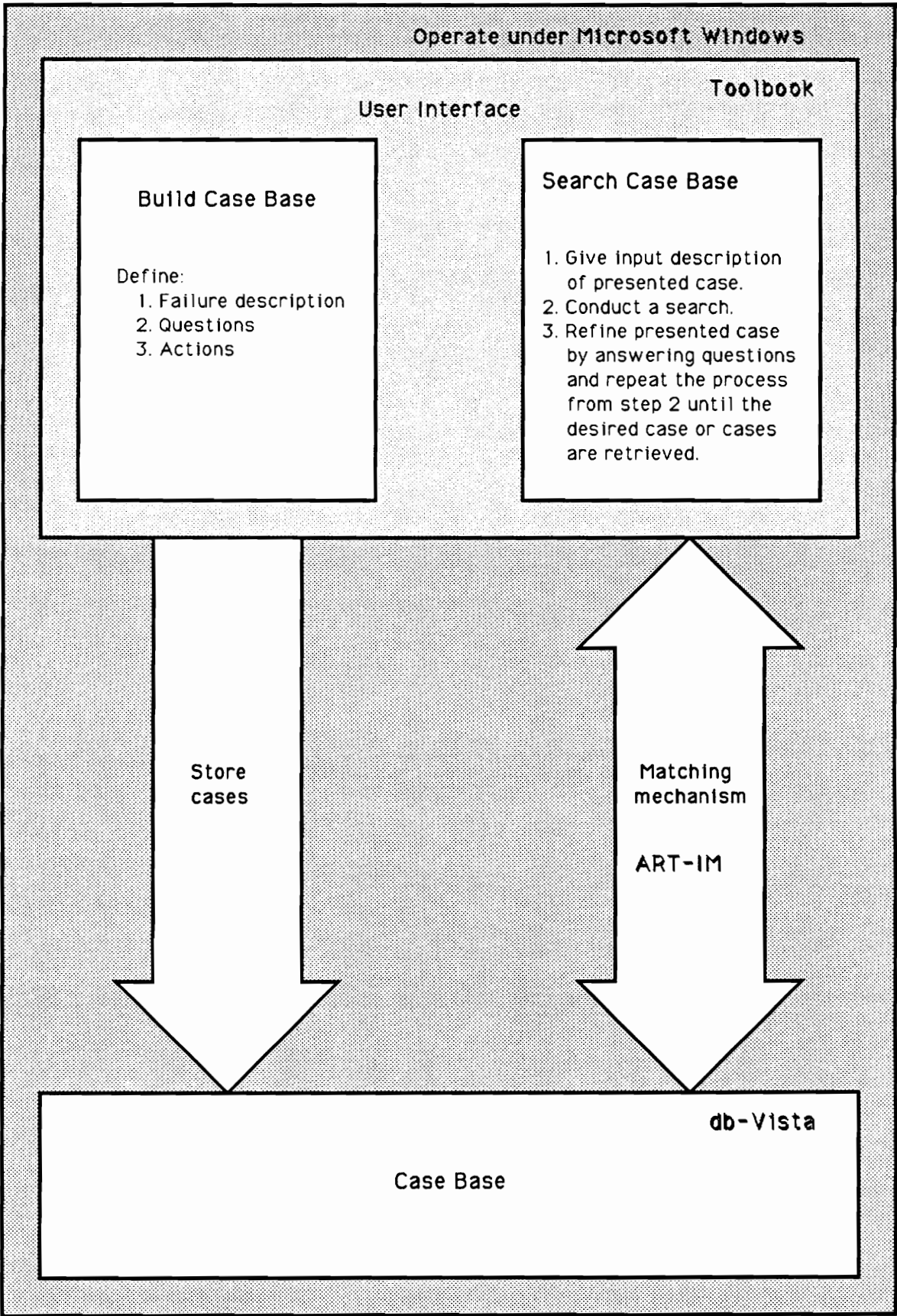
Figure 5.3 CBR Express Functioning

Chapter VI. SAMPLE DIAGNOSTIC CONSULTATIONS

In chapter VI sample diagnostic consultations by using CBR Expresss 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

```
 Q Search                    Search completed.

Description:
Automobile won't start



Questions about this Problem:                          Answers:
 Does the starter motor turn the engine normally ?     Not Answered
 Are there any corroded or loose starter motor connections ?  Not Answered
 Is the cylinder pressure low ?                        Not Answered
 Does the automobile start ?                           Not Answered
 Is there moisture in the distributer cap ?            Not Answered
 Is voltage reaching the plug ?                        Not Answered
 Is the gas tank empty ?                               Not Answered
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   Search completed.

Description:

Automobile won't start

Questions about this Problem:	Answers:
Is there moisture in the distributer cap ?	Not Answered
Is voltage reaching the plug ?	Not Answered
Is voltage reaching the distributer ?	Not Answered
Are there any loose connections on the coil ?	Not Answered
Does the starter spin without turning the engine ?	Not Answered
Does the starter motor turn the engine normally ?	Yes
Does the automobile start ?	No

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

Browsing Question: | Answers:

Is voltage reaching the plug ? | Not Answered
| Not Answered
Disconnect each plug lead in turn at the spark plug end, and hold the | Not Answered
end of the cable with rubber or an insulated tool about 6 mm away | Not Answered
from the cylinder block. Spin the engine on the starter motor. | Not Answered
Sparking between the end of the cable and the block should be fairly | Yes
strong with a regular blue spark to proof that voltage is present. | No

Browsing Case:
Description: Automobile won't start
Questions:
Does the starter motor turn the engine normally ? Yes
Is voltage reaching the plug ? Yes
Actions:
The spark plugs are wet, dirty or wrongly gaped.

Figure 6.3.   Sample Consultation

Search

Description:

Automobile won't start

Questions about this Problem:	Answers:
Is the cylinder pressure low ?	Not Answered
Is there moisture in the distributer cap ?	Not Answered
Does the starter spin without turning the engine ?	Not Answered
Is it difficult to start the engine ?	Not Answered
Is the fuel pump faulty ?	Not Answered
Is voltage reaching the plug ?	Yes
Does the starter motor turn the engine normally ?	Yes

Recommended Actions:

94 The spark plugs are wet. dirty or wrongly gaped.
57 The cylinder compressions are too low
57 Moisture in distributer 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

Questions about this Problem:	Answers:
Is the cylinder pressure low ?	Not Answered
Is there moisture in the distributer cap ?	Not Answered
Does the starter spin without turning the engine ?	Not Answered
Is it difficult to start the engine ?	Not Answered
Is the fuel pump faulty ?	Not Answered
Is voltage reaching the plug ?	Yes
Does the starter motor turn the engine normally ?	Yes

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 Search completed.

Description:

Difficulty in engaging gears

Questions about this Problem:	Answers:
In which way does the clutch malfunction ?	Not Answered
Are there any clutch hydraulic fluid leaks ?	Not Answered
Are the clutch master cylinder correctly adjusted ?	Not Answered
Is the brake fluid level under the minimum mark ?	Not Answered
Bleed the clutch system - Is the malfunction corrected ?	Not Answered

Recommended Actions:

51 Clutch hydraulic leak.	
51 Clutch master cylinder incorrectly adjusted.	
24 Empty brake fluid reservoir.	
21 Air in the clutch system.	
17 The clutch is internally faulty.	

Figure 6.6.   Sample Consultation

Search

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,

Answers:

Not Answered
Not Answered
Not Answered
Not Answered
Not Answered

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   Search completed.

Description:

Difficulty in engaging gears

Questions about this Problem:	Answers:
Does the brake pedal feel spongy or travel excessively ?	Not Answered
Are there any brake fluid leaks ?	Not Answered
Bleed the brake system. Is the problem corrected ?	Not Answered
Is the master cylinder pushrod correctly adjusted ?	Not Answered
Are there any clutch hydraulic fluid leaks ?	No
Is the brake fluid level under the minimum mark ?	No
Bleed the clutch system - Is the malfunction corrected ?	Yes

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

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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.

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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."

DESCRIPTION
"Automobile won't start. Starter fails to turn engine. Battery will not hold charge for long. "
QUESTIONS
Question2 : "No"
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"
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"

Question2 : "No"
            ACTIONS
                        Action6
END CASE

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"
            ACTIONS
                        Action28
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"
            ACTIONS
                        Action20
END CASE

BEGIN CASE Case10
            TITLE
                        "Transmission input shaft bearings worn."
            DESCRIPTION
                        "Transmission noisy in neutral."
            QUESTIONS
                        Question8 : "Yes"
            ACTIONS
                        Action7
END CASE

BEGIN CASE Case11
            TITLE
                        "Transmission and/or differential internally defective"
            DESCRIPTION
                        "Transmission noisy only when moving, in all gears. "
            QUESTIONS
                        Question9 : "Yes"

```
        ACTIONS
                Action8
END CASE

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"
        Question43 : "No"   (SCORING : -)
        Question4 : "Yes"
        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 : -)
        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
                    Question55 : "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
                "Distributer 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 : -)
```

```
                Question62 : "No"          (SCORING : -)
                Question63 : "No"          (SCORING : -)
                Question64 : "No"          (SCORING : +)
        ACTIONS
                Action55
END CASE

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 : +)
        ACTIONS
                Action54
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 : +)
        ACTIONS
                Action56
END CASE

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

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 distributer 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 : -)
        Question73 : "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"
        Question78 : "Yes"   (SCORING : +)
    ACTIONS
        Action67
END CASE

BEGIN CASE Case69
    TITLE
        "Loose wheel nuts."
    DESCRIPTION
        "Knock or clunk noise"
    QUESTIONS
        Question75 : "Yes"
        Question77 : "Yes"   (SCORING : +)

```
        ACTIONS
                Action68
END CASE


BEGIN CASE Case70
        TITLE
                "Shock absorbers worn"
        DESCRIPTION
                "Excessive bouncing and pitching"
        QUESTIONS
                Question79 : "Yes"        (SCORING : -)
                Question80 : "Yes"
        ACTIONS
                Action69
END CASE


BEGIN CASE Case71
        TITLE
                "Shock absorber mounting bushes worn."
        DESCRIPTION
                "Click cluck noise"
        QUESTIONS
                Question81 : "Yes"
                Question82 : "Yes"        (SCORING : +)
        ACTIONS
                Action70
END CASE


BEGIN CASE Case72
        TITLE
                "Springs weak."
        DESCRIPTION
                "Excessive bouncing or pitching"
        QUESTIONS
                Question79 : "Yes"        (SCORING : -)
                Question80 : "No"         (SCORING : -)
        ACTIONS
                Action71
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 : +)
        ACTIONS
                Action76
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
```

Question87 : "Yes"
                Question91 : "Upper wishbone..." (SCORING : +)
                        (FULL : "Upper wishbone mounting bushes")
        ACTIONS
                Action80
END CASE

BEGIN CASE Case82
        TITLE
                "Worn anti-roll bar mountings."
        DESCRIPTION
                "Excessive pitching and rolling."
        QUESTIONS
                Question79 : "Yes"
                Question92 : "Worn anti-roll bar..."   (SCORING : +)
                        (FULL : "Worn anti-roll bar mountings")
        ACTIONS
                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")
        ACTIONS
                Action82
END CASE

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

Action102
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."
```

```
        QUESTIONS
                Question118 : "Yes"        (SCORING : -)
                Question120 : "Yes"        (SCORING : +-)
        ACTIONS
                Action111
END CASE

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

```
        ANSWERS
                TYPE : YES_OR_NO
END QUESTION

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

```
        MISMATCH : 100
ANSWERS
        TYPE : YES_OR_NO
END QUESTION

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 angel 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 temprature 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 owners 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."
```

```
        WEIGHT
                MATCH : 10
                MISMATCH : 5
        ANSWERS
                TYPE : TEXT
END QUESTION

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
        MISMATCH : 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 licince
number plate is secured to the lid. "
    WEIGHT
        MATCH : 10
        MISMATCH : 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
        MISMATCH : 5
    ANSWERS
        TYPE : YES_OR_NO
END QUESTION

BEGIN QUESTION Question36
    TITLE
        "Are any lights inoperative ?"
    TEXT
        " "
    WEIGHT
        MATCH : 10
        MISMATCH : 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

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

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 windscreen 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 owners 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

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

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 their 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

MISMATCH : 5
  ANSWERS
    TYPE : YES_OR_NO
END QUESTION

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 pistonring."
  WEIGHT
    MATCH : 10
    MISMATCH : 5
  ANSWERS

```
                TYPE : LIST
                LIST : "Tapping noise" "Tickling noise"
END QUESTION

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 distributer cap ?"
        TEXT
                "Remove the distributer cap and look for condensation in the distributer 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 proof that voltage is present."
        WEIGHT
                MATCH : 10
                MISMATCH : 5
        ANSWERS
                TYPE : YES_OR_NO
```

END QUESTION

BEGIN QUESTION Question60
      TITLE
           "Is voltage reaching the distributer ?"
      TEXT
           "Take off the high tension lead from the center of the distributer 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 distributer 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

MISMATCH : 5
        ANSWERS
                TYPE : YES_OR_NO
END QUESTION

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

TITLE
                "Is there any tracking on the distributer cap ?"
        TEXT
                "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."
        WEIGHT
                MATCH : 10
                MISMATCH : 5
        ANSWERS
                TYPE : YES_OR_NO
END QUESTION

BEGIN QUESTION Question68
        TITLE
                "What do the spark plugs look like ?"
        TEXT
                "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."
        WEIGHT
                MATCH : 10   ·
                MISMATCH : 5
        ANSWERS
                TYPE : LIST
                LIST : "Grey-brown deposits" "Dry, black, sooty deposits " "Wet, oily deposits"
"Electrodes glazed with core nose white - few deposits" "Electrodes burned away; core nose burned,
glazed" "Split core nose"
END QUESTION

BEGIN QUESTION Question69
        TITLE
                "Does the vehicle vibrate ?"
        WEIGHT
                MATCH : 10
                MISMATCH : 5
        ANSWERS
                TYPE : YES_OR_NO
END QUESTION

BEGIN QUESTION Question70
        TITLE
                "Are any of the wheels out of balance ?"
        TEXT
                "The wheels will have to be tested on a balance machine."
        WEIGHT
                MATCH : 10
                MISMATCH : 5
        ANSWERS
                TYPE : YES_OR_NO

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

TYPE : YES_OR_NO
END QUESTION

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

```
        ANSWERS
                TYPE : YES_OR_NO
END QUESTION


BEGIN QUESTION Question98
        TITLE
                "Does the brake pedal judder when braking ?"
        WEIGHT
                MATCH : 10
                MISMATCH : 5
        ANSWERS
                TYPE : YES_OR_NO
END QUESTION


BEGIN QUESTION Question99
        TITLE
                "Are any of the brake calipers retaining bolts loose ?"
        WEIGHT
                MATCH : 10
                MISMATCH : 5
        ANSWERS
                TYPE : YES_OR_NO
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
        ANSWERS
                TYPE : LIST
                LIST : "Worn brake pads" "Worn brake pads and brake disc."
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
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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

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"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
            LIST : "No malfunction." "Clutch judder." "Clutch drag." "Clutch slip." "Clutch squeal."
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 distributer. 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 a 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 ?"
        TEXT
                    "Check for any fuel leakage from the carburetor while the throttle is operated."
        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

MISMATCH : 5
          ANSWERS
                    TYPE : YES_OR_NO
END QUESTION

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

Actions Printout

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."

END ACTION

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 detentes 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 angel which causes wear. If the teeth have already been wear 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 striped 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

TITLE

"The fuel octane rating is too low."

TEXT

"Use fuel with a higher octane rating"

END ACTION

BEGIN ACTION Action38

TITLE

"Incorrect gearshift lever plate adjustment."

TEXT

"Slacken the two retaining bolts or screws, align the four holes then tighten the bolts or screws."

END ACTION

BEGIN ACTION Action39

TITLE

"The cylinder compressions are too low"

TEXT

"The engine will have to be striped for detailed inspection."

END ACTION

BEGIN ACTION Action40

TITLE

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

TEXT

"Secure the intake manifold"

END ACTION

BEGIN ACTION Action41

TITLE

"The crankcase ventilation hoses are loose."

TEXT

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

END ACTION

BEGIN ACTION Action42

TITLE

"Uneven cylinder pressure causes engine to misfire or/and idle erratically"

TEXT

"The engine will have to be removed for detailed inspection"

END ACTION

BEGIN ACTION Action43

TITLE

"The fault can be any of: worn pistons, worn cylinder bores, or worn pistonrings"

TEXT

"The engine will have to be removed and striped for detailed inspection."

END ACTION

BEGIN ACTION Action44
        TITLE
                "A piston ring is most probably broken."
        TEXT
                "The engine will have to be striped for detailed inspection."
END ACTION

BEGIN ACTION Action45
        TITLE
                "The valve gear are most probably worn."
        TEXT
                "The engine will have to be striped 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 striped 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 distributer."
                TEXT   .
                        "Replace the wire between the coil and distributer."
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 distributer cap."
                TEXT
                        "The tracking lines are paths which conduct electricity across the gap thus letting it
run to earth. Replace the distributer 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 balljoints are worn."
        TEXT
                "Replace balljoints."
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 striped 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 free play. "
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 striped for detail inspection."
END ACTION


BEGIN ACTION Action111
        TITLE
                "The air cleaner is chocked."
        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
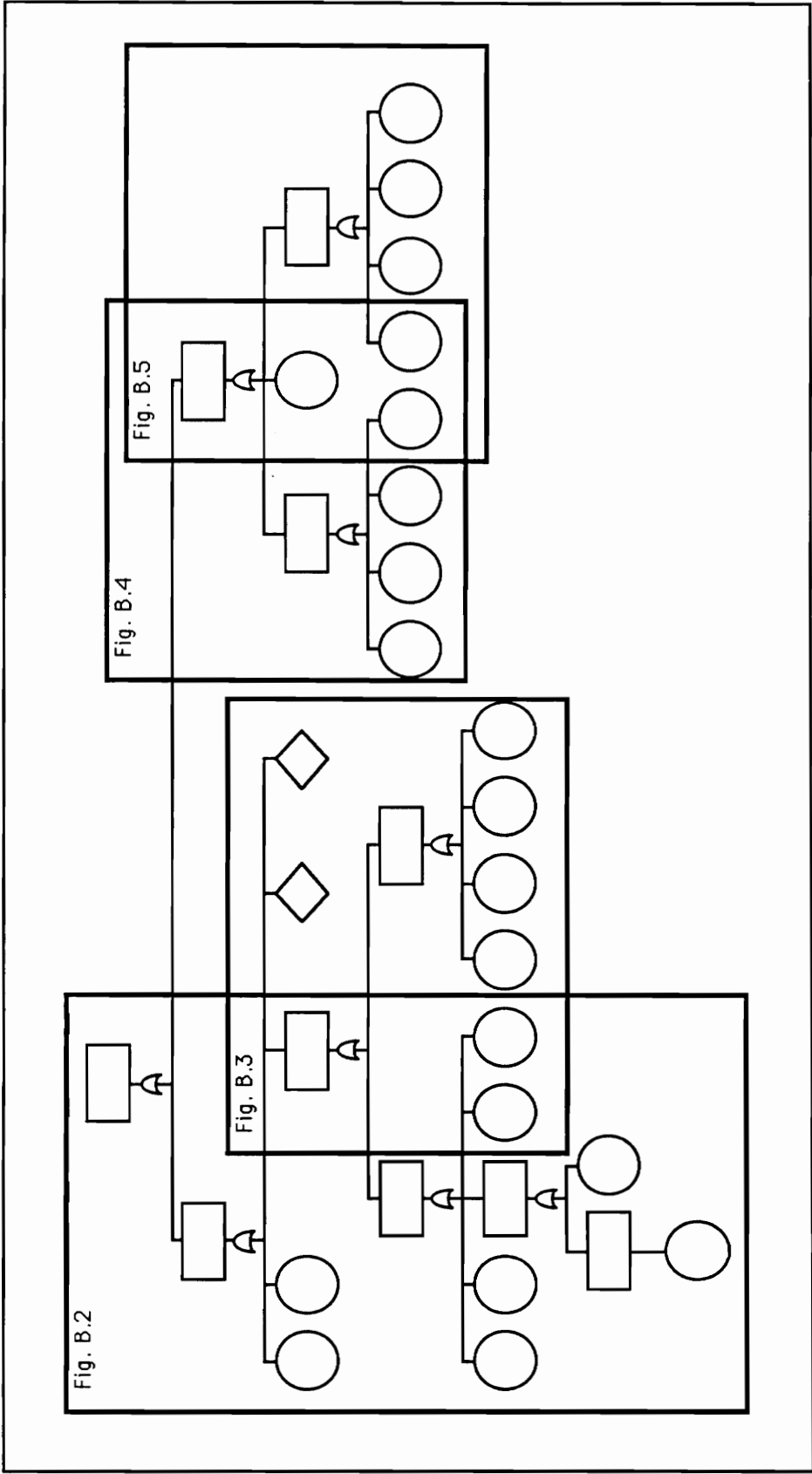
Figure B.1. Figure outlay of Fault Tree Analysis
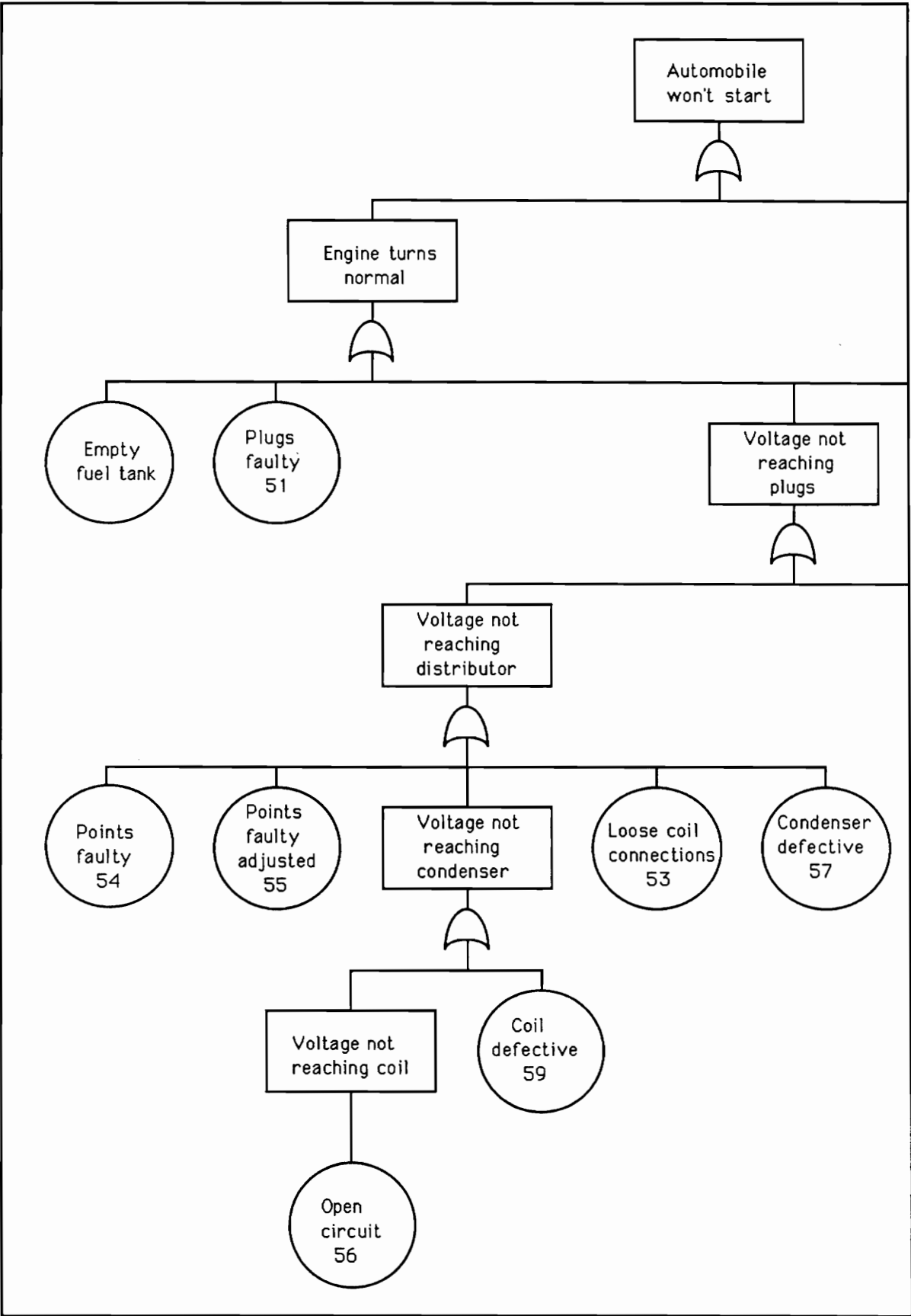
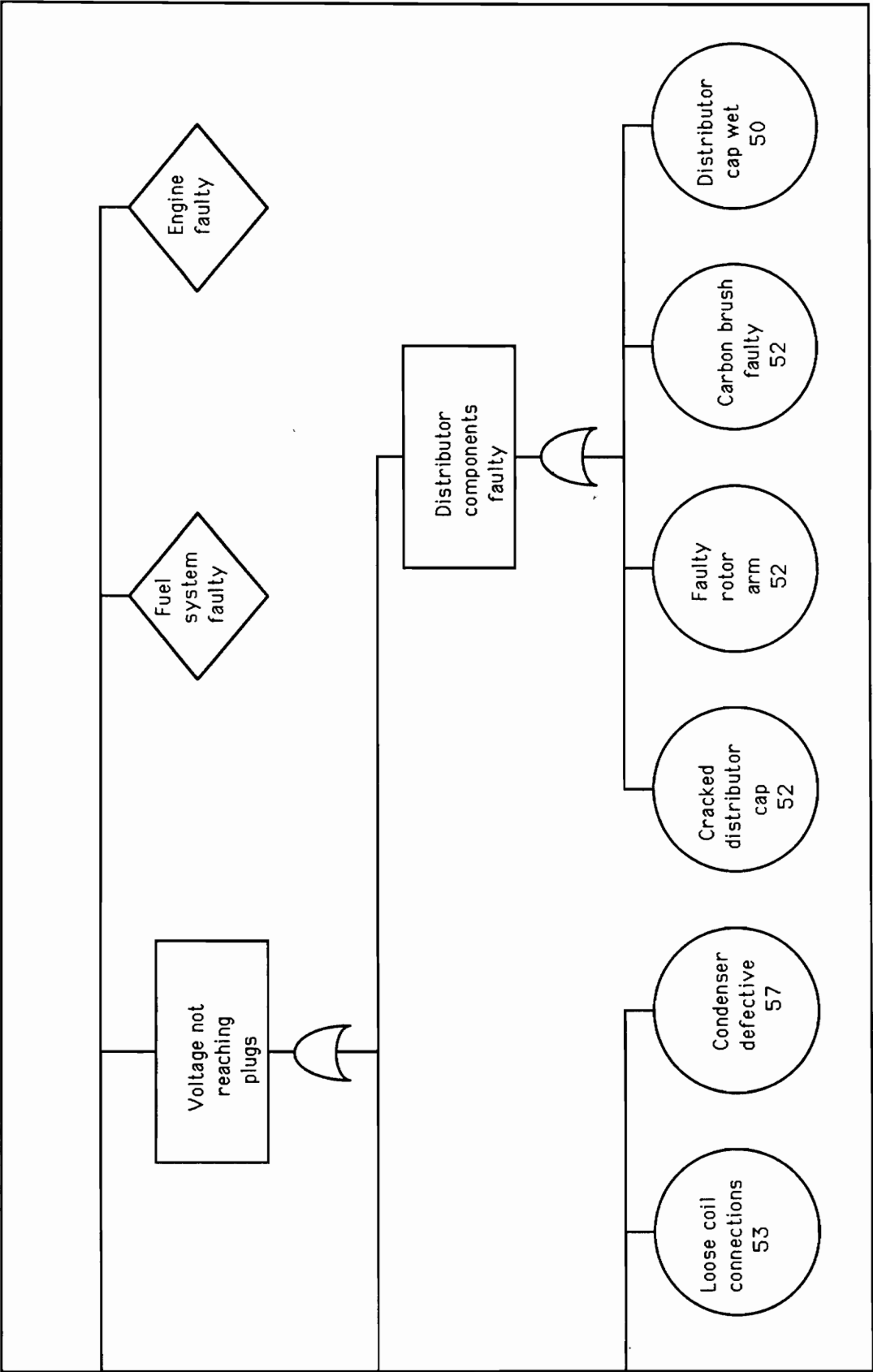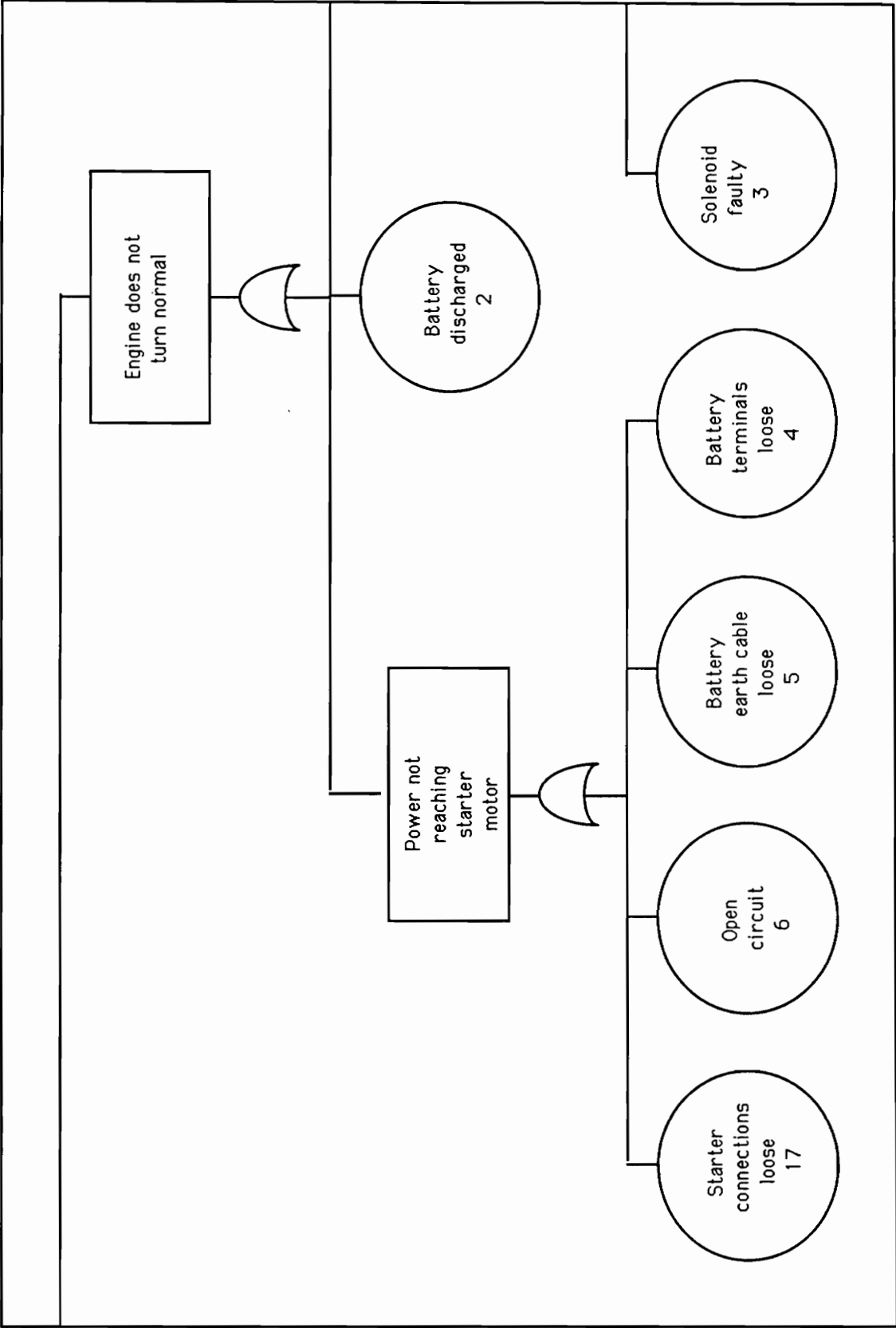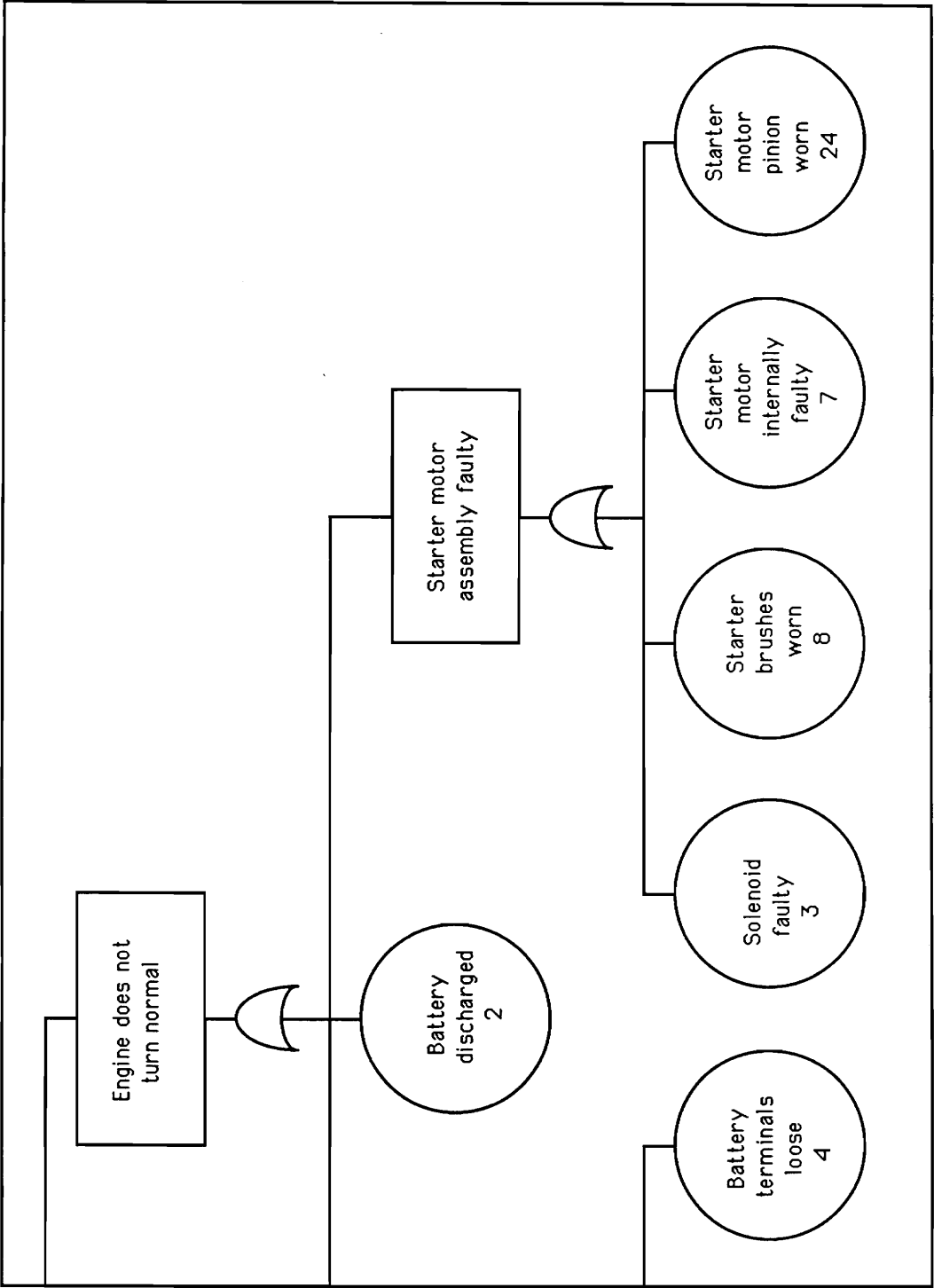Figure B.2 Fault Tree Analysis

Figure B.3 Fault Tree Analysis

Figure B.4 Fault Tree analysis

Figure B.5 Fault Tree Analysis