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(APPENDICES)

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M CRAIG

Factors that inluence the receptivity to fault diagnostic learning when a systems approach is applied. A technology transfer study.

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APPENDIX C

Module 1 Listening and Questioning.
Module 2 Strategies.
Module 3 Systems Thinking.
Module 4 Fault Diagnostic Recording.
Module 5 Costing.

There is a Module 6 on managing the training function which is not directly relevant to fault diagnosis; this is available as a separate module.

Training
in
Fault Diagnosis

A Systems Approach

Module 1

Listening and Questioning

Malcolm Craig.
1991.

INTRODUCTION TO MODULE ONE : LISTENING AND QUESTIONING

This module is in two parts:

Part One	Listening
Part Two	Questioning

The two parts of the module are closely linked. Each part of the module is divided into five sections (A–E) of learning text.

CONTENTS – PART ONE

PART ONE

LISTENING

HOW TO USE PART ONE

LAYOUT

There are five main sections of learning text.

Each section begins with the statements:

- who it is for
- what you will need to have with you
- an estimate of the time you will need to allow
- aims of the section
- objectives of the section

Each section follows a format of:

- theory
- practical
- reflection
- self-report evaluation of the aims and objectives.

The practical exercises have been designed for use on a conventional training course, ideally in-house on company premises. Alternatively, it is possible for you to work through the material yourself by taking note of how to do this in the text, and by making use of the audio-taped materials.

Most benefit is to be gained by working through the text in the company of others. Therefore, if you are unable to make use of a formal course setting, it is recommended that you find at least one other person who will work through the material with you.

SELF-ASSESSMENT

At the beginning of Section C you are asked to do a listening exercise. You are asked to repeat the exercise at the end of Part One. This exercise is designed to provide a before-and-after measure of your listening.

The exercise and the control material for the exercise are in the Tutor Manual which accompanies this module.

PART ONE SECTION A : SELF-DIAGNOSTIC QUESTIONS

WHO SHOULD WORK THROUGH THIS SECTION?

Anyone who works directly or indirectly in places where troubleshooting is carried out. For example:

- troubleshooters
- operators of equipment
- managers, supervisors
- medical practitioners.

WHAT YOU WILL NEED

- a notebook and a pencil
- access to at least two other people.

HOW MUCH TIME?

You will need to allow between 10 and 15 minutes to complete the diagnostic section.

AIMS OF THIS SECTION

The aims of this section are:

- to encourage you to think about listening if you have not done so already

- to give you a starting point; a measure of level of awareness and knowledge about listening before you begin working on the module.

OBJECTIVES OF THIS SECTION

At the end of this section, you should be able to:

- list at least ten points which are recognised as important to the skill of listening
- describe the differences between listening and hearing.

When you have completed this self-diagnostic exercise, check against the model answers. Model answers to these questions are on page 39.

QUESTION 1

What do you know about listening?

List anything you can think of that could be important to listening.

....

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QUESTION 2

What are the differences between 'hearing' and 'listening'?

Note down brief points about any differences you can think of.

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QUESTION 3

Some people say that listening is a natural activity, similar to smelling. What do you think?

Note down whether you agree or disagree with this view and try to give reasons.

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QUESTION 4

Non-verbal behaviour, like raising your eyebrows, is said to be part of our listening skill. Can you think of any examples of non-verbal behaviour which could be important to listening?

List examples of this kind of behaviour that you see as important to listening.

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QUESTION 5

How do we know the difference between someone who has listened well and someone who simply has a good memory?

Not an easy question but one that is worth thinking about at this stage. Note down any thoughts you have about this.

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QUESTION 6

How many reasons can you think of for saying that listening is crucial for anyone working either directly or indirectly with troubleshooting?

Make a list of any reasons you can think of.

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QUESTION 7

How 'good' a listener are you?

Rate yourself on the scale below for home and at work.

	Excellent	Very Good	Good	Fair	Poor	Awful
AT HOME	......	......	.....	.....	.....	.....
AT WORK	......	......	.....	.....	.....	.....

QUESTION 8

How 'good' at listening are people you know?

Rate three people whom you know well on the scale below.

Names	Excellent	Very Good	Good	Fair	Poor	Awful
....	......	......	.....	.....	.....	.....
....	......	......	.....	.....	.....	.....
....	......	......	.....	.....	.....	.....

(Later, ask them to judge themselves on this scale.)

It is a good idea to come back to questions seven and eight after you have completed Part One of this Module, to see if:

(a) you would change the ratings
(b) you have changed the standards you have used to make the ratings.

Finally, ask family and colleagues to rate you on this six-point scale and see how the results compare with your own judgement.

QUESTION 9

How do you approach listening?

		Frequently	Often	Usually	Almost Never	Never
(a)	I am put off listening by accent or speech that is too quiet.	1	2	3	4	5
(b)	When someone has given me information. I summarise what I have understood them to have said.	5	4	3	2	1
(c)	I get on with the job as soon as possible while the problem is explained to me.	1	2	3	5	4
(d)	I use face-to-face, eye-to-eye contact while listening for information.	4	5	3	2	1
(e)	I allow silence of up to 30 seconds if the other person is considering what to say.	5	4	3	2	1

(f)	I ask questions while the other person gives me information.	1	2	5	2	1
(g)	When the speaker has finished I ask for any other information.	5	4	3	2	1
(h)	I ask for words or sentences to be repeated if they are not clear to me.	5	4	3	2	1

THE MEASURE

If you have scored between 30 and 40 your approach to listening is quite good.
If your score is between 10 and 25 you have some work to do on your general approach.

CONCLUSION

Now that you have completed these self-diagnostic questions, it is worth going over them again quickly to see if you can add anything more to your answers.

When you are satisfied that you have done all that you can do, it is a good idea to compare your results with one or more persons who have also completed this section. If you cannot do this, go through the section with one other person to share ideas.

Now turn to pages 39–41 where 'model' answers are listed.

Do not be put off if you found answering these self-diagnostic questions difficult; it is not a test. They are designed simply to give you a baseline from which to start the module. It is more surprising if you did very well on these questions because we are rarely taught the vital skill of listening.

PART ONE SECTION B : FACTS WORTH KNOWING ABOUT LISTENING

WHO SHOULD WORK THROUGH THIS SECTION?

- troubleshooters
- operators/users of equipment
- managers/supervisors
- medical practitioners
- process/production engineers
- stores personnel.

WHAT YOU WILL NEED

- A quiet period to ponder.

HOW MUCH TIME?

- You will need to allow about 15 minutes to absorb this section.

AIM OF THIS SECTION

The aim of this section is:

- to present facts about listening in a concise way.

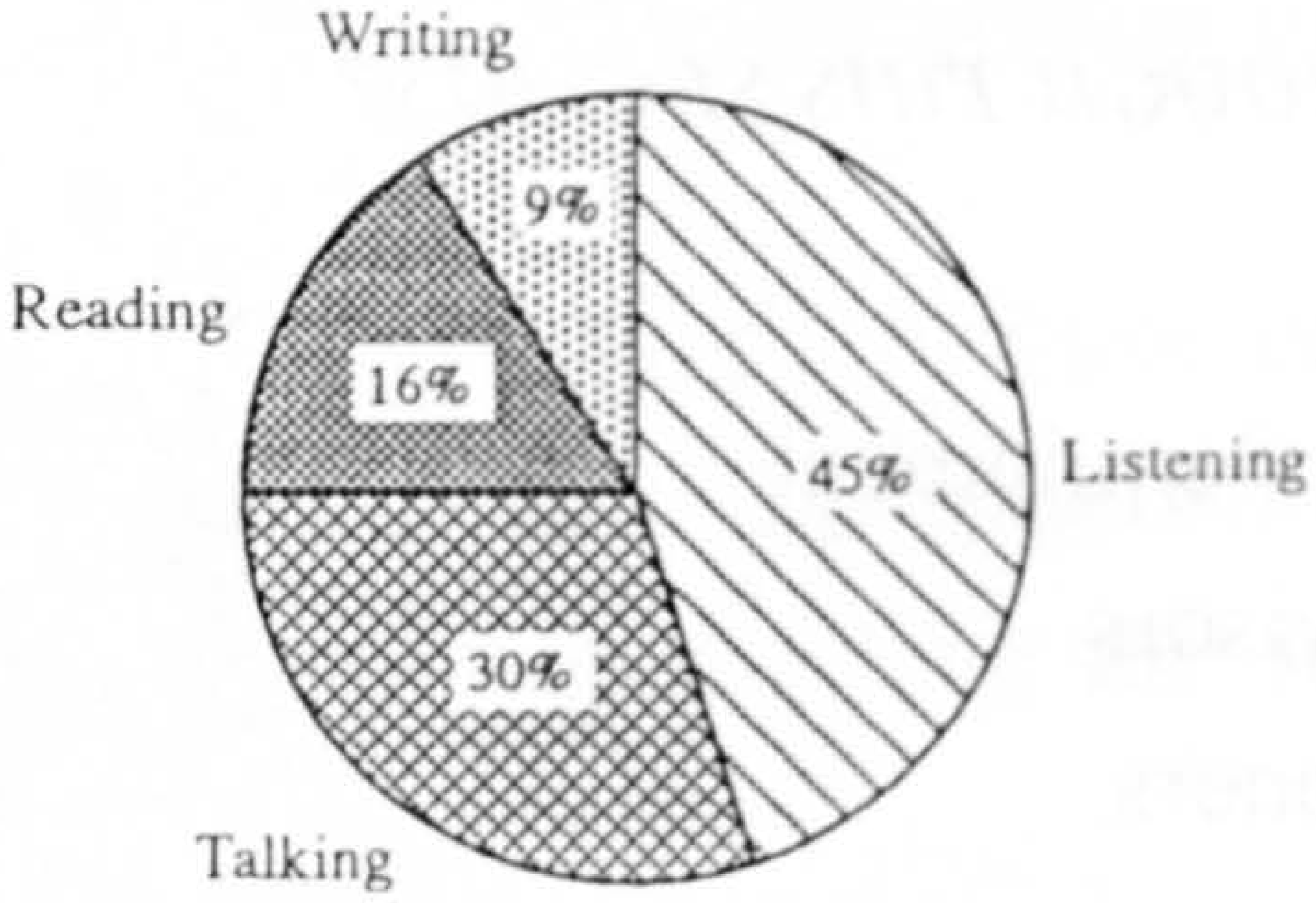
OBJECTIVE OF THIS SECTION

At the end of this section you should be able to:

- state at least ten reasons why listening is a skill worth improving.

CONSIDER THE FOLLOWING STATEMENTS ABOUT LISTENING

1. "Listening is our most used verbal activity" (Paul Rankin, Ohio State University, 1928).



2. Listening is the least taught verbal activity; in schools and colleges in the United Kingdom it is almost zero; this is not so in the United States of America.

3. Listening is the main channel through which we learn.

4. Listening skill level has been linked to a number of major disasters, including the Charge of the Light Brigade. In the worst ever aviation disaster, when 583 people died, the major cause was given as poor listening.

5. Listening is a very selective activity; we listen for what we want to hear.

6. Listening is thought, by most people, to be passive behaviour like meekness and quietness. Talking, on the other hand, is seen as influencing behaviour associated with strength and power.

7. Listening, to be effective, must be active behaviour; it must be obvious to others that you are listening.

8. Listening takes place in the hearing space around you, and between your ears. (Hearing takes place only in the ears.)

9. Listening is a learned activity.

10. Listening performance can be improved.

11. We talk at around 200 words per minute, we can think at between 300 and 500 words per minute; when listening we outpace the speaker. This is a problem to be overcome.

CONCLUSION

Do not try to memorise these statements. It is better if you turn this short section into an activity in one of two ways.

ACTION

1. Read through each statement on page 12 (with one or two other people, if possible) and consider whether or not you agree with the statements.

2. Do this activity alone. Take each statement and briefly note down your ideas about it, with any examples that could serve as illustrations. Use the space below to do this.

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PART ONE SECTION C : WHAT YOU LISTEN FOR

WHO SHOULD WORK THROUGH THIS SECTION?

- troubleshooters
- operators/users of equipment
- process/production engineers
- medical practitioners.

WHAT YOU WILL NEED

- time and use of facilities in your own workplace
- notebook and pencil
- tape recorder/player.

HOW MUCH TIME?

You will need to allow between 35 and 45 minutes to work through this section.

AIMS OF THIS SECTION

The aims of this section are:

- to emphasise how, in listening, we select what we want to hear
- to provide practical exercises in the use of listening skills.

OBJECTIVES OF THIS SECTION

At the end of this section you should be able to:

- get a before-and-after measure of listening effectiveness
- practise active listening as related to troubleshooting activities.

SIX MAIN REASONS FOR LISTENING

When working at any job that involves fault-finding and diagnosis, there are six main reasons why practitioners need to learn and/or improve listening skills.

(1) **To check out the familiar running/behaviour of machines, equipment or processes and to listen for differences.**

To know when something sounds wrong, you first of all need to know what it sounds like when it is working correctly.

In the case of medical practitioners, it is the human body that one is listening to.

(2) **To collect information from users; that is, operators, customers, patients, etc.**

In order to listen well you have to use encouraging non-verbal behaviour, to ask questions at the right time, to summarise what was said, and to make clear to the speaker that you understand the problem before you take action.

(3) **To share information with your colleagues.**

To listen well here is to overcome the "I've heard it all before" attitude. You have to be an 'ear' for what may be a serious problem for your colleague, even though it may not be a problem for you.

(4) **To gather information about other parts of the process which could be affecting the results of your work.**

To listen well here you need to use all your listening skills to cope with jargon or other unfamiliar wording used in other areas. In addition, you may have to ask questions until you understand.

(5) **To listen for detail; that is times, how often, how noisy, etc.**

To listen well here you need practice in listening for facts, homing in on key words and measures. Note taking is also part of the listening process here. (The shortest pencil is superior to the longest memory.)

(6) **To listen sympathetically, that is listening carefully to the customer or operator who is 'tired' of trying to get it fixed.**

To listen well here is to demonstrate interest by the use of active listening; listening to accounts of 'what happened last time', asking for more information, checking out detail.

Often a customer is heard to say "at least someone listened to me this time". Of course, effective action is also needed to back up effective listening.

PRACTICAL EXERCISES

Each of the six practical exercises which follow has been designed to help you develop your listening skills.

Exercise One – Familiar Situations

Summary of the theory

One major problem for listeners is that it is too easy to hear what we either want to hear or expect to hear. The result is that our listening becomes very selective; we choose bits of information or bits of sound.

Practical

For this practical you will need to work alongside a colleague or other course member.

Ideally, go into a familiar location at your workplace, and either stand or sit not more than 1 metre apart from each other. Both must remain silent for five minutes, and during this time both of you will take notes of all that you can hear.

Note: If you cannot use such an area, you can both go to another place where you can listen for sounds: the street, station, shopping precinct, etc.

Reflection (1)

The result of this five minute exercise can be handled in two ways.

(i) Present your results on a flip chart to the group, if this is done as part of a course.

(ii) Discuss the results with your partner alone.

Whichever method is used the aim is to compare the two sets of results. To what extent are they the same? How are they different?

Reflection (2)

The lesson to be learned is that in many cases there can be two troubleshooters at the scene of a problem, and each one is acting on different information because their listening was different.

By practising effective active listening these differences can be reduced.

Exercise Two – Listening to the other person

Summary of the theory

This exercise concerns the listening we do when face-to-face with another person: customer or operator. Here we do not only hear what is said but we must take account of how it is said, from voice tone and general body movements.

Practical

One person must act as the customer or operator who is reporting a fault. To do this a script will be used from the Tutor Manual which accompanies this Module.

Alternatively, listen to the tape, Side A, (script 1).

You may take notes while you listen to what is said.

Listen to the script once only.

After the script, make notes about important points and number them in order of importance as you see them, and finally summarise the problem in a few words.

If you do this as part of a course, make full use of the session by comparing results. Do some people extract more detail? More meaning?

If you are doing this alone, run through the taped script again to check the effectiveness of your listening. What kind of information, if any, was missing: facts, measures, feelings? Are you inclined to miss one type of information rather than another?

Reflection

We will reflect on the first two exercises. One difficulty in listening is that we are often taking in different types of information which are not always given in a logical order, i.e. the customer, operator or troubleshooter who rambles.

BECAUSE SOMEONE IS DIFFICULT TO LISTEN TO, IT IS NO EXCUSE FOR NOT LISTENING. WE NEED TO WORK HARDER AT ACTIVE LISTENING.

The next exercises should help you to appreciate this problem and move a step closer to effective listening.

Exercise Four – Listening to Colleagues

Summary of the theory

Effective listening in this situation is of enormous benefit to you, your colleagues and your organisation.

How often have you heard comments such as:

> "The senior managers never listen in this place"
> "The boss never listens to me"
> "Nobody listens around here"
> "No point in telling maintenance, they don't listen"

Possibly the biggest block to effective listening here is the belief that "I've heard it all before".

Even if you have heard it all before, or think you have, **your duty to colleagues is to listen well if they are taking time and effort to talk with you.**

YOU NEVER KNOW WHAT YOU MAY LEARN IF YOU REALLY LISTEN.

Practical – Listening to Colleagues (a)

Grab a colleague who is either a troubleshooter or a user of equipment, and get him or her talking by following the questions laid out below.

Q1. "Tell me, what would you say was the most difficult part of your troubleshooting work?"

Remember non-verbal behaviour. Allow time to answer, up to 30 seconds

Exercise Three – Specific Listening

Summary of the theory

The idea here is that we can improve our listening skill by, first of all, practising listening for specific facts, ideas, feelings, measures, etc; then putting them together. This helps to emphasise what it really means 'to be listening'.

Practical

Listen to script 2, either spoken by someone in your group or on the tape (Side A).

One person listens for measures, one for facts, one for reasons, one for ideas.

Make notes either as you listen or at the end of the script, then put your results together. The outcome should be a good report of the problem. However, the purpose of this exercise is not to introduce a labour-intensive means of gathering information but to give you practice in listening for specific items. This is not the same as hearing what we want to hear unconsciously. This time we have made a conscious effort to listen for specific items.

The effective, active listener does this for each specific item, but combines them all together no matter how varied the kinds of information.

If you are alone, practise listening for different bits of information by replaying the tape, then listen for the entire information.

Reflection

This concentration on listening for specific facts, ideas, sounds, etc. is recommended as a means of making you a more conscious, active listener. You need to start combining the items as soon as you can.

if necessary. (This is longer than you think when questioning.) Do not jump in if you do not get an immediate reply. This is a vital listening lesson.

Q2. Given that you have been given an answer, say:

"Right, ********* is the most difficult. Can you tell me more about this?"

Now begin to use Active Listening:

- Look at the person eye-to-eye, not at the wall, your feet, or notebook. Maintain actual eye-to-eye contact around 30% of listening time.

- Use encouraging noises, verbal and non-verbal, e.g. "yes", "I see", "mmm", "ah" and so on.

- Keep the information coming by the use of active listening, rather than the use of too many new questions by using:

"Tell me more"
"Then?"
"Yes" or 'Yes?"
"You say 'frequent jamming'? "
"What else can you tell me about feedback?" and so on.

Do **not** say 'Is there anthing else?" or words to this effect. This is an open invitation to block the flow of information.

ACTIVE LISTENING DOES AS MUCH, AND AT TIMES MORE, THAN QUESTIONING IN GETTING THE INFORMATION YOU NEED.

When you have practised active listening like this with a colleague for at least five minutes and not more than ten minutes, discuss with your colleague how much active listening goes on in your department.

Practical – Listening to Colleagues (b)

For the second part of this exercise, do what you did in part (a) but this time use a more natural situation. To do this, say to yourself: "The next time a colleague comes to talk over something about the job or to tell me something, I'm going to use active listening, 'pull out all the stops'. When he or she has gone, I'm going to check out how much more I got from the exercise".

Reflection

A point worth making at this stage is that it is possible to fake 'good' listening as far as outward appearance is concerned. If you are not in the habit of doing this you may like to try it. Use the outward verbal and non-verbal signs of effective active listening, but at the same time think about a totally different topic. You will be hearing the other person but not listening. How convincing can you be?

If you are familiar and experienced with this practice you are a bad listener.

Exercise Five – Unfamiliar Situations

Summary of the theory

When taking a sytems approach to fault-finding and diagnosis, it is necessary to talk and listen with people who work beyond the boundaries of your immediate work and concerns. For example, if you are an electronics troubleshooter this could be:

- buyers, stores personnel
- designers of equipment and/or process
- inward goods inspection
- production managers and supervisors.

Have you come across unfamiliar words and phrases, and often unfamiliar ways of looking at the purpose of the job?

The key to effective active listening in this situation is the use of **prompt** and **checking questions**, either while the person is speaking if he or she is happy with interruptions, or as soon as it is your turn to speak.

For example:

- Will you explain that a bit more?
- DOT? What does that stand for?
- Feed forward? What is that?
- I've not come across that term; what does it mean?

Do **not** say: "Can you repeat that in plain English?" There are more subtle and more effective ways of getting clarity.

This again is part of Active Listening.

BEING FULLY PREPARED TO ADMIT IGNORANCE IS AN ESSENTIAL BEHAVIOUR FOR EFFECTIVE ACTIVE LISTENING.

Practical

For this exercise you need the help of someone who does a completely different job from your own. If you are on a course there may be such a person amongst the course members.

As with the previous exercise, do this one first by using the questioning method below, and then by using a more natural situation.

Q1 "Tell me about what you consider to be the most critical part of your work."

As before, allow silence if necessary.

Now use Active Listening with the addition of prompts and checks to clear up any misunderstanding. Examples:

"Can you explain that?"
"AT?" (Use only tone of voice to get what you want here.)

Q2, Q3 ... Use new questions sparingly, only if the other person has dried up.

Pick on a key word he or she has said and say (for example) "Control? Can you say a bit more about how you do that?"

Notes on non-verbal behaviour. In this situation the other person will often look elsewhere while thinking about their work; he or she dictates the amount of eye contact. As the listener you should be ready to match the eye-to-eye contact whenever the other person chooses to look at you.

Distance apart ('personal space' in jargon). Is this the same as it would be with a colleague you work with? Does it matter? Think about this now.

Repeat this exercise, but this time choose a natural situation when someone from a different area of work comes up to talk with you.

Reflection

A key sign of an effective listener is the trouble taken to listen for and 'learn' the other person's name when being introduced for the first time. In making useful contacts across departmental boundaries this is vital. What do you do if the other person mumbles his or her name, or it is not heard properly? Good listeners say "Sorry, I didn't get your name", or words to this effect. If, soon afterwards, the name has gone out of short-term memory, the good listener will do a quick check.

Do some people have better memories than others, or are they better listeners?

Exercise Six – Listening sympathetically

Summary of the Theory

The key to effective listening in this situation is to make time for quiet Active Listening. What is meant by this is **the skill of using non-verbal behaviour to show that you are listening.** Listen to the 'case' being made; the meaning of what is being said. Questioning should be rarely used while the person is speaking, ("Listen, will you, hear me out"). This means that you must listen well, so that you can summarise back to the other person your understanding of the situation.

Troubleshooters who must provide a service to customers/clients need to practise this type of listening.

Essential points are:

- time must be given for this type of listening
- it cannot be done properly if attempted while doing another task
- questioning must be zero, if possible, while the person is speaking
- encouraging non-verbal behaviour is used in place of questioning
- summarising to show the listener has understood is essential feedback to the speaker in this situation
- only after summarising is it wise to ask any questions which are needed to clarify the points made.

There is a true story about a dentist who, from time to time, broke clients' jaws. Yet invariably the injured people went back for regular d[illegible]atment. As a dentist he listened to them and discussed each case as though it was unique. It was this approach that made people return.

Listening is a much undervalued skill in terms of providing a service to customers. With the above points adequately covered, most customers would feel well satisfied that notice had been taken of their circumstances. The follow-up action necessary to correct the situation must be seen as complementary to good listening.

Practical (a)

To do this exercise use the script provided in the Tutor Manual, script 3, or use the taped version if you are doing this alone.

If in a group, you must have one person to play the role of the concerned customer, while others act as service providers and, it is hoped, as active listeners.

At the end of the reading the concerned customer must summarise on a sheet of paper what his or her main concerns are, in no more than a dozen lines, without the others seeing the result.

At the same time, the others in the group will also summarise what they understand the concerns to be, after listening to what the customer had to say.

Outcome

It is not possible to pre-judge the actual outcome of such an exercise here but it is quite possible that differences of interpretation will be given, for example:

(a) strong agreement in the group and with customer
(b) strong agreement in the group but not with customer
(c) weak agreement in the group but some members agree with the customer.

There is clearly a problem if (b) is the outcome. It may be that the customer is saying one thing but meaning another, or perhaps the listeners are placing interpretations on what they are hearing. In other words, the group may have discerned what they think the 'real' concerns are.

It is for this reason that summarising and feedback to the customer are essential to give the customer the opportunity to say "No, that is not what I meant" or "Yes, that's the problem".

Reflection

The above exercise, more than any other, highlights the difference between hearing on the one hand and listening on the other.

In outcome (b) just discussed, the hearing and memorising of what was said would not have identified the difference between the group and the customer. The customer would have replied "Yes, that is what I said". The need to listen for meaning, just as earlier you listened for special items, is what makes listening such a crucial skill.

Practical (b)

This exercise must be done in a natural situation, when the opportunity arises. Talk with someone whom you have done work for, or provided a service to, using the format laid out below.

Q1. "Tell me, what particularly pleases you about the service you receive?"

Now listen for the reaction. Nothing? Ah, well, you can't win them all.

If you do get a response, use active listening to keep the flow of praise coming.

Note: It is what pleases customers that is the best guide for improving service, not complaints. Be positive.

You can of course try the next question.

Q2. "Tell me, what particularly displeases you about the service you receive?"

Repeat Active Listening as for Question 1.

Reflection

Note on non-verbal behaviour: when you say "Tell me", say this with your arms relaxed, palms open inviting comment, not arms folded across the chest or clasped in a defensive way.

Good listeners typically begin contact in such a way.

PART ONE SECTION D : LISTENING TO YOURSELF

WHO SHOULD WORK THROUGH THIS SECTION?

- troubleshooters
- operators/users of equipment

WHAT YOU WILL NEED

- tape recorder/player

HOW MUCH TIME?

- You will need to allow between 15 and 30 minutes to complete this section.

AIM OF THIS SECTION

The aim of this section is:

- to increase your level of awareness about self-directed listening.

OBJECTIVES OF THIS SECTION

At the end of this section you should be able to:

- make good use of self-directed listening
- question (through Active Listening) your own reasons for using particular methods when fault finding.

SUMMARY OF THE THEORY

Troubleshooters and others who get involved with practical problems often talk to themselves out loud. This only helps if the person concerned can make sense of what he or she is saying.

How well do we listen to ourselves?

For example, an engineer, a nurse or a chemical plant operator will, from time to time, ask themselves "if that ......" type questions. If that temperature goes up when I do this but not if I do this, it means that .... or could it mean ....? I had better get more information. I know! I'll ask about ...... and so on.

It is vital that the troubleshooter listens carefully to his own deliberations. Listening well in this situation means avoiding easy assumptions by stopping to repeat, and asking "But is that so?" It also means listening for words like 'obviously', 'must', 'never', that lead to jumping to conclusions too quickly which can result in a costly faulty diagnosis.

Inner speech works in much the same way. That is, talking through a problem but not out loud. Could we think at all and solve problems without this facility?

We must check with ourselves here too, for example:

- how valid is that statement?
- is that what I really mean?
- can I safely try that out now?
- are you sure that's the reason before you speak?
- I'll go through that possible solution again in my head – listen this time!

PRACTICAL

You need to think first of all about a typical symptom that you can come across in your work, e.g.

- blemishes on a plastic moulding
- decrease in fluid flow
- repeated stabbing pains in the lower back
- hashered wave on an oscilloscope
- packet jamming irregularly on packaging machine.

When you have decided on a symptom, start up the tape recorder and talk through the typical reasoning you use to deal with such a problem. If possible, it is helpful if you can do this at the actual scene of the possible symptom to make the experience as realistic as possible.

When you have done this, play back and listen to your deliberations.

REFLECTION

It is useful if you can have the recording of a colleague talking through the same symptom – from symptom to possible faults, cause and any other observations.

In this situation you can both listen and compare results from listening.

As a result of this exercise, can you see any way to approach the task differently? Although this is the subject for Module Two on Strategy, such an exercise used for listening can help you reflect on how you listen to yourself.

PART ONE SECTION E : LISTENING IN GROUPS

WHO SHOULD WORK THROUGH THIS SECTION?

- troubleshooters
- operators/users of equipment
- process/production engineers
- medical practitioners.

WHAT YOU WILL NEED

You will not need any equipment for this section.

HOW MUCH TIME?

You will need to allow between 15 and 30 minutes to complete this section.

AIMS OF THIS SECTION

The aims of this section are to:

- enable you to relate the skill of listening to group work
- provide you with information about the effects that group work has on listening behaviour.

OBJECTIVES OF THIS SECTION

At the end of this section you should be able to:

- describe the key points about group working which affect listening behaviour.

SUMMARY OF THE THEORY

A common situation for many troubleshooters, operators and their supervisors and managers, is for a group to form around a problem. Typically, one person deals with the first report of a symptom and the solution becomes more difficult to find than was anticipated. The problem then escalates, bringing in one, two, three or more people; each one has a view about that particular problem. How do we use effective Active Listening in this situation?

A major problem here is to create time and space to listen when what you really want to do is either to speak yourself or to get on with the practical job of finding the solution.

Think very carefully about the following statement.

Whenever it is our turn to speak in a group, the chances of using effective Active Listening are almost zero.

Why do you think that this is so?

PRACTICAL (a)

For this exercise you must first of all think about the last time you were a member of a group in which each person had to introduce him or herself to others. You may have done this on a course associated with this training.

Consider how well you listened to the person immediately *before* your turn; probably not very well compared with how you listened to those who spoke *after* it was your turn.

The same can apply to fault-finding by group work. Listening can be difficult to practise.

Realising this, and being fully aware of the problem is a major step towards changing your listening behaviour the next time you find yourself in this situation.

In group fault finding it is essential that one person stands back from the activity to be in a position to step in when he or she judges that progress is not being made. It is at this time that listening must take over. The controller must ask the group to consider what they now know about the problem. Each person must listen actively while each contribution is made. This is the only way to identify what is **not** known about the problem. The aim is to reduce the 'problem space'.

To make active listening work in this situation, it is necessary to overcome our natural tendency to concentrate on what we want to say and ignore or half-listen to what is being said at the time.

PRACTICAL (b)

This exercise must be done in a group. Each member gives a talk to the others for at least 3 minutes and not more than 5 minutes. The order of speakers is organised at the beginning. Ideally, the topic should be about the person's own involvement in fault-finding and diagnosis. The next person to speak is asked to summarise the talk, picking out the main issues.

This person and the group must listen without taking notes.

The tutor will start the process off by giving the first talk.

REFLECTION

The aim of these exercises is to raise the level of awareness about listening in groups, and about one of the major problems, that of listening when we ourselves have something we want to say.

There is no easy means of overcoming this problem, but full awareness about listening in groups is a significant step towards improved group work.

A further point to make is that when someone is either speaking in a group or to a group, a good tip is to look at people who are 'with' you, i.e. the listeners should look interested. Again, as in one-to-one listening, you must show that you are listening as well as actually doing it.

PART ONE : MODEL ANSWERS TO SELF-DIAGNOSTIC QUESTIONS

QUESTION 1

Here is a typical list of points.

(a) Some people are better listeners than others.
(b) 'Interest' and listening are closely linked.
(c) "You never listen" is a common remark.
(d) Listening is a skill.
(e) As a skill it is rarely taught.
(f) It is good when someone really listens to you.
(g) Poor listening has cost lives.
(h) Hearing and listening are not the same.

QUESTION 2

Hearing	**Listening**
(a) A natural activity/function	(a) A learned activity
(b) Passive behaviour	(b) Active behaviour
(c) Happens in the ears	(c) Happens between the ears
(d) Any problems with it are physical	(d) Any problems with it are mental

QUESTION 3

Listening is (or should be) very active behaviour which is not improved naturally or simply by practice or experience. Practice and experience in this case only make it permanent, not necessarily better. Most natural behaviour like smelling, hearing and tasting are difficult to improve in performance; listening on the other hand can be improved significantly.

QUESTION 4

(a) Distance you stand or sit from the person who is speaking.
(b) Amount of time, as percentage of total, you spend looking at the other person face to face.
(c) Amount of encouraging noises (not words) you make: mmm! oh! ah ah! eee! (if you're a Geordie) cor! (if you're a Cockney).
(d) Use of facial expressions: eyebrows up, down, together; lips open, pursed, forward, smiling.
(e) Arms – hidden behind back, folded, relaxed.
(f) Hands – clasped, in pockets, on other person, fidgeting, stroking beard, nose, ears, hair, etc.
(g) Dilating of pupils (no control over this).
(h) Use of silence, allowing other person time to think.

QUESTION 5

The main measure of listening skill use is the understanding of what has been said. Hearing, combined with a good memory, can produce a word-for-word copy of what was said, but this does not necessarily mean that listening has taken place. Listening has taken place when the listener can feed back to the speaker his or her understanding of what was said using his or her own words. A second measure is the number and quality of the questions that the listener can ask, either during the talking if the speaker is happy with this, or at the end of the talking.

QUESTION 6

The gathering of information is crucial to troubleshooting. From people who operate the equipment (listen to them). From people who control processes, i.e. process engineers (listen to them). From the equipment noises (listen to it). From fellow troubleshooters (listen to them). Effective, acute listening is vital but is a much neglected skill in this area of work.

QUESTION 7

At this stage it does not matter **how** you make this judgement; it is sufficient that you think about making it.

Does the situation make any difference to your listening, at home, at work?

When you ask others for their judgement on you, are the results the same as your own judgement?

QUESTION 8

Again, this question simply encourages you to think about listening in another way; how easy is it for you to rate three people? What standards can you use? Are all three the same or is one very much better? If there are differences between the three, what can best account for such differences?

These and other issues around the subject of listening will be taken up in the next section of Part One, under "Checklist of 'Good' and 'Bad' Listening Behaviour".

QUESTION 9

How you approach listening is very important. This is mainly a question of attitude. For example, can your skill as a listener overcome your lack of interest in someone who is, in your view, uninteresting or a poor speaker? You should be able to exercise your listening skill whatever the circumstances; this is vital for people who must fault-find. This short questionnaire provides a basic measure of your general approach as part of this early section designed to diagnose your level of awareness about listening.

PART ONE: CHECKLIST OF 'GOOD' AND 'BAD' LISTENING BEHAVIOUR

TEN POINTS ABOUT GOOD LISTENING

'Good' listeners:

- allow time for others to speak and to think; they allow silence
- use relaxed limb positions; folding, clasping, fidgeting are avoided
- make sure a distance is maintained between self and speaker that is comfortable to the speaker
- use encouraging non-verbal signals, have an open relaxed manner, use facial expressions to show encouragement
- use verbal signals to encourage flow of information, 'Yes', 'I see', 'Then?'
- check out any terms, words, phrases that are unfamiliar: "Please explain", "BOT? What is that? I have not come across that term before ...."
- look at the other person face-to-face and maintain eye-to-eye contact at least 30% of the contact time
- use different listening methods, depending ... whether they are listening for detailed information in groups, alone, sympathetically, in unfamiliar situations, etc.

- check out quickly anything they have missed: word or term, person's name, etc.
- summarise in a few key words what they have understood the speaker to have said.

These ten basic points form the basis of Effective Active Listening (EAL). Each one has been expanded upon in this module.

TEN POINTS ABOUT BAD LISTENING

'Bad' listeners:

- half-listen while thinking of what to say next themselves
- avoid face-to-face contact
- show outward signs of listening when they are not
- are put off listening by speakers' poor delivery or uncertain manner
- think hearing and listening are much the same
- are too eager to make the point and so interrupt the speaker
- are tense, suspicious and/or defensive
- easily forget the other person's name soon after being introduced
- allow words, phrases, etc. to pass unchecked when they do not understand their meaning
- are easily distracted by events around them.

PART ONE: LIST OF USEFUL REFERENCES

Bormann, E G (1969)	*Interpersonal Communication in the Modern Organisation* (Prentice Hall).
Burley-Allen, M (1982)	*Listening, The Forgotten Skill* (Chichester, Wiley).
Fletcher, C (1988)	*Talking and Listening to Patients; The Modern Approach* (Nuffield Provincial Trust, London).
Mackay, I (1984)	*A Guide to Listening* (BACIE, London).
Numrich, C (1987)	*Consider the Issue; Developing Listening and Critical Thinking Skills* (Longman, NewYork).
Steil, L K (1983)	*Listening* (Chichester, Wiley).
Wolff, I F (1983)	*Perceptive Listening* (Holt Rinehart and Wilson, London).

PART TWO

QUESTIONING

CONTENTS – PART TWO

HOW TO USE PART TWO

LAYOUT

There are six main sections.

Each section begins with statements:

- who it is for
- how much time is needed
- what you will need to have with you
- aims of the section
- objectives of the section.

Each section follows the format of:

- statement
- learning test
- examples where appropriate
- activities where appropriate.

USE

Most benefit is to be gained from this material if it can be used as part of a formal training course on listening and questioning for fault finding and diagnosis. If this is not possible, you are encouraged to find at least one other person who can work through this material with you. It can, of course, be read as a normal text book would be read.

PART TWO SECTION A : SELF-DIAGNOSTIC QUESTIONS

WHO SHOULD USE THIS SECTION?

- troubleshooters
- operators/users of equipment
- managers/supervisors

HOW MUCH TIME?

- you will need to allow between 45 and 60 minutes to complete the section.

WHAT YOU WILL NEED

- notebook and pencil
- the cooperation of others.

AIM OF THIS SECTION

The aim of this section is:

- to encourage you to think about the skill of questioning, and in particular the idea that questioning is a skill that can be improved through training.

OBJECTIVES OF THIS SECTION

At the end of this section, you should be able to:

- describe and use different types of questions which are important to the task of fault-finding and diagnosis

- describe and use a sequencing of questions that is appropriate to your own situation

- identify typical errors in questioning which are relevant to fault-finding and diagnosis

- carry out an initial self-assessment of your own questioning skill.

SELF-DIAGNOSTIC QUESTIONS

Before each self-diagnostic question there is a short statement. Please read this before either recording your answer in a notebook or using the space on these pages.

STATEMENT 1

There are different types of questions. For example, people commonly think of questions as being either 'closed' – you can answer only "yes" or "no" – or 'open', in which case you can give longer answers. There are at least thirty types of questions altogether, of which ten are particularly useful to fault-finding and diagnosis.

QUESTION 1

Which types of question, other than open or closed, could be important to fault-finding and diagnosis?

You should be able to think of ten.

....

....

....

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....

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....

STATEMENT 2

Errors can be made when practising the skill of questioning. For example, a quite common error is to ask two or more questions, all rolled into one 'question'. There are at least fifteen typical errors, of which ten are to be avoided when fault-finding and diagnosing.

QUESTION 2

Which typical errors do you think are to be avoided when fault-finding and diagnosing? You should be able to think of ten.

....

....

....

STATEMENT 3

When trying to locate a fault, a person will either question him or herself, or question a person who uses the equipment. The medical practitioner does much the same, although the other person is normally the patient who has a problem rather than a fault. The order or sequence in which these questions are asked is important to fault-finding and diagnosis. This is especially true of the first question to be asked.

QUESTION 3

What would you say is so important about the first question to be asked?

....

....

....

STATEMENT 4

Thinking about the order that questions can follow, it is possible to list at least seven distinct steps that a troubleshooter or equipment operator can go through when locating a fault. At each of these steps there are appropriate questions to be asked.

For example:

STEP ONE	*Place: where does the symptom show?*
STEP TWO	*Description: what does the symptom look/smell/sound like?*
STEP THREE	*When: what time? how often?* *When did you first notice it?*

QUESTION 4

To complete this list, how many other steps can you think of in your own situation?

....

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STATEMENT 5

Asking the right questions at the right time is vital, whether asked of yourself or of others. What is also vital is asking the right number of questions, in the time between first knowing about the problem until eventual diagnosis.

QUESTION 5

What would you say was vital about asking the right number of questions?

....

....

....

STATEMENT 6

In the same way that you were asked to assess yourself on your own ability to listen in Part One of the module, please repeat the exercise here for questioning.

QUESTION 6

How good are you at asking questions?
Rate yourself on the scale below for home and at work.

	Excellent	Very Good	Good	Fair	Poor	Awful
AT HOME	......	......	.....	.....	.....	.....
AT WORK	......	......	.....	.....	.....	.....

STATEMENT SEVEN

Thinking about other people's ability to question makes you consider what measures that you use to judge the use of this skill.

QUESTION SEVEN

In your opinion, how good at questioning are people whom you know well?

Action: Rate three people you know well, on the scale below.

Names	Excellent	Very Good	Good	Fair	Poor	Awful
....	......	......	.....	.....	.....	.....
....	......	......	.....	.....	.....	.....
....	......	......	.....	.....	.....	.....

(If possible, ask them to judge themselves on this scale, and compare their judgement with your own.)

At the end of this module you will be asked to come back to questions 6 and 7 to see if:

(a) you would change the ratings
(b) you have changed the standards you have used to make these ratings.

(If possible, ask family and colleagues to rate you, and make a comparison between your judgement and theirs.)

STATEMENT EIGHT

Your overall approach to the skill of questioning can make a significant difference to how well you gather fault information and, consequently, to the reliability of your results.

Question Eight is on the next page.

QUESTION EIGHT

How well do you approach questioning?

Rate yourself on the scale below by ticking the appropriate place on the scale as honestly as you can.

Statement	Frequently	Often	Usually	Almost Never	Never
(a) I use questions in a step-wise logical order.	5	4	0	1	2
(b) I find trick questions useful if checking on what the other person has done (operator/ user/ trouble-shooter).	0	1	5	4	2
(c) I use easy lead-in questions when dealing with a person new to me.	5	4	0	1	2
(d) I ask lots of questions to make sure I get as much information as possible	0	1	5	4	2
(e) I do a rough plan of the questions I am going to ask.	5	4	0	1	2
(f) My questioning is always different because no two jobs are the same.	0	1	5	4	2
(g) I can accept 'don't know' answers without complaining.	5	4	0		2
(h) I do my job without asking too many questions.	0	1	5	4	2

THE MEASURE

If you have scored between 30 and 40 you have, by this measure, quite a sound approach to questioning. On the other hand, if your score is below 20 you have some work to do on your general approach to the use of this skill.

CONCLUSION

Now that you have completed this self-diagnostic section, it is worth going over it again quickly to check whether you can add more, or take some away.

When you are satisfied that you have done all that you can, you should compare your results with others who have completed this section. If this is not possible, try talking it over with a friend or colleague, to share your ideas about the skill of questioning.

As in Part One (Listening), do not be put off if you found some of the questions difficult to answer. This is not a test of any kind; the questions are designed to encourage you to think about this subject of questioning, and to provide you with a baseline from which to begin Part Two. Like listening skills, the skills of questioning are not normally taught in either education or training programmes.

Now check your results with the 'Model Answers' on pages 77-81.

PART TWO SECTION B: THE IMPORTANCE OF QUESTIONING TO FAULT FINDING AND DIAGNOSIS

WHO SHOULD USE THIS SECTION?

- troubleshooters
- operators/users of equipment
- managers/supervisors
- production/process engineers
- buyers/stores personnel
- quality assurance/control personnel.

WHAT YOU WILL NEED

- time to read and think.

HOW MUCH TIME?

- you will need to allow 10 minutes to complete this section.

AIM OF THE SECTION

The aim of this section is:

- to enable you to appreciate the important part that questioning plays in the work of fault finding and diagnosis.

OBJECTIVE OF THE SECTION

At the end of this section you should be able to:

- give at least four examples from the area of fault finding and diagnosis which demonstrate the value of effective questioning.

INFORMATION GATHERING

First and foremost, fault finding and diagnosis is about handling information.

To get this information we can question and listen to the following people:

- customers, clients
- colleagues
- operators, users of machinery, processes, equipment
- Quality Assurance personnel
- buyers
- stores personnel
- process/production engineers
- managers, supervisors
- designers
- outside contractors
- specialist troubleshooters
- maintenance personnel.

Anyone missing? All of those listed above carry information which can be crucial to the total process of fault finding and diagnosis.

To continue the list .....

- machines, equipment, processes
  (You need to question what they are telling you when you listen to them.)

- drawings, manuals, technical journals
  (Do you question what they are telling you?)

INVOLVING OTHERS

Very often you can involve others more effectively in the process of fault finding and diagnosis by questioning rather than by simply giving them the information.

This means asking questions like, "Does this fault only happen at this stage?", instead of saying, "You know this fault only happens here and at the low pressure valve". The other person may not feel like questioning this statement, but may well cast more light on the fault if asked a question. Besides, when people are asked questions, they feel as if they are being consulted and therefore get a greater sense of involvement.

CHECKING EXPERIENCE

'Experience' is one of the most bandied about words in the area of fault finding and diagnosis. ("It is all down to experience, you know.") In a world of rapidly changing technology, experience is of doubtful value, and over-reliance on it can be positively damaging. Experience does not teach; it only makes practices permanent, whether good or bad.

The skillful use of questions can provide a check on long-held beliefs about the causes of faults in a system, as for example "We keep getting this fault. Are you sure about the cause?" Such questions seek to check on 'the way we have always done things'. People who have to begin learning new skills after some years of relying on experience can benefit enormously if they adopt the skillful use of questions.

PART TWO SECTION C: TEN FACTS ABOUT QUESTIONING

WHO SHOULD USE THIS SECTION?

- troubleshooters
- operators/users of equipment
- managers/supervisors

WHAT YOU WILL NEED

- the cooperation of others.

HOW MUCH TIME?

- you will need to allow 10 minutes to complete this section.

AIMS OF THIS SECTION

The aims of this section are:

- to summarise the essential points to be made about questioning for fault finding and diagnosis.

- to encourage discussion about the essential points of questioning skill.

OBJECTIVES OF THE SECTION

At the end of this section you should be able to:

- describe and discuss the essential characteristics of questioning skills.

TEN FACTS ABOUT QUESTIONING

(1) Questions can be seen as challenging by the person being questioned. For this reason, question avoidance is a common problem for collectors of information.

The ability of questioners to overcome this problem is part of the skill of asking questions.

(2) There are seven standard steps when asking questions in order to fault-find and diagnose. For each of these steps there is an appropriate sequence of questions to be applied.

(3) The order in which questions are asked in a fault-finding diagnostic task can often influence the effectiveness and efficiency of the outcome.

(4) The first question to be asked in any fault-finding diagnostic task is of crucial importance to the outcome.

(5) The skillful, and sparing, use of questions is one sign of the effective listener.

(6) There are two 'broad' approaches to the asking of questions. One (cognitive) is about asking for detail; facts about the machine or the process. The second (affective) is about asking for attitudes and beliefs; what people think of a particular service provided by operators, troubleshooters, etc.

(7) At the detailed level of questioning there are at least thirty types of question which can be asked. Ten of these can be recognised as useful to the task of fault-finding and diagnosis.

(8) At the broad level of questioning there are three categories of question: closed, semi-closed and open.

(9) Questioning carried out by an expert can be less effective than if done by a lay person, especially when investigating diagnositc procedures. That is unless the expert is very skilled at questioning and can avoid making too many assumptions.

(10) Finally, there are fifteen typical errors which can be made when practising the skill of questioning in any situation. Ten of these errors are to be avoided when gathering information for fault-finding and diagnosis.

These ten facts serve two purposes here:

(a) to summarise what has been covered so far
(b) to provide a focus on the essential uses and characteristics of questions.

Rather than try to memorise these facts, it is better for your learning if you can talk about each one, either with one other person or in a group.

PART TWO SECTION D: SPECIFIC QUESTIONING TECHNIQUE

WHO SHOULD WORK THROUGH THIS SECTION?

- troubleshooters
- operators/users of equipment
- managers/supervisors
- production/process engineers

WHAT YOU WILL NEED

- notebook, pencil, tape recorder/player.

HOW MUCH TIME?

- you will need to allow between 60 and 70 minutes to complete this section and section E.

AIMS OF THIS SECTION

The aims of this section are:

- to introduce you to specific kinds of question
- to give you an illustration of the questions typically used.

OBJECTIVES OF THE SECTION

At the end of this section you should be able to:

- make effective use of specific questioning technique
- describe and give examples of questioning technique.

THE REDUNDANT QUESTION

How often redundant questions are asked is one of the key measures in fault finding and diagnosis. So, what is the redundant question?

There are two types of redundant question.

(1) The question asked at a time when you already have all the information you need to make a decision about the fault.

(2) The question that does not give you any more information than you already have, but still leaves you needing more information before you can make a decision. In other words, you need to ask a different question.

In Module Two on Strategy you will find an exercise on avoidance of the redundant question.

At this point, take time to recall a recent sequence you went through, either as a troubleshooter or as an operator involved in a fault event, and see if you can make a strong case for each bit of information gathered. In this way you may be able to identify examples of the redundant question.

The technique here is to reflect on the information you take time to collect and ask yourself, "How essential is it?".

THE 'IF THIS, THEN THIS' QUESTION

This is one of the most powerful methods of questioning when fault-finding and diagnosing.

It is essentially this form of questioning that makes people say that troubleshooters need to be logical. To use this method effectively, you need to be clear in your own mind about symptom, fault and cause. Let's take, for example, the following statement.

> *Any one symptom may be associated with two separate faults. Only one of these faults is causing the symptom.*

So we can then proceed as follows:

> "IF THIS symptom exists, THEN these two faults, *x* and *y*, are possible. .... IF THIS is working, THEN .... possible fault *x* is not the cause. could it be *y*? ...." and so on.

The technique here is to realise that information about what *is* working is as valuable as information about what is *not* working.

Instead of saying, as some people do, "Oh, that is working, I can forget about that", the technique and drill of saying "IF THIS is working, THEN what is that telling me?" should be used regularly.

"IF THIS is working/not working THEN what is that telling me?"

can translate into something like this:

"IF THIS logic gate is working and is at 1, THEN this output should be at 1." That is, one causes an effect on the other. Only in this way is it possible to be sure that a particular fault is also the cause.

THE IDEA-SEEKING QUESTION

This type of question should be in regular use to seek ways of doing things differently and more effectively.

The main aim behind the use of this question is to sow the seeds of an idea by questioning, rather than trying to push an idea through the system.

For example; "This machine gets lots of faults; downtime is nearly 40%. What do you think about the idea of running it at fewer products per hour to see if, as I believe, this will greatly reduce the downtime?"

Here is another example. "Much of our downtime is caused, not in the actual fault-finding and diagnosing, but in doing things like making up cables. What do you think of the idea of having this done in the stores or, better still, by our suppliers?"

The technique here is to ask the question "How can this be done differently?" Some people seem to come up with ideas more often, and more easily, than others. Part of this ability comes from their natural style of approaching everyday tasks. However, other people will rarely identify different ways because they do not ask this question in the first place.

Now, choose a familiar fault situation and ask this question about your approach to it.

THE CRITICAL INCIDENT QUESTION

The essence of this question is that it helps both questioner and the person questioned to focus in detail on essential points.

One problem when collecting fault information is that it is easier to generalise than to concentrate on specific detail. The technique of using the critical incident question helps us overcome this tendency to generalise.

There are four typical ways that the critical incident question is used in fault-finding and diagnosis.

(1) It can be used to help operators/users of equipment describe in more detail what they have observed about a particular fault.

(2) It can be used to gather information about the most critical faults which occur in a system.

(3) It can be used to get precise descriptions of specific faults for the purpose of maintaining records and machine histories. (See Module Four).

(4) It can be used to help build up a knowledge-based system of symptoms, faults, causes, action, feedback. This can be the prelude to the development of your own expert system.

The technique can be used either in a one-to-one questioning situation or in a group of, say, maintenance and production personnel together.

The technique can only be learned by being in a group of people, where one pair at a time can use the technique while others observe. In this way learning is through participation and observation.

This should be included in any formal course on fault-finding and diagnosing.

An example of the critical incident question technique

TS = troubleshooter
OP = operator

TS: What would you say was the most critical fault that you get on this machine?

OP: Difficult to say, there are hundreds really.

TS: Hundreds? Okay, can you think of one that causes most problems, an incident that typically happens which makes a critical difference to the machine's performance, and your bonus?

OP: Well, all these machines have adjustment problems.

TS: Right, can we think about adjustment and on your machine in particular?

OP: Yes, okay.

TS: What is a typical incident when there is an adjustment problem?

OP: Well, first there is a juddering sound, then the machine stops.

TS: What is the most critical fault when this happens?

OP: Well, the fitter comes and adjusts those cams; that usually does the trick.

TS: The machine goes out of adjustment then?

OP: Not really, because this usually happens when we have changed over to a new batch of packaging. That's what causes it really.

This is a good point at which to leave our pair. The many implications of this, not necessarily uncommon incident, can be identified from this short exchange.

If you are following this training through a formal course, there will be the opportunity for you to practise this technique, using scripts from the Tutor Manual, otherwise the tape may be used.

By using this probing technique of critical incident questioning, it is possible to gather the finest detail about faults and their causes. Whenever someone who is questioned about a symptom or a fault begins to generalise, time is inevitably wasted. The use of the critical incident question brings the questioning down to detail.

THE VALUE QUESTION

Most diagnostic questioning is concerned with facts. A very important part of the work, however, is to provide a service to another person (e.g. the customer of a gas engineer), or to another department (e.g. maintenance department which provides a service for a production department). Certain questions can be used to gather customer perception of the service.

The aim here is to be positive in questioning whenever possible. The need is to ask questions which tap good positive behaviour rather than inviting complaints. Information about what makes a particular troubleshooter or operator effective is of far more value in improving fault finding and diagnosis than information about what makes them ineffective.

The value question is always an 'open' type question. Here are some typical open questions which are appropriate.

- What pleases you most about the service you get from our engineers?
- What have you noticed about the service since we allocated one person to look after your maintenance contract?
- How would you most easily identify an effective troubleshooter?

Although the questions are worded in positive terms, if a customer has a complaint it can still come out. The first question above is a good example of this.

Now you can write down value questions of this kind which are relevant to your own situation. Use the space below.

PART TWO SECTION E: LOGICAL STEPS IN QUESTIONING

In this section we are going to build on the seven questioning steps introduced in the Self-Diagnostic Questions (Section A).

To recap, the seven steps are:

(1) *Place* – where does the symptom show?
(2) *Description* – noise, smell, temperature increase/decrease etc?
(3) *Timing* – how long ago, how often, when?
(4) *Setting* – only at change of product, plant start-up, etc?
(5) *Aggravating or Easing* – what makes it worse/better?
(6) *Quantity* – the number of signs, one or more symptoms, slowing down, intermittent, etc?
(7) *Associated symptoms* – what else may be going wrong?

For each of these steps we can apply a standard questioning procedure. Although this procedure is used extensively in the medical profession, the message here is that this approach is equally valid for other areas of fault finding diagnostic work.

First, you must recognise that the order of these steps is not set in stone; the important thing is that all the steps are covered. Sometimes your sequence of questioning can follow the sequence just given. At other times, the other person will give you the information earlier.

This is the procedure.

(1) START	Open statement: "Tell me...."
(2) FACILITATE	"Can you tell me more?"
(3) LISTEN	Only interrupt when absoutely necessary.
(4) ACCEPT	Allow silence, time to think.
(5) AVOID IRRELEVANCE	Get back to essentials.
(6) CLARIFY	"So the noise only happens when ...."
(7) OBSERVE	Give speaker close attention. Listen.
(8) SUMMARISE	Pull points together, show you understand.

The following extract of questioning has been chosen because it is general to everyone. This helps to illustrate the steps and the sequencing in use.

TS = Troubleshooter
OP = Operator (Can be any user or customer)

TS: What can you tell me?
OP: Well, the chain keeps coming off.

TS: What else can you tell me?
OP: It's usually when I go uphill (silence ..... steps 3 and 4). Oh yes, and only when I change down.

TS: Changing down on any gear?
OP: Yes, that's right (silence ...) and sometimes going uphill and not changing gear.

At this point the TS has some points covered, but what about any other signs or associated symptoms?

TS: What other signs can you tell me about?
(remember never say anything else)
OP: No, that's about it, (silence ...) no problem.

Note: The TS does not remind the OP that he/she said that the chain keeps coming off. Good customer relations here.

TS: What else can you tell me? (Step 8) Has the bike been damaged at all?

OP: Only the front wheel, when I ran into a kerb last week.

The TS in this situation already has a number of possible faults in his/her mind, e.g. slack chain, chainwheel out of line, change arm out of adjustment, gear wheels loose, gear cable damaged, frame twisted. On the information available the last fault could be a good candidate for the cause. Questioning, listening, and only then looking to check out the possible cause can save a lot of time.

Remember, the seven steps can be covered in any order so long as each step is covered. However, the questioning procedure needs to be followed, that is:

(1) START
(2) FACILITATE
(3) LISTEN
(4) ACCEPT
(5) AVOID IRRELEVANCE
(6) CLARIFY
(7) OBSERVE
(8) SUMMARISE

Now choose a fault situation you know well, and write down the seven steps. Then fill in the detail as it is typically given. Next write down the questions in the way you would ask them, following the eight-step procedure. Follow the format of the cycle chain problem.

When first learning a formal method of questioning it seems long-winded. But it can soon become second nature.

SEQUENCE OF STEPS : RELATED QUESTIONS

There are typical types of questions that can be asked at each step.

STEP ONE – PLACE

The symptom is where? .... can you show me?
Which part is it?
Is it here ..... or here?
Where?

STEP TWO – DESCRIPTION

What does it sound like?
What makes you say its wrong?
Can you describe it?

STEP THREE – TIME

What time?
When did you first notice it?
How long has it been like this?

STEP FOUR – SETTING

Come across this before?
What were you doing at the time?
Has anything been changed?

STEP FIVE – AGGRAVATING OR EASING

What makes it worse?
What makes it better?
Can we make it worse?

STEP SIX – QUANTITY

How many times?
How much came out?
What do you mean by 'a lot'?

STEP SEVEN – ASSOCIATED SYMPTOMS

What else may be going wrong?
Other than this problem, what can you tell me?

PART TWO: MODEL ANSWERS TO SELF-DIAGNOSTIC QUESTIONS

QUESTION 1

There are ten types of questions useful for fault finding and diagnosis, in addition to 'open' and 'closed'.

(1) **The semi-closed or fact finding.** For example, "How often has the pump cut out during the past hour?" A yes/no answer cannot be given, yet it cannot be called an 'open' question.

(2) **Opener type.** To start off fault information gathering. For example, "Can you tell me what happened?," or can be a request such as "Tell me".

(3) **Comparison.** To compare one state with another. For example, "What is the difference in the surface quality since I changed the pressure setting this morning?"

(4) **What if.** To check out ideas. For example, "What if we changed the sequence to run the line at a higher temperature first?" The question that can mark the person who seeks to do things differently.

(5) **Mirror.** To help information givers to focus on vital points by repeating key words and phrases. for example, "The coil jams?" or "Only at start up?" the doctor may ask "Only when you bend?"

(6) **Value.** To gather views, beliefs, attitudes. For example, "Tell me, what do you think about the service our engineers provide?"

(7) **Silence.** To give others time to think. Used properly this is a form of questioning too.

(8) **Critical Incident.** To focus attention on specific fault incidents. For example, "Tell me, what would you say was the most critical cause of faults on this plant?"

(9) **Reflective.** To think out loud, then question. For example, "It seems to me there is not a lot we can do until the temperature drops. What do you think?"

(10) **Summary.** To pull together what is known. Very useful when fault-finding and diagnosing in a group. For example, "Now, as I understand it, the problem is loss of pressure. Normally it's due to a blocked filter, but not this time. Am I right?" "Anything else?"

QUESTION 2

Ten typical errors to avoid.

(1) **Complex.** That is the use of too many words, and too many ideas. For example, "The problem as I see it is not so much circulation system as the way we control the overall temperature. Let me ask you a question. I wonder what the difference is between the runs when we keep adjusting the temperature, taking account of outside temperature, when loading bay doors are open, for example, or does this not make any difference? What do you think?"

(2) **Interrogative.** That is to ask 'why' type questions. For example, "Why do you think that happened?" or "Why did that happen?" This type of question is quite sound in most situations, but is not productive when fault-finding and diagnosing. Think about this. (It is dealt with more fully in Module Two on "Strategy".)

(3) **Impulsive.** That is to jump in with a solution too quickly. For example, "We did this last time didn't we? Must be that."

(4) **Unclear.** Usually caused by asking a question when ill-prepared. For example, I wonder whether we should have checked, I mean adjusted, that control. You know the one I mean? On second thoughts I'd better look at that. Now what do you think?"

(5) **Too long.** This needs little explanation. Most effective questions can be typed within three lines across an A4 sheet.

(6) **Trick.** That is to ask questions that have a hidden agenda. For example, "You have adjusted this?", when to be open you should have asked "You have not adjusted, have you?" This type of questioning does not help to maintain good relations.

(7) **Jargon.** To include words and phrases frequently which are familiar to you but not necessarily to others. A bad habit, especially when using a systems approach, where you communicate far more across department boundaries. For example, troubleshooter talking to a designer: "Can you suggest a possible explanation for the OW valve sticking some hours after we have purged the HO Line from the double bottom to the header?" Although the designer knows the system, he or she does not necessarily know the operator's jargon.

(8) **Negative.** To give some possible confusion. For example, "How did you not do that?"

(9) **Dependent.** That is to answer the question you must be able to recall answers you gave to a question (or questions) earlier. Favourite technique with lawyers, but not too helpful for fault finding and diagnosis.

QUESTION 3

In any fault-finding diagnostic task, the importance of the first question asked is seldom appreciated.

This first question normally sets a person off on a particular track which can be difficult to escape from if the solution is not to be found there.

QUESTION 4

The medical profession drills into its students a step-wise procedure for getting information for diagnosis. This is done much less in other professions where fault-finding and diagnosis must be performed. There are seven steps to the questioning.

STEP ONE	Place. Where does the symptom show?
STEP TWO	Description. Noise, smell, pain, rise in temperature?
STEP THREE	Time. How often, how long, when?
STEP FOUR	Setting. Only when there has been a change of product?
STEP FIVE	Aggravating or Easing. What makes it worse? What makes it better?
STEP SIX	Quantity. Number of signs, one or more symptoms slowing, intermittent?
STEP SEVEN	Associated symptoms. What else may be going wrong?

QUESTION 5

The gather of information can take up a large proportion of total diagnostic time. One sign of an efficient troubleshooter, as well as an effective one, is that he or she asks the right number of questions, not too many, nor too few. It amounts to saying to yourself, "I now have enough information to make a decision".

QUESTIONS 6, 7 AND 8

No 'model answers' here.

The purpose of these questions is to provide you with a before-and-after check on your understanding of questioning ability. This is not a measure: only you can judge whether your ratings done at the beginning have changed as a result of completing this section.

USEFUL REFERENCES

Mackay, I (1980) *A Guide to Asking Questions* (BACIE, London).

Morgan, W L (1969) *The Clinical Approach to the Patient* (W B Saunders, Philadelphia).

Tumulty, P A (1973) *The Effective Clinician* (W B Saunders, Philadelphia).

Training
in
Fault Diagnosis

A Systems Approach

Module 2

Strategies

Malcolm Craig.
1991.

CONTENTS

INTRODUCTION

This module deals with the various techniques and strategies used by people who perform fault finding and diagnostic tasks. It is through the choice of appropriate techniques, and their optimum use, that effective strategies can be developed. For example, typical questions could be:

- "Do you have an effective strategy for fault finding and diagnosing binary-coded decimal counters?"
- "Do you have an effective strategy for fault finding and diagnosing the folder mechanism on this printing press?"

An 'effective strategy' means that you can, given a symptom, choose one or more techniques and apply them in an efficient manner.

AREAS COVERED

An important point to make clear at this early stage is that the module covers only fault finding and diagnostic techniques. It does *not* include skills and knowledge used during the rectification of faults. The full area covered by the module is shown in FIGURE 1.

A = 1

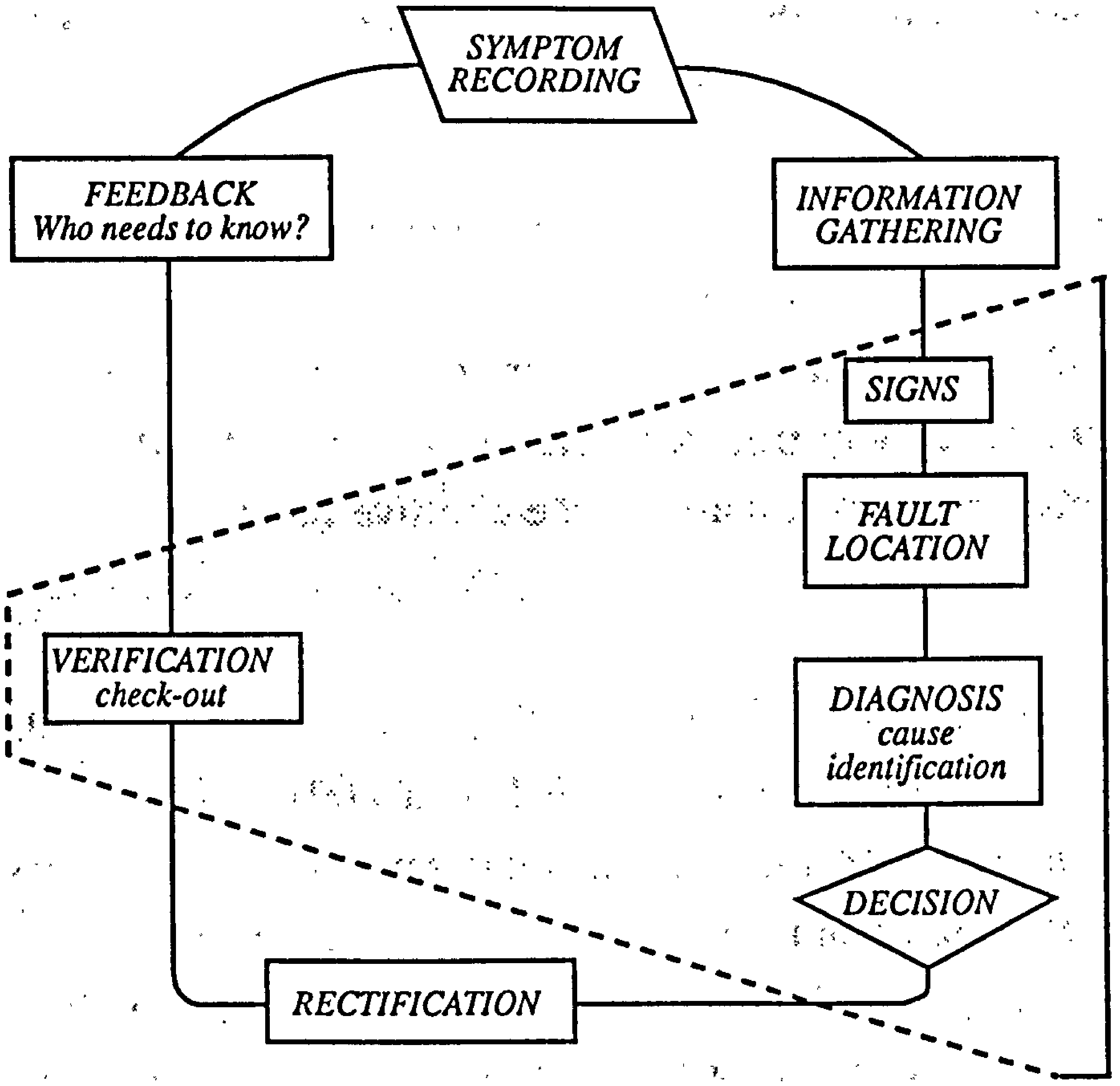

FIG. 1

STARTING POINT AND ASSUMPTIONS

Before anyone (troubleshooter, operator, process engineer) begins a fault finding diagnostic task, particularly in an area new to them, they need to ask two questions:

- "Do I know how the system, the machine or the process actually works?"
- "Can I operate the system, the machine or the process confidently?"

J = O

The first assumption is that you can answer 'yes' to at least the first question and preferably 'yes' to the second.

Knowledge about how a system, a machine or a process works is a necessary part of fault-finding and diagnostic tasks. This knowledge is not, however, sufficient if the tasks are to be performed to maximum efficiency. The complete toolkit of any troubleshooter, or anyone else who is involved in locating faults and causes, must include effective fault finding and diagnostic strategies.

The second assumption is that the skills and associated knowledge of fault-finding and diagnosis can be learned separately from other skills and knowledge in use on the job. This is not to say that the techniques presented here are in isolation from practical examples; such examples are used as a means of learning the techniques. The important point to keep in mind is that the emphasis is on learning the techniques, and the technical detail of practical examples is used only as a means of illustrating the techniques in use.

And finally, a question to end this Introduction:

> "Can you choose an appropriate technique from a range of fault finding and diagnostic techniques, and apply it effectively to a symptom?"

If you can give a confident 'yes' to this question, then you need only skim read over this module to check whether there is anything worth picking up. You never know!

SECTION A: SELF-DIAGNOSTIC QUESTIONS

WHO SHOULD WORK THROUGH THIS SECTION?

- troubleshooters
- process/production engineer
- supervisors.

WHAT YOU WILL NEED

A pen, and preferably access to colleagues for discussion purposes.

HOW MUCH TIME?

You will need to allow between 20 and 30 minutes to complete this section.

AIM OF THIS SECTION

The aim of this section is to help you gain awareness about strategy use in fault finding and diagnosis.

OBJECTIVES OF THIS SECTION

At the end of this section you should be able to:

- assess your own prior understanding of this topic
- state your use of techniques
- state and describe the seven basic reference points in fault finding and diagnosis
- recognise common errors that can be made when diagnosing.

C = 1

When you have competed this self-diagnostic section, check your results against the 'model' answers given on page 82

QUESTION 1

There are many techniques used in fault finding and diagnostics. Name **three** of these. Write your answers in the space below.

(If you do not have actual names for the techniques but you recognise them as techniques, write down your own brief descriptions and see how these compare with the 'model' answers)

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L = 1

QUESTION 2

There are seven basic reference points in all fault finding and diagnostic tasks. These are:

1 symptom
2 sign
3 expectation
4 fault
5 cause
6 verification
7 feedback

Describe what each of these reference points means to you. Write your answers in the space below.

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C = O

QUESTION 3

What does the word 'diagnosis' mean to you?

QUESTION 4

Describe at least three ways in which errors can occur when someone is diagnosing.

A = 1

QUESTION 5

"Every fault is different, and there are as many ways to solve as there are faults". In the space below write down your observations on this statement.

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QUESTION 6

"Like leaders, good troubleshooters are born, not made". Write down your observations on this statement.

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D = O

QUESTION 7

Listed below are some of the more common techniques used in fault finding and diagnosis.

How many of these techniques have you used? (Please tick)

	Extensive Use	Used	Not Used
Algorithm	....	....	....
Bracketing	....	....	....
Breaking the loop	....	....	....
Decision tree	....	....	....
Half-split	....	....	....
History-use	....	....	....
Hot-cold	....	....	....
Input/Output	....	....	....
Known comparison	....	....	....
Output/Input	....	....	....
Probability	....	....	....
Random search	....	....	....
Signal tracing	....	....	....
Symptom-function	....	....	....
Substitution	....	....	....
Visual search	....	....	....

B = 0

QUESTION 8

How many of these techniques do you know?

	Known	Aware of	Not Known
Algorithm	....	....	....
Bracketing	....	....	....
Breaking the loop	....	....	....
Decision tree	....	....	....
Half-split	....	....	....
History-use	....	....	....
Hot-cold	....	....	....
Input/Output	....	....	....
Known comparison	....	....	....
Output/Input	....	....	....
Probability	....	....	....
Random search	....	....	....
Signal tracing	....	....	....
Symptom-function	....	....	....
Substitution	....	....	....
Visual search	....	....	....

Ex 9 = 0 Hz

- Now that you have completed this self-diagnostic section, go back again over the questions to see if there is anything you would like to add.

- When you have done this, turn to pages 82 – 84 where you can compare your answers with the 'model answers'.

N = 0

SECTION B: FIRST STEPS

WHO SHOULD WORK THROUGH THIS SECTION?

- troubleshooters
- operators
- process/production engineers
- supervisors/managers.

WHAT YOU WILL NEED

- access to some typical symptom information in your work
- pen and notebook.

HOW MUCH TIME?

You will need to allow between 15 and 20 minutes to complete this section.

AIMS OF THIS SECTION

The aims of this section are:

- to enable you to develop the idea of basic reference points
- to provide you with practical examples of reference point use.

OBJECTIVES OF THIS SECTION

At the end of this section you should be able to:

- use a standard sequential approach to fault finding and diagnosis
- describe the distinction between symptom, fault and cause.

P = 1

There are seven basic reference points on which fault finding and diagnosis are based. These are:

1. symptom
2. sign
3. expectation
4. fault
5. cause
6. verification
7. feedback

It is useful at this stage to have definitions for these reference points as they are used in this module.

1 Symptom

A symptom is the first indication we have that 'something is wrong'. **It is an undesired change in performance.**

2 Sign

More precisely than a symptom, a sign gives us an indication that a fault exists. Signs help us to narrow down the area of the fault. **Signs help us to reduce the size of the problem space.**

3 Expectation

Expectation is the statement we must make about the specific kind of problem that exists. **Expectations that we state about a fault and its cause are either supported or not supported as a result of diagnosis.**

4 Fault

A fault is that component or condition in a process that has changed from normal, correct operation; in other words **it no longer functions as it should.**

5 Cause

A cause is the link we make between the identified fault or faults and the original symptom. A full diagnosis requires that a causal link be made between the fault(s) and the problem. **A cause is the ultimate reason for the problem.**

6 Verification

Verification is the thorough check-out done by observation, manual probing, and questioning that the diagnostic decision was the correct one. An ageing component may *cause* a high current to flow through a resistor. Replacing the burnt out resistor without verification will not have covered the cause. **Verification is carried out to ensure that no other cause can exist.**

7 Feedback

Feedback of fault diagnosis information is done to ensure that other individuals, and the organisation, learn from the experience. **Feedback ensures that those who need to know do, in fact, know.**

If you are not familiar with each and every one of these steps, the next example will help you by showing these steps used in practice.

Ex 9 = 0Hz

EXAMPLE 1

Symptom

Screen interference when an electronic game is played on a monitor.

[Techniques of Symptom-Function leads to the decision that something is wrong in the area of the RF oscillator, the functional block].

Sign

A sign is picked up when the technique of signal tracing indicates a problem between the ROM and the microprocessor.

Expectation

The troubleshooter can say, preferably out loud, that a break in the signal path exists in a small well defined area.

Fault

Further tests are made which seek to give support to this expectation, and a break is found in a conductive path on the PC board.

[The technique of substitution removes the symptom].

Cause

At this stage it appears that the identified fault was also the *cause* of the symptom.

R = 0

Verification

Checking-out observation, probing, touching; this verifies that no other cause could exist before declaring the 'problem fixed'.

Feedback

Who needs to know?
What do they need to know?
How is it to be communicated?
Feedback completes the fault finding diagnostic cycle. See FIGURE 1, page 2.

Another way of considering the use of these basic reference points is to state one symptom and then think of possible reasons. This example uses an object we all know, the motor car.

G = 1

EXAMPLE 2

Symptom

Poor braking response.

Possible Signs

Fluid on the ground
Burning smell
Rubbing noise when a wheel is turned etc.

Possible Expectations

Leaking pipe
Worn brakeshoes
Loss of fluid, etc.

Possible Causes

Badly adjusted brakeshoes. Poor preventative maintenance. Badly fitted pipe coupling. Driving over too rough ground, etc.

Verification

Check-out braking system (functional block) to ensure that no other cause can exist.

Feedback

Explain fully to driver/owner. Inform, if necessary, last person who fixed it. Inform, if necessary, manufacturer, etc.

Now go on to do the practical exercise on the next page.

PRACTICAL EXERCISE 1

Choose a symptom that you come across in your work and, using the format given in Example 1, break down the typical process you go through from symptom recognition to feedback.

Ex 9 = 16 Hz

Ex 10. I = 0

Comments on Exercise 1

Now ask yourself whether the break-down of what you do in the case of this symptom is what you do naturally anyway.

Are there differences between the approach using this format of reference points and your own approach? Which is the better of the two?

When you correct a fault, how sure are you that the cause has been covered? How can you be sure that everyone who needs to know does know?

The next two examples are provided to help you see more clearly the actual *relationship* between these reference points.

U= O

EXAMPLE 3

A medical doctor learns of a *symptom* from his or her patient, then asks questions, probes and seeks out *signs* to help narrow down the 'problem space'. A doctor who practises a whole-person approach may ask about work, family, interests, etc. when looking for *signs*. Then an expectation is either given out loud or a number of expectations may be referred to more expert opinion. An expectation is checked out against other possible expectations, and testing leads to a problem (*fault*) being identified. Further checks are made to ensure that no other *cause* could exist. Then *verification* is conducted normally through an appointment system until the patient can be declared well. *Feedback* is maintained through history-taking in the form of patient records. On the whole, this last step is done more effectively in the medical profession than in the engineering profession.

EXAMPLE 4

A gas engineer learns of a *symptom* from his or her customer. All external controls and external inputs are checked, using the technique of visual search, before anything is dismantled. At this stage the engineer is looking for *signs* to narrow down the 'problem space'. An *expectation* is given, and support for this is looked for by consulting a manual/schematic, and/or observation, testing and probing. When a *fault* (or faults) has been located, further checking is made to ensure that a causal link exists between fault(s) and the symptom. When rectification is complete, *verification* by check-out is made to ensure that no other *cause* exists. *Feedback* is given to owners and, if necessary, to the manufacturers/designers, as well as to supervisors, stores, and fault record system. (In practice, feedback here is normally to the engineer's memory only.)

E = 1

Comment on Example 3 and Example 4

As can be seen from these two examples, there is a similarity between the medical profession and the engineering profession when using the basic reference points of fault finding and diagnosis. This similarity extends into the use of techniques which are considered in the next section.

W : 1

SECTION C: EXPECTATIONS

WHO SHOULD WORK THROUGH THIS SECTION?

- troubleshooters
- operators
- process production engineers
- supervisors/managers.

WHAT YOU WILL NEED

Time to reflect on and list the expectations that you use.

HOW MUCH TIME?

You will need to allow between 15 and 20 minutes to complete this section.

AIM OF THIS SECTION

The aim of this section is to introduce you to and to help you to develop the use of expectations in fault finding and diagnosis.

OBJECTIVES OF THIS SECTION

At the end of this section you should be able to:

- form clear expectations about fault situations
- describe the importance of well-formed expectations.

INTRODUCTION

Before doing anything about a reported symptom it is vital that your expectations are stated clearly. If you have no idea what you can expect to find, or have no expectation about possible fault(s) and cause(s), you are almost certainly going to diagnose inefficiently.

For this reason we are going to spend some time considering expectations before thinking about actual techniques of fault finding and diagnosis. Expectations form the first part of our strategy building.

B = O

FORMING EXPECTATIONS

Expectations about faults and their causes are formed in three typical ways.

1 Experience-based

Immediately after a troubleshooter is told about a symptom, he or she says something like, "Ah, it must be the temperature control at the second stage". This expectation is stated with confidence because it is based on what has happened before.

2 Record-based

This is formal, and usually more reliable than the first way. From a list of possible expectations linked to that symptom, an expectation is selected on the basis of either being the most probable, the most easily checked, or simply the only one possible. This way of forming expectations relies on a good symptom-fault record system.

3 Analysis-based

As a result of consulting the manual/schematic, asking questions and listening, a considered expectation is given. (As technology develops and becomes more complex this way of expectation forming is becoming more common and more necessary.)

Now do the practical exercise on the next page.

PRACTICAL EXERCISE 2

How do you form expectations?

Write down three typical symptoms, and alongside each, list the possible expectations you can think of for that symptom.

Now ask yourself: "How much do I rely on experience for my expectations, how much on records, and how much on analysis?"

Ex 9 = 8 Hr

Ex 10. H = 1

It is interesting also to see how many expectations you can think of for each symptom. Normally the number is between four and seven, despite some troubleshooters saying "There are hundreds of reasons why this should go wrong". However, in reality most people cannot consider more than around five expectations at any one fault situation.

E-9 · OHL

E-10 M·O

ADVANTAGES AND DISADVANTAGES OF WAYS OF FORMING EXPECTATIONS

Experience-based expectations

Clearly if you find that expectations based on experience work well for you, this is potentially the most effective method of formulating expectations. **There are, however, some serious disadvantages to consider.**

(a) This approach to expectation-forming can result too easily in *symptoms* being fixed, rather than *causes*. The quick response usually means there has been a number of examples of that symptom occurring, a sure sign that causes are not being covered.

(b) The experience approach relies heavily upon a few people who have expectations stored in their memory, built up over a period of time, in some cases over years. When technology changes, these people normally expect to begin the long process again of slowly building up this 'experience'. Changes are now too rapid for this to happen.

(c) The 'certainty' that often accompanies this type of expectation-forming can lead to a blinkered approach, a mental 'set'. If the expectation is not supported, the ability to think beyond this mental set tends to be poor.

Given that these disadvantages can be avoided, this way of forming and giving expectations about faults and causes can, nevertheless, be quick and of real value to the organisation.

V = O

Record-based expectations

Record-based expectations, those that rely on accurate well-maintained fault records, are some of the most consistently reliable and valid. Good fault records provide a valuable tool for fault finding and diagnosis.

Analysis-based expectations

These are most often used with complex systems or pieces of equipment. Time spent in careful study of the known facts and in analysis of the situation can save hours of futile searching and testing. For some troubleshooters who prefer to 'get on with the job', this seems to be a hard lesson to learn. As technology becomes more complex it is vital that practitioners stand back and analyse before taking any action.

S = 1

POSITIVE AND NEGATIVE INFORMATION

The checking of expectations produces two types of information:

- positive information
- negative information.

This is illustrated in Examples 5 and 6.

EXAMPLE 5

Positive Information

We get positive information when what we say in our expectation is supported.

Expectation: "I believe that the gate valve on the discharge pipe is not closing properly"

Result of checking: Damaged valve setting

In this case the stated expectation has been supported.

E = 1

EXAMPLE 6

Negative Information

One of the major weaknesses to be observed when people are fault finding and diagnosing is in their failure to use negative information.

Expectation: "I expect the output from that OR gate will be at logic 0".

Results: Test shows the output to be at logic 1.

What the troubleshooter *does* at this point is usually crucial to the outcome of this fault finding diagnostic task. If the response is to say, "Oh, that's alright", and then to move on to test elsewhere, valuable negative information that could save a lot of further testing may be lost.

Even though your expectation has not been supported, negative information can be as valuable as any positive information.

Your next move should be to ask yourself the question "What is that logic 1 telling me?". (This method of questioning was covered in Module 1). The aim is to eliminate as much as possible of the circuit by using this negative information.

The same applies to the case of Example 5. After finding a correctly functioning gate valve, you would need to stop and ask "What is that telling me?"

Although this 'use of negative information' probably does not merit the distinction of being called a 'technique', you may like to add it to the list on page 9.

K = 1

FINAL COMMENT ON EXPECTATIONS

An interesting point raised in this section is about your overall approach to fault finding and diagnosis.

If you begin by wanting to *prove* your expectation to be correct, you almost automatically dismiss information which contradicts your expectation.

If you begin by wanting to *dismiss* your expectation, you are more likely to use the information that you get. You say something like "Ah, I can eliminate that. Now, what does that tell me?" It is worth thinking about this and talking it over with colleagues.

The importance of clear expectation stating cannot be stressed too strongly. The expectation you choose dictates the next part of the fault finding diagnostic process. Misleading or wrong expectations lead to more downtime when a correct expectation can lead to rapid solution.

Note

If you are interested, the academic word commonly used for expectation is *hypothesis* (plural, *hypotheses).* Hypotheses are either supported or not supported on the basis that nothing can be actually proved. The negative information referred to here is related to what is called the Null Hypothesis. We felt that 'expectation' was a more learner-friendly word than 'hypothesis'.

F = 1

SECTION D: TECHNIQUES

WHO SHOULD WORK THROUGH THIS SECTION?

- troubleshooters
- process/production engineers
- supervisors/managers

WHAT YOU WILL NEED

- access to fault information in your own work
- pen and notebook.

HOW MUCH TIME?

- You will need to allow between 40 and 50 minutes to complete this section.

AIMS OF THIS SECTION

The aims of this section are to:

- provide you with guidance on the choice of techniques
- provide you with practical examples of techniques in use.

OBJECTIVES OF THIS SECTION

At the end of this section you should be able to:

- state the use of at least ten techniques
- choose the most appropriate techniques
- practise the use of selected techniques.

THE IMPORTANCE OF HAVING A RANGE OF TECHNIQUES

The more techniques that you know and can use, the greater will be your choice and the more flexible your strategies.

A strategy for fault finding and diagnosing on a radio receiver may consist of one or more techniques. For example, here are three possible strategies.

Strategy One

"I have a set order of checks that experience tells me is the quickest way to find a fault. It usually works. Any unusual fault I remember for the next time I come across it".

Strategy Two

"I look at the type of receiver and split the circuit into functional blocks. Because most of these circuits are in series, a half-split technique is useful in locating the problem block and eventually the faulty part. I then do a visual search to check for any other possible causes of the fault located. I normally remember the faults and causes".

Strategy Three

"First I check my fault log to see if a ready answer is there. If not, I use a symptom-function technique in the form of an algorithm. Is it this? YES-NO. Is it this? YES-NO, and so on until I have located the fault. I do a thorough visual search and check-out. The results are entered into a fault log in the form of symptom – fault – cause – action, by jotting notes into each of the four columns.

These three strategies are given for example purposes only; depending upon the complexity of the equipment or of a process, the strategy can be more extensive or could be even simpler.

H = O

Particularly effective troubleshooters develop strategies which are most appropriate to their own circumstances.

All the components that go to build up an effective strategy are shown in FIGURE 2.

Before looking at particular techniques in more detail, this is a good point at which to reflect on your own strategies.

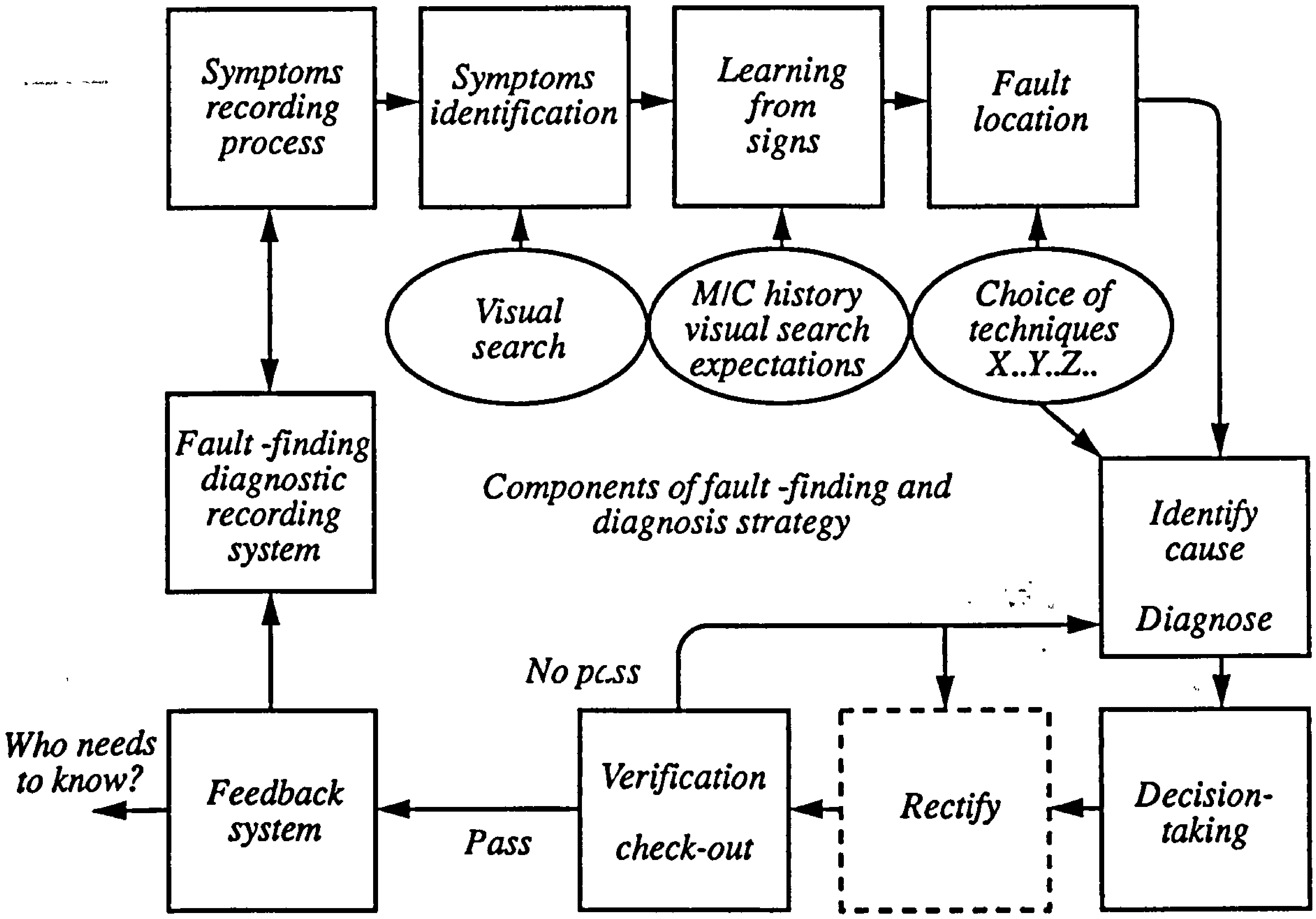


FIG. 2

Ex 9 = 0 Hz

Ex 10. J = 0

PRACTICAL EXERCISE 3

Following the example of the model shown in FIGURE 2, try drawing an illustration of your own favourite strategy, or as you probably think of it, your 'approach'. You may like to draw more than one, if you tackle different problems by using different approaches. The drawing does not have to be the same lay-out as FIGURE 2; use your creative ability to do what you think best. Producing diagrams of this kind usually helps us to think more clearly about what we do in practice. Use the space below and on the next page.

Ex 9 = 64 Hz

[illegible]

L = O

NOTES

THE MOST COMMON TECHNIQUES

We will now consider fifteen specific techniques. These are as follows:

- random search
- visual search
- input to output
- half-split
- symptom - function
- signal tracing
- substitution
- probability
- hot - cold
- bracketing
- breaking the loop
- history use
- algorithms
- fault tree
- known comparison.

Here is a brief description of each.

(a) Random Search

This technique is based normally on 'use of experience', by diving in and checking out the most likely area because that is what happened before. True random search is used when this 'what happened before' technique does not work and there is no diagnostic strategy to fall back on. The result is a random search technique or 'trial and error'. Interestingly, this technique can be more effective than input-to-output or output-to-input techniques. See the model shown in FIGURE4.

Ex 9 = 0 Hz

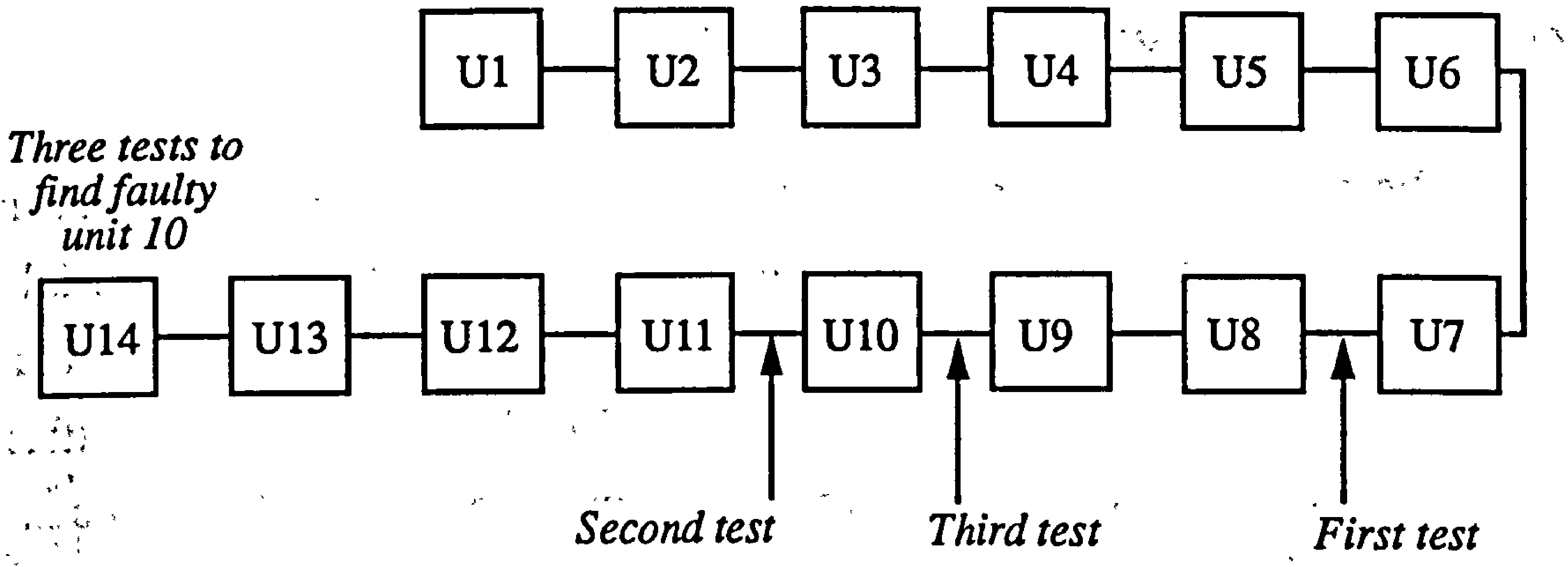


FIG. 3

There are however some disadvantages in using this technique. First, it is of little help in solving intermittent faults. Second, it can be very time consuming on large complex systems. Third, because it is not based on an overall strategy there is less likelihood of uncovering obscure fundamental causes of faults.

(b) Visual Search

This is a much undervalued technique. It is quite common for maintenance engineers to be surrounded by dismantled parts and scratching of heads, when a 'troubleshooter' comes along, pokes around, looks carefully and points to a loose wire. "That woman is a genius" they all say.

This technique relies on the troubleshooter having a clear picture of what the system, the machine or the process looks like when it is performing well. Unless you have this picture it is difficult to know quickly when anything is not well. It has been suggested, but no evidence is available, that effective troubleshooters use a form of pattern recognition: they can recognise anything that disturbs their pattern. In practice, visual search goes with question-asking and listening, touching and collecting as much information as possible in a short time, before anything is actually done. This is a powerful technique that has no real disadvantages, and repays thorough practice.

(c) *Input to Output*

The name is very descriptive; this technique is sometimes mistakenly called a 'logical' approach, when what is meant is a sequential or systematic approach. Because the testing or checking-out goes from A to B to C ... and so on until the fault is found, the result can be either a lucky early solution or a time consuming process. If feedback is involved, which modifies the system, it is quite possible that even after a long search the solution is still not found. That is unless a technique such as 'Breaking the Loop' is used as well.

Also the technique takes no account of probability of failure. All units or components are assumed to have the same chance of failing. Statistically, over a range of typical faults, this technique is one of the slowest in producing results.

(d) *Half-split*

This is sometimes known by the more dramatic title of 'Divide and Conquer'. This technique is most suitable for systems in series, such as a radio system. When the search was being done for these modules, an aircraft engineer waved a highly complex schematic in the air and said, "Go on, half-split that". He was voicing the feelings of many troubleshooters who learn about half-split at college (one of the few techniques taught), and then attempt to use this technique in practice. However, given the right circumstances in which events run in series, this technique is powerful. (See FIGURE 4.) In situations such as packaging lines, chemical pipework or paths from robot arms to control motors, the technique can be used to good effect.

T= 1

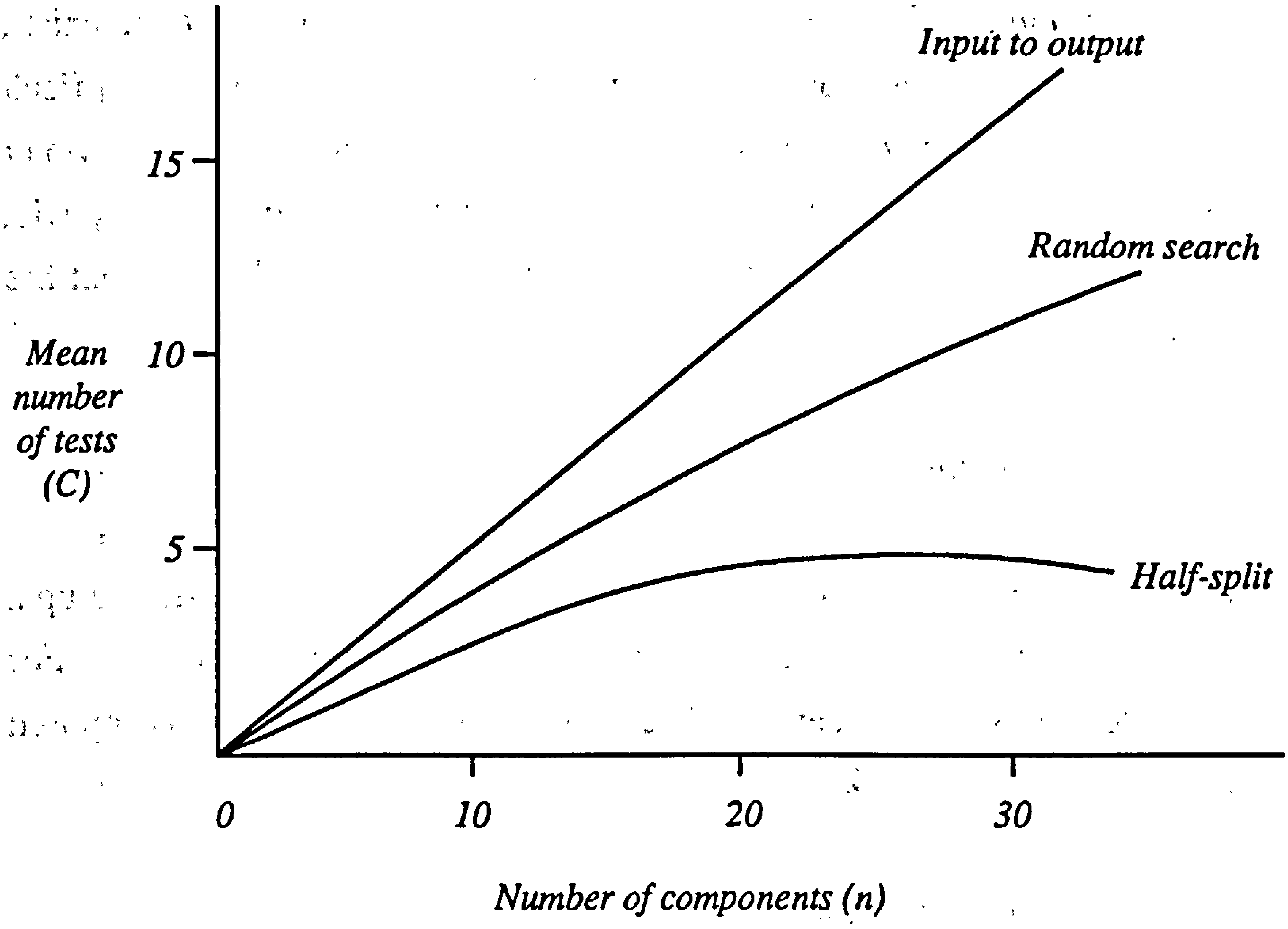


FIG. 4

The principle is quite simple. A check or test is made at the halfway point between input and output.

If a sign of the problem exists at that point, a second check or test is made halfway between that point and the input. Again, if a sign still exists, a third check or test is made halfway between that point and the input ... and so on, until the fault is located. If the first check or test was found to be working, a point halfway between that point and the output would be checked and so on. This is a faster means of locating faults than either input-to-output or output-to-input techniques. (The method is illustrated in FIGURE 3 on page 38.)

The technique is difficult to use in systems where **convergence** exists, that is where two or more inputs come into one unit. It is also difficult to use where **divergence** exists, one output from a unit supplying two or more other units. People using the technique cannot cope easily with feedback. Otherwise, this is a standard well-known technique that has its uses.

(e) Symptom-Function

This technique relies upon the person using it being able to divide up a machine, a process or circuit into distinct functional blocks. For example, a naval engineer could see a sonar system as being composed of four functional blocks:

1 transmit block
2 control block
3 counting block
4 receive block.

Each block can be seen as independent in the sense that each has clear inputs and outputs. At first the engineer sees these as 'black boxes'.

Engineers who maintain effective fault record systems of such equipment (this is dealt with more fully in Module 4) will have a list of symptoms and the most typical blocks where faults related to a particular symptom are to be found. This enables very rapid fault location to be made.

The symptom-function technique is an essential *part* of most effective fault-finding and diagnosis strategies. It is important to appreciate that it is *only a part* because in most cases the technique does not lead directly to the fault.

D = O

The aim of using this technique is to narrow down the problem space as quickly as possible. A basic knowledge of systems thinking can greatly improve the use of this technique (dealt with more fully in Module 3).

(f) Signal Tracing

This technique can follow on very well from the symptom-function technique. When a block or unit has been located as the 'problem area', a series of tests using signal tracing can then be used to focus in on a specific component or part.

This technique normally involves the use of either an oscilloscope, or a logic probe in the case of digital circuits. An existing signal is traced, or a signal can be injected into the circuit. This provides a clear, well-controlled means of recording results and, if recorded fully, can help reduce the time taken when the symptom occurs next time. One problem is that it sometimes relies on the use of expensive test equipment. It also assumes easy access to the system under test.

(g) Substitution

This technique uses the substitution of a 'good' component, unit or part for a suspect or faulted item. This technique is more commonly used with printed circuit boards, where the fault board is removed so that fault finding and diagnosis can be done down to component level in a workshop.

There are clear advantages in this technique. It provides speed of rectification, and in some cases can be carried out by less experienced personnel, thus freeing scarce expertise for other tasks.

There can be serious disadvantages to this technique if the process is not well controlled.

(a) It can involve the costly stocking of spares, storing up capital in other words. (See Module 5).

(b) It can involve the replacement of non-faulty items which are not used again, or the replacement of two or more items when only one is defective.

(c) It can too easily cover up fundamental causes, especially when there are no dedicated service engineers. That is, different engineers return each time to fix a recurring fault by using substitution technique, and each time fail to discover the *cause.* In such situations, it is necessary to involve stores personnel more fully in the fault finding diagnostic process. They need to be in a position to highlight such trends in the troubleshooter's work. (See Module 6).

Given that this substitution technique can be well controlled, and the viability of actions justified in terms of costs, this is a sound means of fault finding and diagnosis.

Substitution can only be justified for the following reasons:

(a) as a means of replacing a faulty item which will be repaired later

(b) as a means of getting a system back on stream as quickly as possible

If a third reason is introduced: 'as a means of quickly locating the faulted item', this signals bad practice.

(h) Probability

Although this is a very powerful technique it cannot, on the evidence available, be described as commonly in use.

The *probability* that a particular symptom will be caused by a particular fault should be valuable information for any troubleshooter. However, one of the difficulties in using this technique is that it demands some logical thought.

There are two broad approaches to the use of the probability technique:

1 our belief about the probability of a *general* cause
2 our belief about the probability of a *particular* cause.

Here is an example to illustrate this.

EXAMPLE 7

General Cause

"The most probable cause of electrical faults...... is over-stressed components".

M= 1

Particular Cause

"The most probable cause of this symptom is vibration which causes the pin connection to work loose". (In this short statement the symptom, fault and cause are all covered).

Machines, equipment and processes do not normally display faults and their causes. Instead, they normally present symptoms, for example:

- (a) "Its not working"
- (b) "It keeps jamming"
- (c) "It overheats"
- (d) "It does not sound right to me".

When we use the probability technique, it can be said that:

> When symptom x (Sx) is present, the probability (P) of it not being fault a (F$\bar{a}$) can be expressed as:
>
> $$P\,(F\bar{a})\,Sx = 0.01.$$
>
> This means that of one hundred machines with symptom x only one will **not** have fault a.
>
> Alternatively, we can work back from a fault and say P (S$\bar{x}$) Fa = 0.01. That is, given fault a (loose amplifier connection), then the probability of it **not** being symptom x (distortion) is one in a hundred.
>
> In other words, 99 times in 100 this symptom will be caused by this fault, or P (Sx) Fa = 0.01.

Ex 9 = 1 Hz

This technique is more commonly used in the medical profession where it can be said that $P(\bar{D})\ S = 0.01$. That is to say, the probability that a person with symptom S *not* having disease D is only one in a hundred.

It will be obvious to you that this kind of information can also be of enormous value to the engineering profession. However, the technique does rely on effective records being kept.

In future we may well see the extensive use of knowledge-based systems, and expert systems. (See Module 6). These will include such data. Until that time arrives, however, there is value in developing a more measurable approach of this kind to fault finding and diagnosis.

(i) Hot-Cold

This technique is used most commonly to help locate **intermittent faults.** Faults shown by the annoying symptoms of 'now it's there, now it's not'. The operator knows by 'sod's law' that the symptom occurs only when the troubleshooter has gone away.

This technique requires the use of changes in external temperature, and applies to electronic circuits and units. The questionable item is heated to a maximum tolerable temperature, around 40 °C. Then tests are made of component inputs and outputs. The temperature is lowered as quickly as possible either by fans or spray freezers. Then the test reading is repeated. As a result of this treatment it is quite possible that one or more components show defects. These are replaced (substitution technique) and in this way the intermittent fault can be removed.

A related approach to this technique is to use gentle vibration of the unit; this can induce a component to show itself as the cause of the intermittent fault.

Before going on to conisder the remaining four techniques, let's just review what we have covered so far in this section. Do Practical Exercise 5 below before moving on.

PRACTICAL EXERCISE 5

(a) So far in this module we have considered nine techniques. You should now reflect on their usefulness, and ask yourself whether you use some or all of them, even if unconsciously. Go back to Self-Diagnostic Questions 7 and 8, (pages 9 – 10) and see if you can now revise your responses.

(b) In the space below, list those techniques which are new to you, and briefly describe the circumstances where they could be of particular value to you.

Ex 9 = 0 Hz

(j) Bracketing

This technique, sometimes know as 'good input – bad output' technique, makes use of schematic block diagrams.

This technique provides reference points and a 'structure' to the way that you localise fault(s) to a specific area.

The actual brackets can be drawn in lightly and moved by use of rubber and pencil. It is also possible to keep the bracket position in your head.

The aim is to move brackets one at a time as a result of testing at the input or testing at the output. By moving a bad output bracket each time a bad output is detected and the good input bracket to a point of no-fault, the problem space between the two brackets will be narrowed down.

(k) Breaking the Loop

The more common techniques of output-to-input or half-split become much less reliable when a system (or circuit) contains feedback loops.

In engineering systems feedback is normally of the negative kind; that is, the purpose is to feedback from an output in order to correct or adjust an input. A central heating system is one of the best examples of negative feedback.

When feedback loops exist to modify the functioning of a system, faults can be difficult to locate.

EXAMPLE 8

Robot systems are good examples of where linear paths work side-by-side with control loops, some of which can be highly complex.

In this case of a linear path between, say, a motor and gripper, the half-split method can be used. In the case of a control loop between a microprocessor and a limit switch there is often the need to break the feedback loop. A substitute signal___ is then introduced to check the true output from the microprocessor.

Comment on Example 8

In the case of more complex control loops it is often necessary to combine techniques. First, symptom-function is used to divide the system into functional blocks in order to check inputs and outputs at block level, then break loops are introduced where necessary when the suspect area has been identified.

(l) History-Use

Well-maintained fault diagnostic records can provide a valuable aid to troubleshooting. The actual design, recording and maintenance of such records is covered more fully in Module 4.

One of the best applications of this technique is through the use of symptom cards. A box containing large index cards is kept close to the machine or the process. Each card is identified clearly in the box by the name of a symptom, e.g. 'overheating', 'hashered waveform', 'vibrating shaft', etc. Each card lists the possible signs, possible faults, and possible causes, as well as what action was taken the last time this symptom occurred. Then most probable fault(s) and cause(s), based on past experience, are recorded.

This box of symptom cards is maintained by having a new card introduced each time a new symptom appears, and existing cards are updated as new experiences are gained.

This technique can be almost fool-proof if the material is well-designed and maintained. This is possibly the most powerful technique and provides the basis for future knowledge-based systems and, eventually, expert systems. (See Module 6).

(m) Algorithms

The technique of using algorithms to aid fault finding and diagnostic tasks is closely linked to the History-Use technique. For example, it is possible to use algorithms in the card system. (See History-Use technique for description of the card system.)

One of the best applications of algorithm use is to help operators (and other users of equipment or procedures) to perform basic fault-checking, so saving the valuable time of technical troubleshooters.

EXAMPLE 9

An algorithm at the most basic level can look something like this:

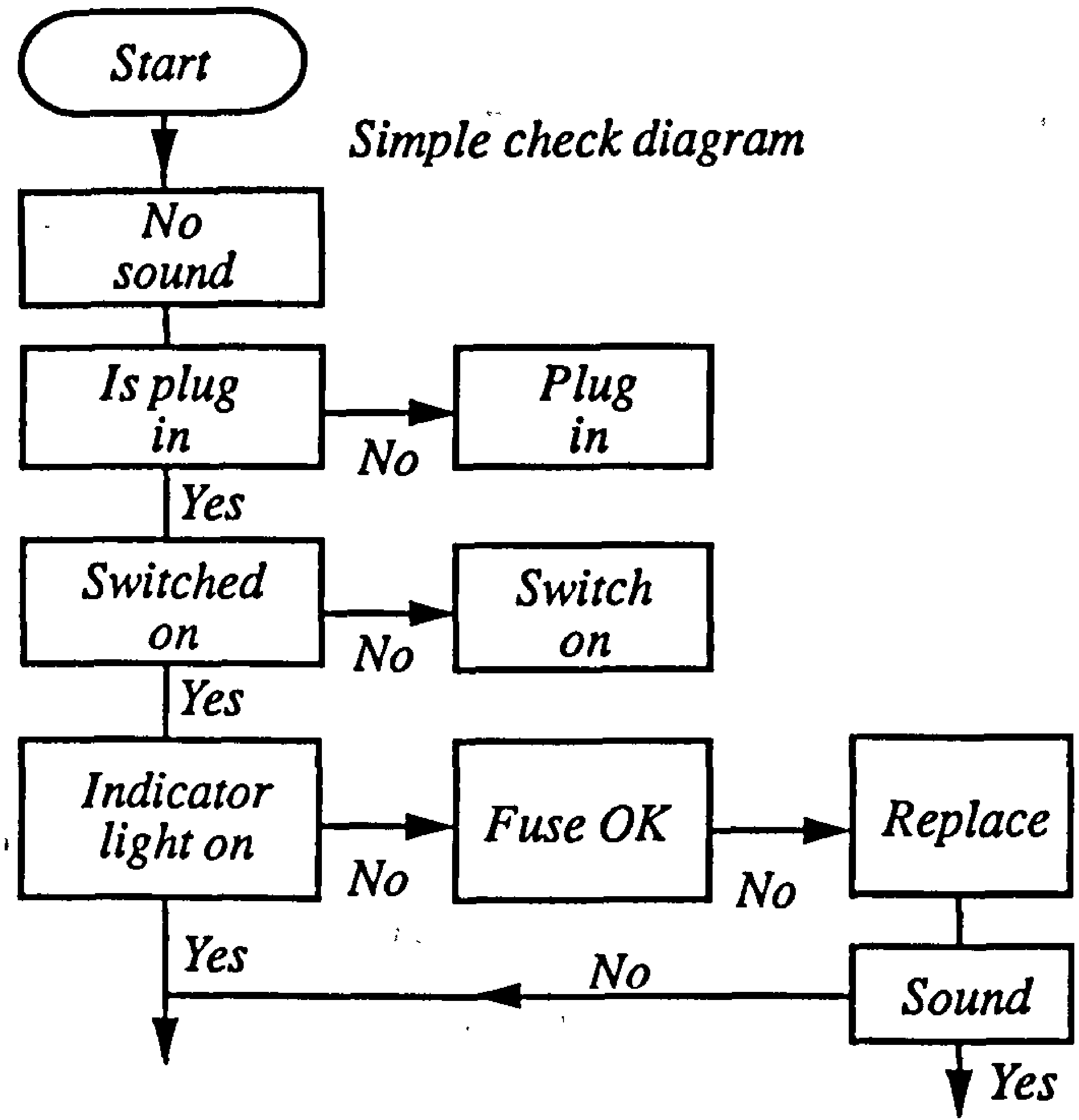


FIG. 5

At a more complex level it can look something like this:

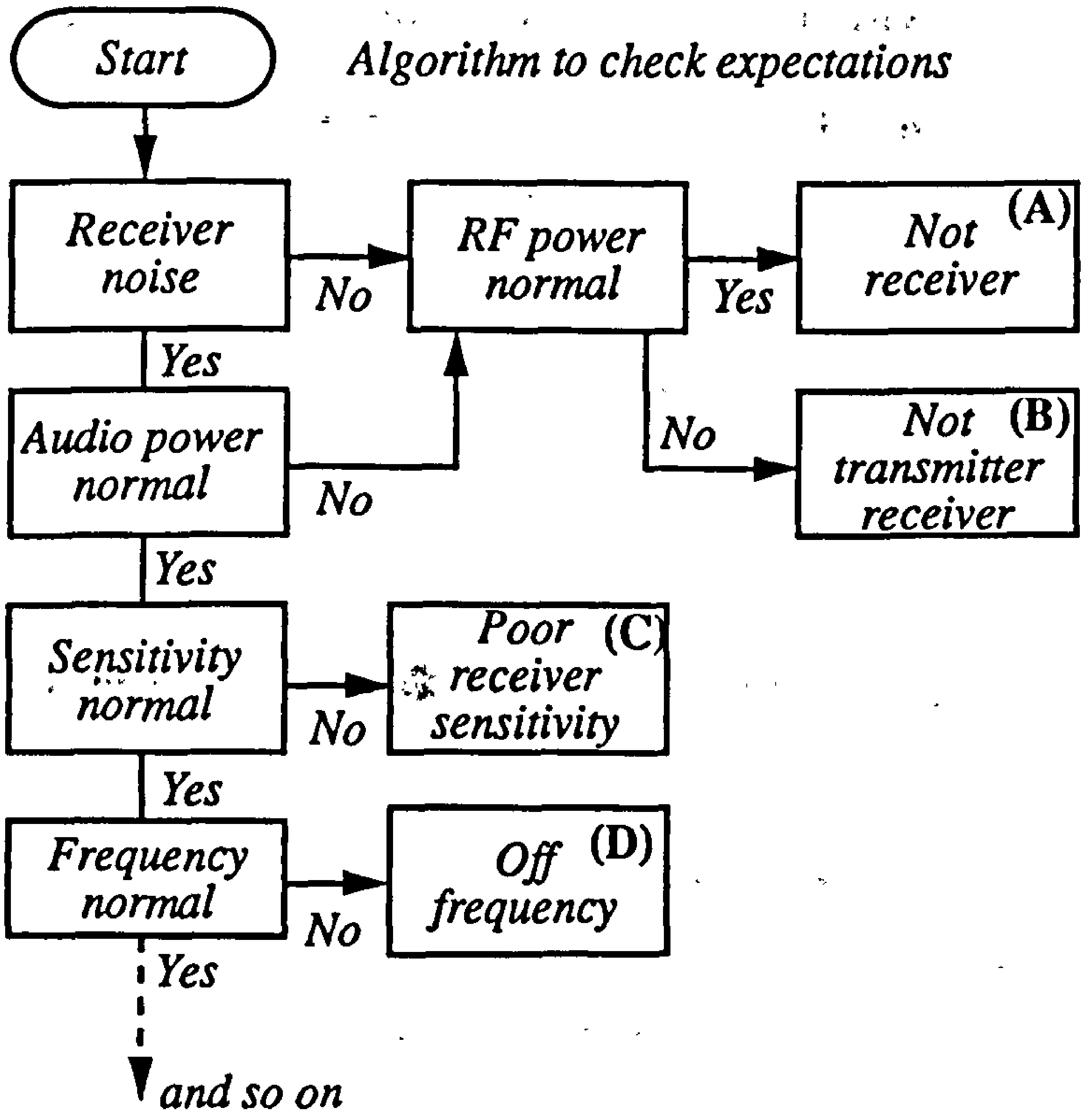


FIG. 6

F = 1

Given that an operator or other user checks through the algorithm thoroughly, the information about what has and has not been checked out in this way is of enormous help to a troubleshooter. The algorithm is also useful in making it clear to operators just what *can* be checked by them.

There are some doubts about the value of algorithms to actual troubleshooters. There is the problem of becoming too blinkered by their regular use. The 'rote' type reaction to faults can easily develop and there is then less chance of thinking beyond the fault to more fundamental causes.

However, as a guide to operators, algorithms can be of considerable value, and they do have uses for troubleshooters.

(n) Fault Tree

This technique is normally used for the analysis of faults or, more broadly, for the analysis of failures. This is done by starting at the stated problem and working through the various options of what could contribute to or be the cause of the problem.

As a direct technique to aid fault diagnosis, the use of fault trees can be simplified from those used in analysis where a common approach is to apply Bayesian statistics. Simple fault trees can be used as a quick reference or 'crib' for many fault situations. The aim is to begin with a recognised symptom. The 'tree' starts when this symptom has been verified by the troubleshooter by checking thoroughly with an operator or at the equipment, that the reported symptom is in fact the correct one and that it is not hiding a more significant symptom. This symptom is the top event and it may have one or more other signs associated with it.

Signs, where they exist can form the first branches of the tree (see FIGURE 7); where no other signs exist a branch goes to possible faults. For each possible fault there are possible causes, or only one cause. For each cause, there are possible actions to be taken or only one action necessary.

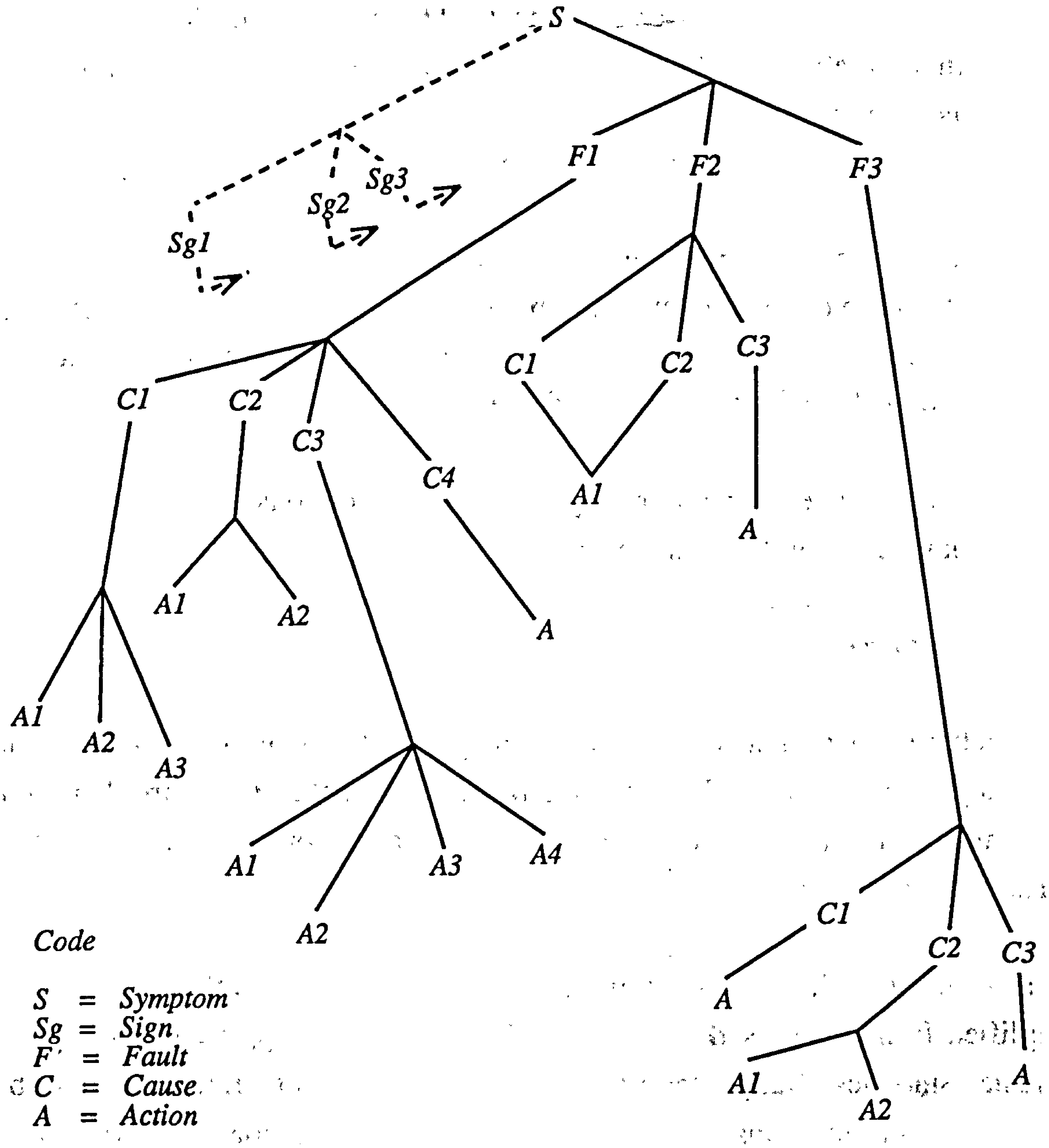


FIG. 7

In FIGURE 7 where Signs, Faults, Causes and Actions are numbered, these numbers will be substituted by your own descriptions from the particular machine or piece of equipment.

Ex 9 = 2 Hz

A further refinement to this basic fault tree is to indicate, from your experience or fault records (See Module 4), the most likely in each case. For example, F2 could be marked (HL) for highly likely; F3 (VL) for very likely, and F1 marked (NL) for not likely. The same could be done for each cause and for each action that could be necessary using a scale such as:

Highly likely HL
Very likely VL
Likely L
Not likely NL

An advantage of such an aid is that there is a handy record of what has been checked. Also the tree can be modified if it is found that what was considered 'not likely' turned out to be a regular cause.

It is readily obvious that such trees can be constructed from the combined knowledge and experience of troubleshooters. Fault-tree notebooks can be constructed for quick easy reference.

(o) Known Comparison

The two most common uses for this straightforward technique are when troubleshooting is being done on a new piece of equipment recently installed, or in equipment where there can be two sets of circuitry the same, such as on an amplifier. In the first case it is necessary to have a known 'good' comparison in the form of an identical piece of kit that works. Knowing what something looks like when it is performing well is an essential requirement if faults, when they happen, are to be detected. This sounds like common sense but one way to illustrate that this statement is not so obvious as it seems is to ask a troubleshooter or operator to describe the key features of a machine when it is working perfectly.

In the second example, a signal can be traced through one circuit and then compared with the other circuit.

A particular problem for troubleshooters is when faults occur on a prototype and there is no evidence that it has ever worked correctly. In this situation the use of known comparison with units or components that do function is one way of overcoming the difficulty.

Now turn to the next page and complete practical exercise 6.

PRACTICAL EXERCISE 6

Now go back over the techniques introduced here, and list them in order of usefulness to you.

Now list techniques that you could use on their own.

Now group techniques together, that is, show how you can combine their use.

COMMENT ON PRACTICAL EXERCISE 6

You should have had specific fault situations in mind when you did this exercise. One situation may be covered adequately by using one technique alone, another by using two or more techniques.

Do avoid the danger of using a technique simply because you know it and have practised it for some time. Try to reduce the number of techniques in use to an essential minimum.

Ex 9 = 32 Hz

SECTION E: CHOOSING AND COMBINING TECHNIQUES

WHO SHOULD WORK THROUGH THIS MODULE?

- troubleshooters
- production/process engineers
- supervisors
- operators.

WHAT YOU WILL NEED

- pen and notebook.

HOW MUCH TIME?

You will need between 25 and 35 minutes to work through this section.

AIMS OF THIS SECTION

The aims of this section are.

- to introduce you to a basic four-step approach which, it is claimed, can be used in all fault finding diagnostic tasks
- to increase your awareness of how techniques can be chosen to fit particular situations.

OBJECTIVES OF THIS SECTION

At the end of this section you should be able to:

- describe the basic four-step approach
- make choices between techniques
- apply the four-step approach.

THE FOUR-STEP APPROACH

We begin with the claim that **all fault finding and diagnosing, irrespective of where it is performed, can be done in four steps.**

Step One

Identify clearly the symptoms.

Step Two

Localise to a functional area. (This is normally done using the symptom-function technique).

Step Three

Isolate a specific part. (This involves the use of specific techniques).

Step Four

Isolate the fault in a specific part and determine its cause.

These four steps cover the process of fault finding and diagnosing from the time when a symptom is first reported to the time when a decision can be made about the fault and its cause.

Now each step will be described in more detail.

Ex9 = 4 Hz

Step One – Clearly identifying the symptoms

Before anyone can recognise a symptom it is necessary to know either what a good condition is supposed to look like, or what a machine or a process is capable of doing. Recognising the 'no-fault' condition is very important.

It is at this step that you do what is probably the most important and most critical part of fault finding and diagnosis.

You must thoroughly check all outward signs, and check all controls that can be checked. (Check that the thing is plugged in at the wall!) Look, question, listen, smell, feel; this is what is meant by 'identifying clearly the symptoms(s)'.

Step Two – Localise to a Functional Area

Most equipment, machinery and process can be divided up into areas, depending upon the function that each area performs.

EXAMPLE 10

A basic television can be divided up into ten functional areas. To complete the areas, however (taking a Systems Approach), it is necessary to consider that other functions, apart from the actual circuit and components of the receiver, can account for certain symptoms. There is the functional area of the aerial, and the area of the transmitter station, which itself can be divided up into other functional areas. It is normally sufficient, however, for the troubleshooter to simply take account of these two additional functional areas: the aerial and the strength of signal provided by the transmitter stations.

Comment on Example 10

It is at this step that most use is made of any available manual, schematics, and further questioning and listening with the users of the equipment, the machine and/or the process.

The block diagram is particularly useful at this time. With this it is possible to apply two techniques which have been described in the previous section: Symptom-Function and/or Bracketing.

The aim of work done at this step is to narrow down the problem area. This is particularly important for the current use of complex pieces of equipment and machinery linked together, such as in flexible manufacturing systems, and in publishing where very complex inserting equipment is combined together.

Step Three – Isolate a specific part

In some situations it may be possible to merge Steps Three and Four. In other words, instead of first isolating a part, then that part's fault, it is sometimes possible to go into the functional area that has been identified and isolate the fault and its cause. This introduces some flexibility into the four-step approach. It is for you to apply the basic principles of this approach in a way that best suits your circumstances.

Step Three alone is most typically used where a circuit or a process is involved; either current (e.m.f.) flowing through wires, fluid flowing through an hydraulic circuit or chemicals in pipework. The principle is the same; all involve flow (movement), pressure, time, and things go wrong in each and every case!

It is at this step that most of the techniques introduced in Section D are used.

- If the identified functional area consists of a number of components, parts or events occurring in sequence, one after the other without feedback loops, then you will probably choose the **half-split technique.**

- If the area consists of electronics and feedback loops, then a combination of **signal tracing** and **breaking-the-loop** may be used.

- If the area consists of easily removed units, modules, or printed circuit boards, the **substitution technique** can be used, but only if good control of spares can be guaranteed. (See Section D on substitution, and Modules 5 and 6).

- If effective machine/process records and histories are maintained, reference to these as fault finding diagnostic aids can be put to good use at this step.

- At this step also there should be, by now, sufficient information to use the **probability technique.** Again this relies upon the maintenance of good records. Given the clearly identified symptom and the isolation of the functional area, details about what is most statistically probable can be of enormous help in quickly isolating the faulted part.

- In the case of an intermittent symptom, and looking for an intermittent fault, the **hot-cold technique** and possibly **the vibration method** that goes with this technique, can be attempted at this step.

Step Four – Isolate the fault and determine the cause

This step is one of careful inspection. The most commonly used technique here is known as 'visual search', although other senses are used too: smell, touch, hearing (plus the skill of listening.)

The aim at this step is to establish the fault and, even more importantly, to ask "What *caused* this fault?" The fault may also be the cause, or there may be one or more causes, either in the functional area being looked at, in the remainder of the equipment or outside the equipment altogether. This question must be asked each and every time that a fault is located.

This step also involves some checking-out to establish that no other faults can exist, and also to take preventive maintenance into account. In other words we need to ask "Is there any other suspicious looking component or device that needs attention as well?"

The goal at the end of Step 4 is that decisions should have been made. For example:

- a decision has been that component X is faulty
- a decision has been that overstressed component Y is the cause of the fault
- a decision has been made to substitute the printed circuit board rather than attempt repair on site
- a decision has been made that no other fault(s) exists, that no other cause(s) exists
- a decision has been made that some tightening of brackets and some cleaning is necessary.

The four-step approach has led, in this case, to five decisions which will be put into practice when the rectification is done. (Reference to the two-stage control model in Module 6 shows how this four-step approach fits into the whole process of fault finding, diagnosis, rectification and verification).

PRACTICAL EXERCISE 7

This exercise can be done in two ways. One could be called 'on-line', and the other 'off-line'. In some companies these are called 'on-the-job', and 'off-the-job'.

On-line

The very next time that a symptom is reported, take a conscious decision to apply this basic four-step approach.

At the end of the fault finding diagnostic task, whether the outcome has been successful or otherwise, answer the following questions.

1 How clearly did you identify the symptom(s) at Step 1?

2 Are you satisfied that, given the circumstances, you fulfilled the requirement of Step 1?

3 How well did the symptom-function technique and/or bracketing isolate the functional block where the problem existed.

4 Was Step 3 needed on its own, or could you combine Step 3 and Step 4?

5 Do the techniques described in Section D or your own techniques fit well into this four-step approach?

6 Can you explain why you either agree or disagree with the claim that this approach has a general application across all fault finding diagnostic tasks?

Off-line

Here is a common symptom(S), and that symptom's most commonly associated fault (F) and cause (C); for example:

- unsteadiness on feet (S)
- impaired senses (F)
- cause ?

Now **you** think of a common symptom, with its most common faults and causes. In the space below, write down a brief explanation of how each step could be applied in that situation.

Now read through Example 11.

EXAMPLE 11

Here is an example of the use of the on-line four-step trouble-shooting approach to a fault on a packaging machine in a pharmaceutical company.

Step One

Symptom reported is 'jamming on tablet-packaging machine'. Operator is asked to clear the jam, and to run the line again to observe the jam. Symptom is clearly a jamming at the first holding mechanism on the line.

Step Two

Symptom-Function is used to draw an imaginary boundary around the problem space. This is between the hopper feeder and the site of jamming. The fault, and cause of the fault, is most likely to be in this functional area, the 'line feed function'.

Step Three

Isolate to more precise part.

Here we use:

- questioning and listening (Module 1)
- visual search (Section D, Module 2)
- known comparison (Section D, Module 3).

Questioning and Listening

TS = Troubleshooter
OP = Operator

TS "What can you tell me?"

OP "All I can say is that it's jammed, and all I have done is change to a new packet. But that's only a different colour, so it can't be that".

TS "What adjustments have been made?"

OP "None."

TS "You say there has been no product change or line speed change."

Visual search, touching of mechanism at site of the jam and at hopper feed. Then Known Comparison technique is used.

Troubleshooter: "Can we run on old packets?"
Operator: "Okay".

The result is fault-free running.

Step Four

Careful visual inspection of packets old and new, side-by-side, shows that there is a slight change in packet configuration.

The decisions made at the end of the four steps are:

- decision to re-adjust the cams to take the new packets
- decision to record this case in the line log (machine history)
- decision to notify the packaging design department that slightest changes of this kind affect production
- decision to request that all changes to packaging material, material thickness, and packaging configuration be notified to production and maintenance in advance.

Comment on Example 11

In a situation of this kind, even using the four-step approach, the outcome could be the fixing of the fault only and not the cause.

The cause is only covered by communicating to the source of the cause, in this case the packaging design area.

In Summary

Symptom	=	package jamming
Sign	=	only with new packaging
Functional Area	=	line feed
Fault	=	mis-match of line adjustment and new packet
Cause	=	lack of advance notification of change
Verification	=	no further problems following adjustment to new packaging

Feedback = (a) communicate request to the design department
(b) record in line log
(c) copy to production/maintenance supervision.

Techniques Used

Symptom-Function
Visual Search
Known Comparison.

Now, you think of a common symptom, its most commonly associated fault and cause, and use the off-line method. In the space below write a brief account of how the four-step approach can be used in that situation. If you wish, you can go back to page 65 and re-read the six questions that followed the on-line exercise.

SECTION F: TECHNIQUES IN USE

WHO SHOULD WORK THROUGH THIS SECTION?

- troubleshooters
- process/production engineers.

WHAT YOU WILL NEED

- a pen and notebook
- access to colleagues to discuss technique used.

HOW MUCH TIME?

- You will need to allow between 35 and 45 minutes to work through this section.

AIM OF THIS SECTION

The aim of this section is to provide you with examples of technique use.

OBJECTIVES OF THIS SECTION

At the end of this section you should be able to:

- find faults and identify causes
- practise techniques
- consider wider implication of technique use.

INTRODUCTION

This section consists of some practical exercises to help you see how techniques are typically used. Some examples are job-related, and some are provided to stimulate your thoughts about fault finding and diagnosis.

There are 'model' answers for this section on page 85 onwards.

EXERCISE 8: FUNCTIONAL BLOCKS

When using the symptom-function technique it is necessary to divide circuits or machines into functional blocks.

Look at FIGURE 8 and see how you would divide this into blocks. Simply draw boundary lines around parts of the circuit lightly in pencil. (You need not be concerned about knowing how the circuit works).

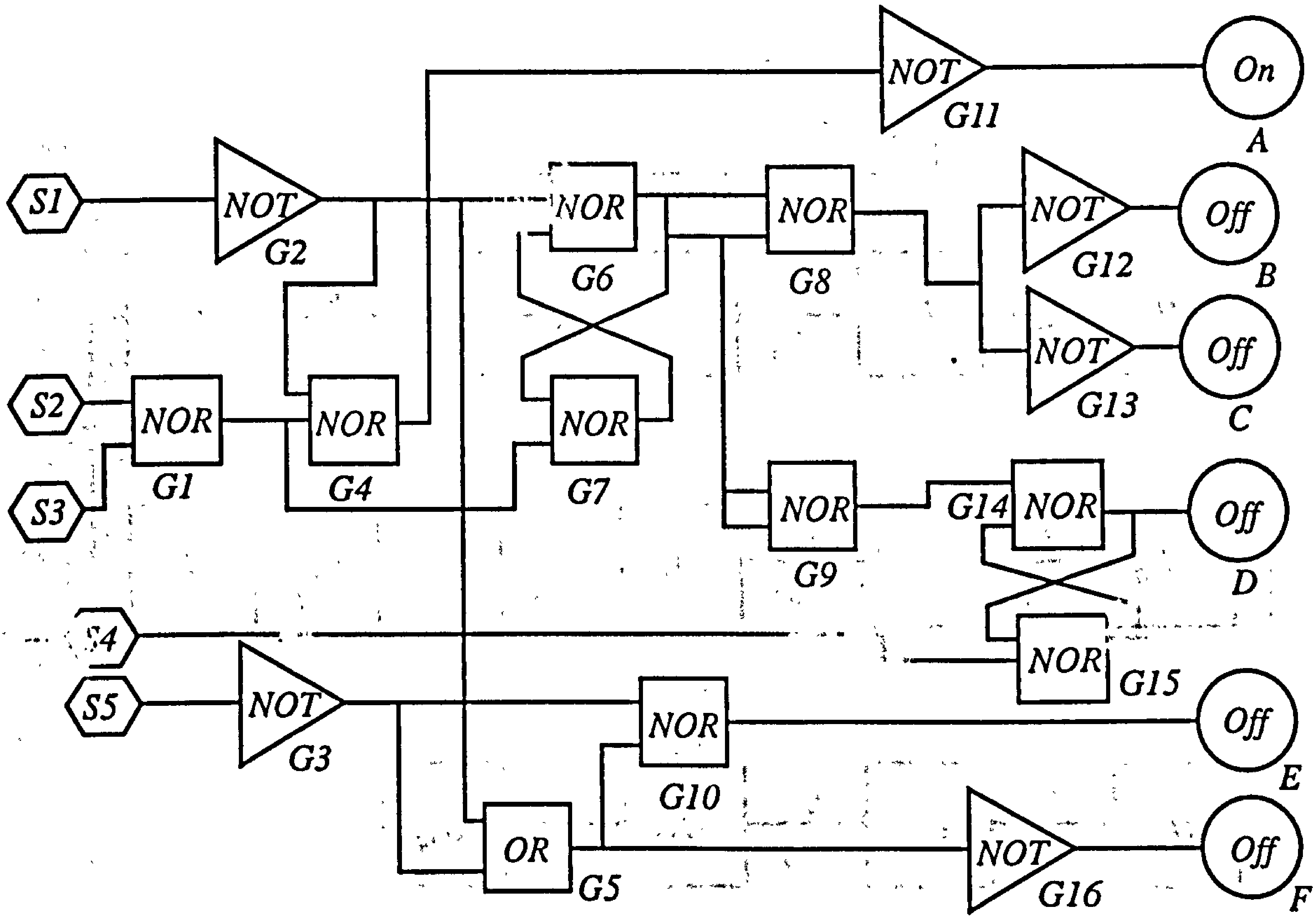


FIG. 8

EXERCISE 9: HALF-SPLITTING

Look at FIGURE 9 and see how many tests are needed to locate the faulty unit.

The units are marked U1 to U14.

The testing of lines between the units is done by a page-turning 'simulation'. (Clever stuff!)

For example, if you want to know the state of line D, turn to page 25 of this Module. This is how you simulate the act of testing.

Use the half-split technique described in the previous section to locate the faulty unit in as few tests as possible. Record each as you do it in the Recording Box.

Recording Box

Fault unit is U ....

No. of Tests ....

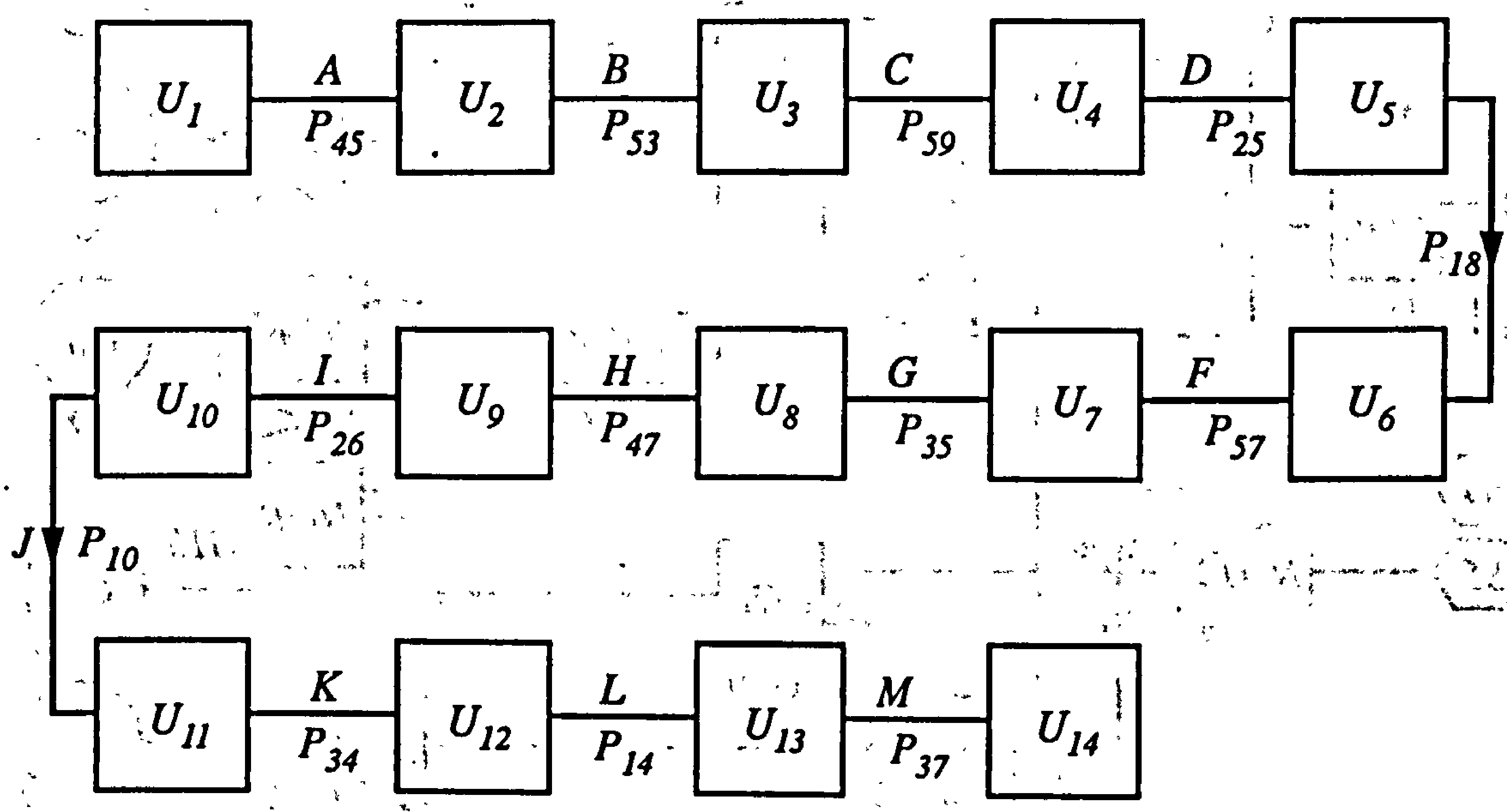


FIG. 9

EXERCISE 10: OUTPUT-TO-INPUT

Look at FIGURE 10 and use an output-to-input technique to find the faulty logic gate in as few tests as possible. Each time you want to test a line, use the page-turning simulation as in Exercise 9.

You need to know something about logic gates to do this exercise. If you don't, it is quite simple to pick up.

Each logic gate marked G1 to G5 has input lines (left-hand side) and output lines (right-hand side).

There are two types of logic gate here

1. The OR gate
2. The AND gate.

HOW THE 'OR' GATE WORKS

This gate gives 1 at output if **either** or **both** input lines are at 1. The gate gives a 0 if both input lines are at 0.

SUMMARY OF 'OR' GATE

Inputs		Outputs
1 1	=	1
1 0	=	1
0 1	=	1
0 0	=	0

HOW THE 'AND' GATE WORKS

This gate gives a 1 at output if **both** inputs are at 1. If **either** or **both** inputs are at 0, the output will be 0.

SUMMARY OF 'AND' GATE

Inputs		Outputs
1 1	=	1
1 0	=	0
0 1	=	0
0 0	=	0

With this information, work backwards from the outputs of the circuit (X, Y and Z) to locate the faulty logic gate that is causing Y and Z to be off. (That is, why 0 signals are coming out of the circuit at these points).

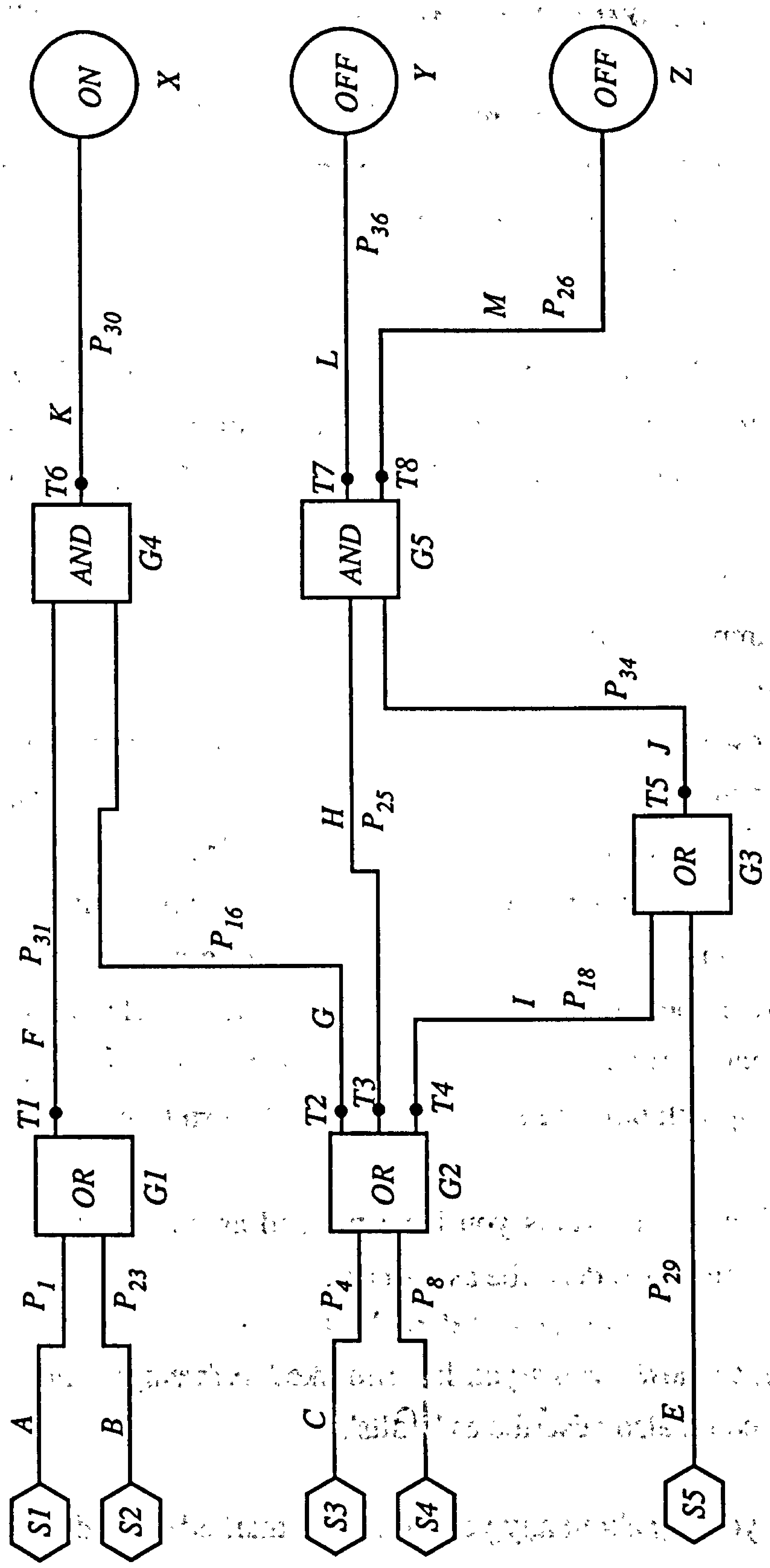
Final Note:

The actual fault will be at one of the terminals which are marked T1 to T8. You have to say which of these are at fault, and which is the cause.

Recording Box

Fault(s) is/are at ....

Cause is at ....



Note: P numbers on each line indicate pages in this module where test results can be found.
The same method of simulating tests is used for Exercise 9.

FIG. 10

EXERCISE 11: SYMPTOMS - CAUSES

This exercise follows on from the fact that in the last exercise there were two faults, but only one was in fact the cause of Y and Z being off. It is important in fault finding and diagnosis that a clear distinction can be made between faults and causes.

Look at the last of common events below and pencil lightly against each one whether you consider it to be a typical **fault** or a typical **cause** by writing **F** or **C** alongside each statement. (If undecided write **U** alongside).

Flat tyre
Lamp gone off
Worn clutch plate
Blown fuse
Jammed valve
Loss of pressure
Too high temperature
Pain in the side
Oil on the ground
Blocked radiator
Pump will not prime
Paper jammed in copier
Loss of vacuum cleaner
Suction
Cycle chain comes off
Bent cycle gear arm
Air in a system
Slipping clutch
Engine overheats
Bent cycle frame
Sink not draining
Worn tyre.

Now look at those events you have marked as 'faults', and see how many of them you could also describe as 'causes'.

Now look at those events you have marked as 'causes', and see how many of them you could also describe as 'faults'.

What can you say about any you may have marked as 'undecided'.

The next two exercises depart from job-related examples, and are included to broaden your thinking about the use of strategies.

EXERCISE 12: TOWER OF HANOI

Fault finding and diagnosis can be seen as a series of problem-solving games. Here is a well known game of this kind. The reason for using this as an exercise is to extend the idea of strategy use. Can you use any techniques to help find the solution to this problem quickly?

The Tower of Hanoi problem was invented by Edward Lucas in the nineteenth century, and can be done with any number of discs, if you have the time to spare, that is.

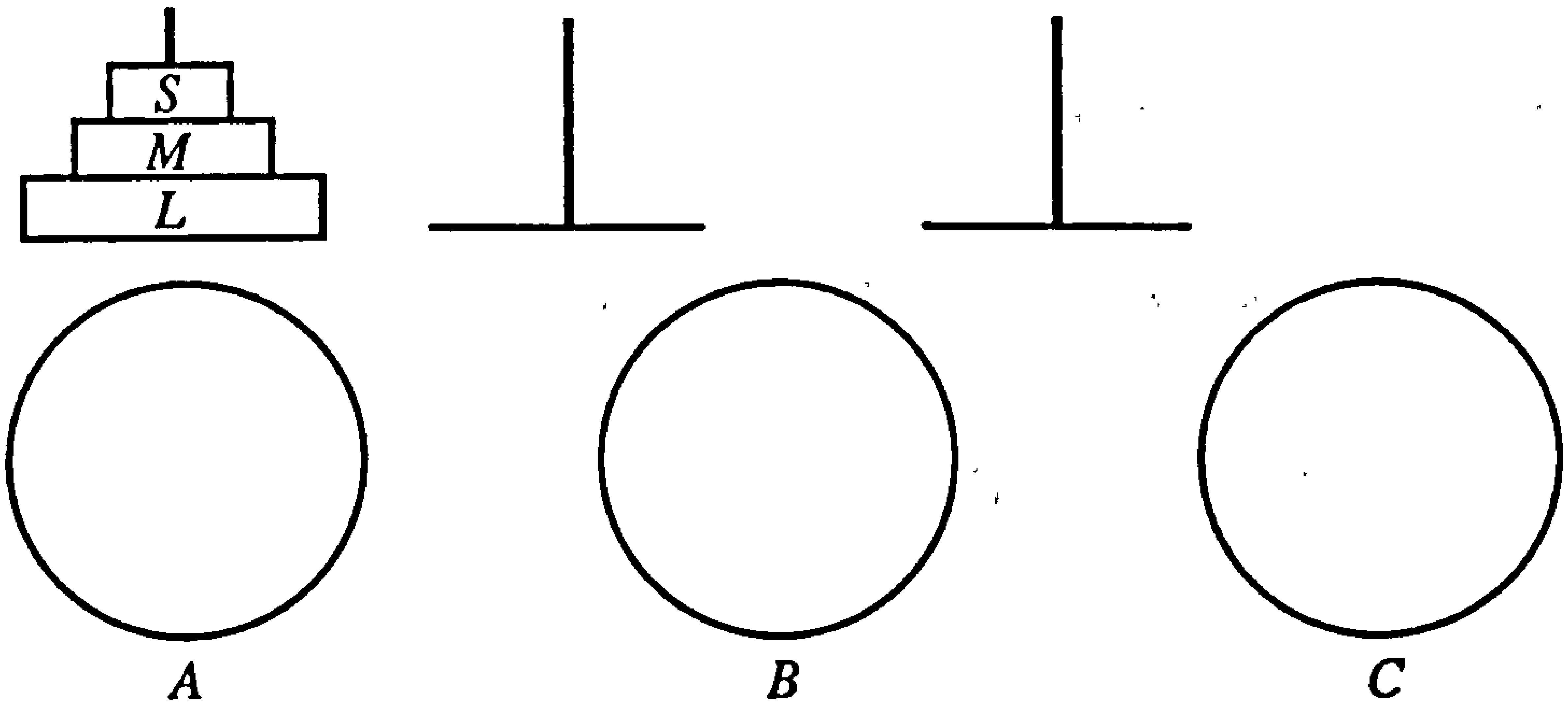


FIG. 11
TOWER OF HANOI PROBLEM

WHAT YOU HAVE TO DO

The Tower of Hanoi problem is normally done by using three upright rods as shown in FIGURE 11. For the purpose of this exercise we will use three coins: (10p, 2p, 1p).

Put all three coins into Circle A, largest at bottom, smallest at the top. The objective is to move all three coins from Circle A to Circle C. However, you can only move one coin at a time, never putting the coin down anywhere but in a circle, and never putting a larger coin on top of a smaller one.

As you make your moves record each one in the column below. For example:

COIN 1p = S
COIN 2p = M
COIN 10p = L

	A	B	C
1.	S		
	M		
	L	–	–
2.	M		
	L	S	–

FILL IN YOUR MOVES BELOW

(Then compare with result in the model answer on page 89.)

A B C

1. ....
2. ....
3. ....
4. ....
5. ....
6. ....
7. ....
8. ....

A B C

9. ....
10. ....
11. ....
12. ....
13. ....
14. ....
15. ....
16. ....

EXERCISE 13: THE NINE-DOT PROBLEM

Simply have a try at solving this problem. Then turn to the 'model' answer where you will find a short discussion about the relevance of this exercise to fault finding and diagnosis. (The solution is there too).

Join the dots together in pencil without going over the same line twice, without your pencil leaving the paper, and with only FOUR continuous straight lines.

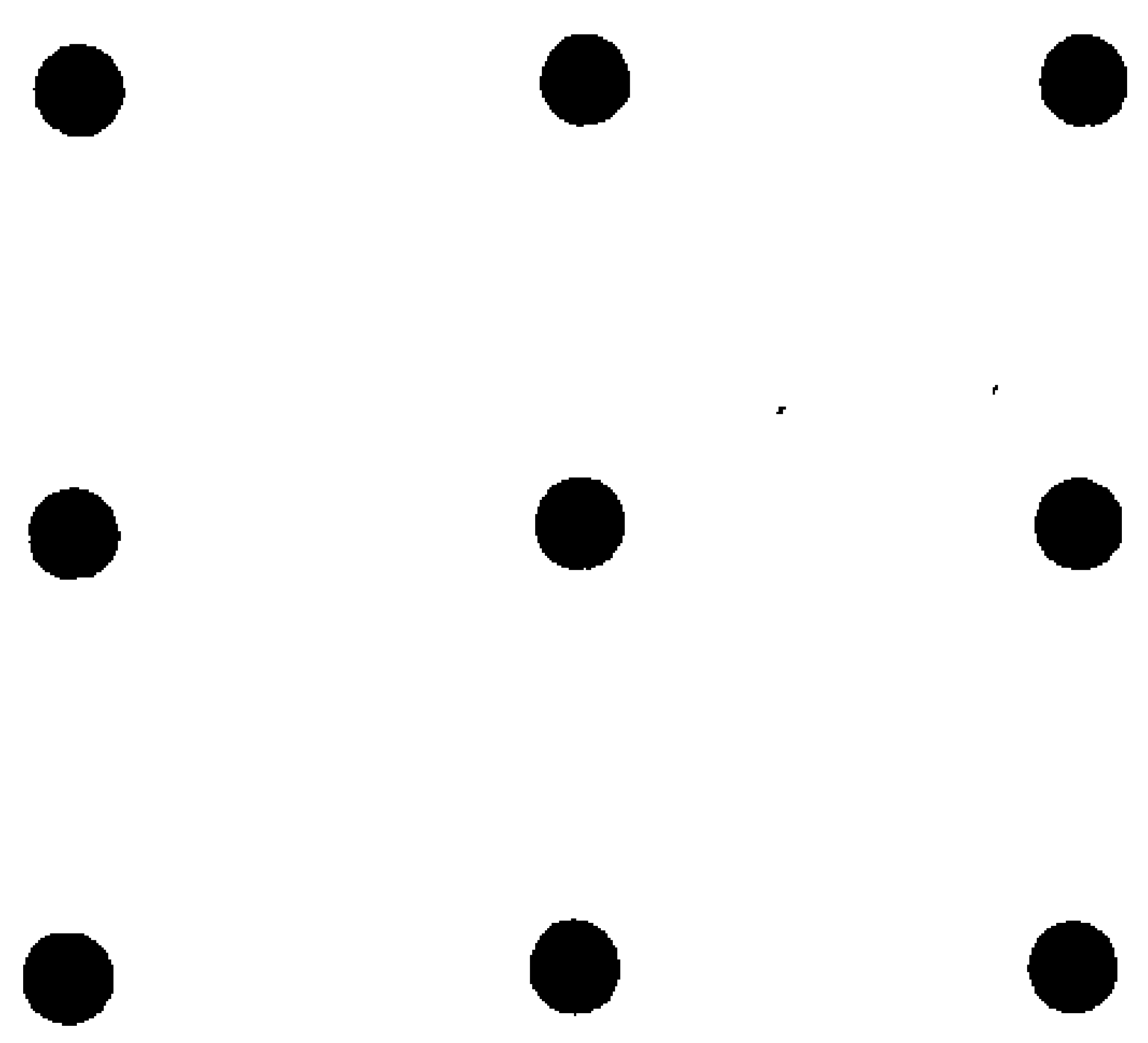


FIG. 12

EXERCISE 14: HANDLING COMPLEXITY

Look at FIGURE 13 and use the same approach to testing adopted in Exercise 9 and Exercise 10, using page turning.

This exercise is similar to Exercise 10, but this time it is more complex and uses more logic gates. You already know the working of the OR gate. Look back at Exercise 10 if you want a reminder.

Here are the new logic gates and how they work.

NAND Gate	This gate gives a 1 at output if **either** input is at 1 or if **both** inputs are at 0. If **both** inputs are at 1 the output will be 0.

NOT Gate This gate simply reverses the input. If the input is 1 the output will be 0. If the input is 0 the output will be 1.

NAND GATE

Inputs		Outputs
0 0	=	1
1 0	=	1
0 1	=	1
1 1	=	0

NOT GATE

Inputs		Outputs
0	=	1
1	=	0

Choose which lines to test to find the faulty gates. You must say which gates are at fault.

Note: P numbers indicate pages.

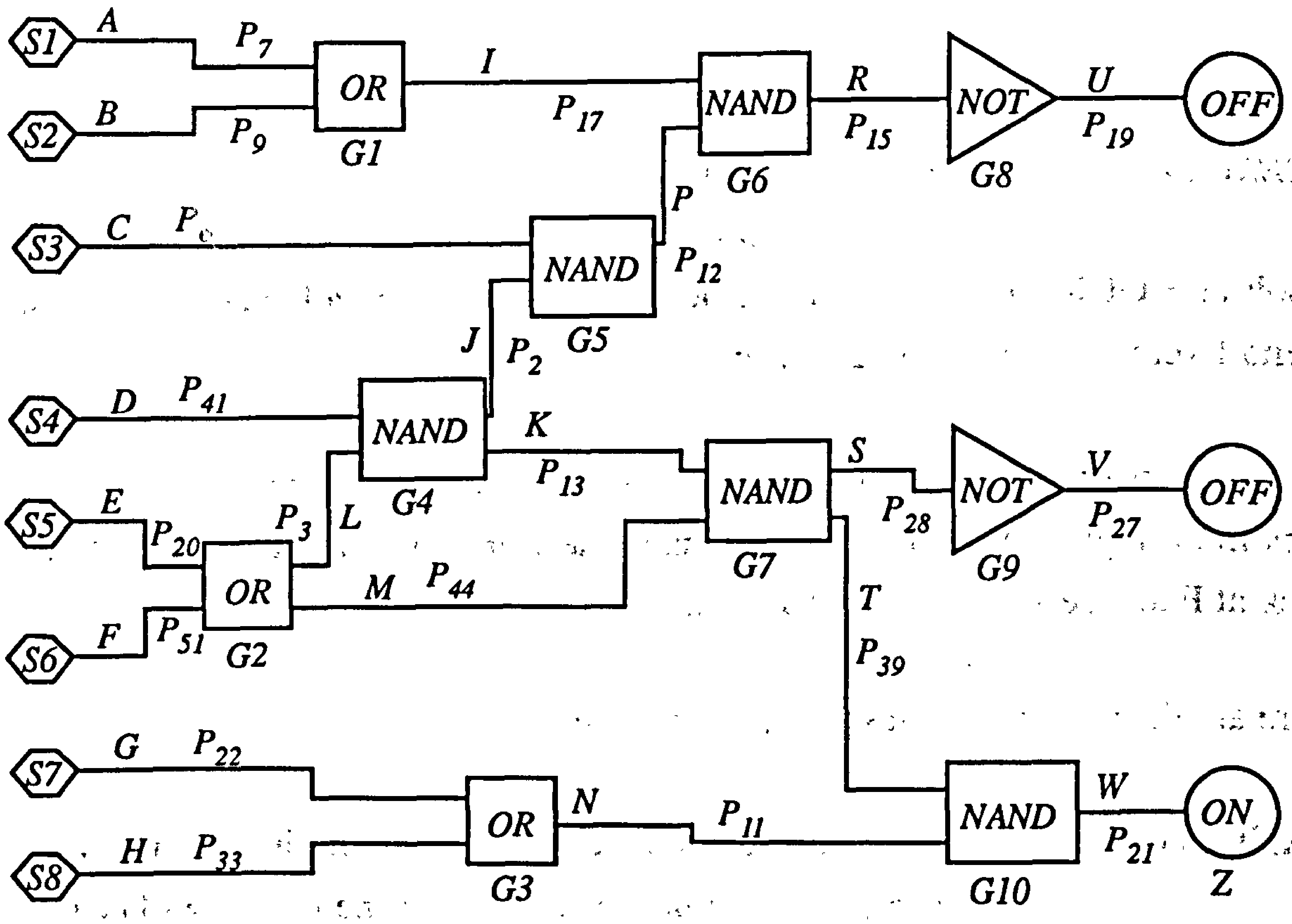


FIG. 13

MODEL ANSWERS TO SELF-DIAGNOSTIC QUESTIONS IN SECTION A

1. The answer you should have here is either the names of three fault finding diagnostic techniques, or a brief description of what you consider to be techniques.

   The 'model' answer is to be found in Section E, where techniques in common use are both named and described.

   The answer you have given to this question should reflect quite well your current use of techniques.

2. Again you must turn to material in this module to find a 'model' answer. In Section B you will find descriptions of the basic reference points used in fault-finding and diagnosis. Compare the answers you gave with the descriptions provided.

3. To give you a 'model' answer here we will begin with a description of a Saoris practice in India*.

> 'The patient is requested to hold
> a saucer filled with oil in which
> a wick is lighted.
> The medicine man drops grains into
> the flame and with every grain calls
> out the name of a spirit.
> The first grain that catches fire indicates
> which spirit caused the illness.'

*Harvey, AM (1979). *Differential Diagnosis.*

This is an objective, practical piece of diagnosis; no argument about that. A cause was identified. Only whether it was the correct cause can be open to question.

The word 'diagnosis' comes from the Greek word meaning 'to distinguish'. It is the distinguishing of symptoms, signs, and faults that leads, by analysis, to the identification of causes. This is the process of diagnosis. Having located the fault (fault-finding) we determine its cause (diagnosis).

A good answer to this question should include at least the fact that diagnosis is the analysis of information gathered between the symptom and the identification of the cause.

4. The main sources of error in diagnosis are as follows:

   (a) incomplete gathering of information (Module 1)
   (b) lack of a well thought out strategy for that particular symptom
   (c) being fixed on favourite solutions which leads to an approach that is too blinkered
   (d) incomplete or wrong technical knowledge about the system, the machine or a process
   (e) over reliance on 'experience'. As Oscar Wilde said, 'Experience is the name everyone gives to their mistakes'.

You may well have given other souices too. It is useful to know as many sources of error as possible.

5. If you tend to agree with this statement, you probably believe also that for any given piece of equipment or machinery there are hundreds, if not thousands, of possible symptoms and possible faults.

If this is the case, then a good idea is for you to think of a machine you know well and list all the symptoms and faults you can think of; have a private brain-storming session, or involve others if you wish. If you can produce lists of more than twenty symptoms and fifty faults, have a drink on me.

To cover such a range of symptoms and their related faults you should need, at the most, only four or five well-chosen techniques.

6. A case can made be for this statement, about troubleshooters that is, not leaders.

The evidence that does give some support to this view comes from the work of William Rouse in the United States. He has shown that effective and less-than-effective troubleshooters can be distinguished by the extent to which they are either reflective or impulsive. This is a measure of what is called 'cognitive style'. Effective troubleshooters are more reflective. It is extremely difficult, if not impossible, to make particularly impulsive people more reflective. This means that the natural approach someone brings to a fault finding diagnostic task can influence how effective they will be. This information has implications for the way that troubleshooters are selected in the first place.

7/8. The last two questions are asked simply as a means of helping you to assess your current position with regard to the use of techniques.

EXERCISE 8

The circuit used for this exercise appears again below. This time, boundaries have been drawn around parts of the circuit in order to divide into blocks. This can help in reducing complexity, and also helps in reducing the number of tests required.

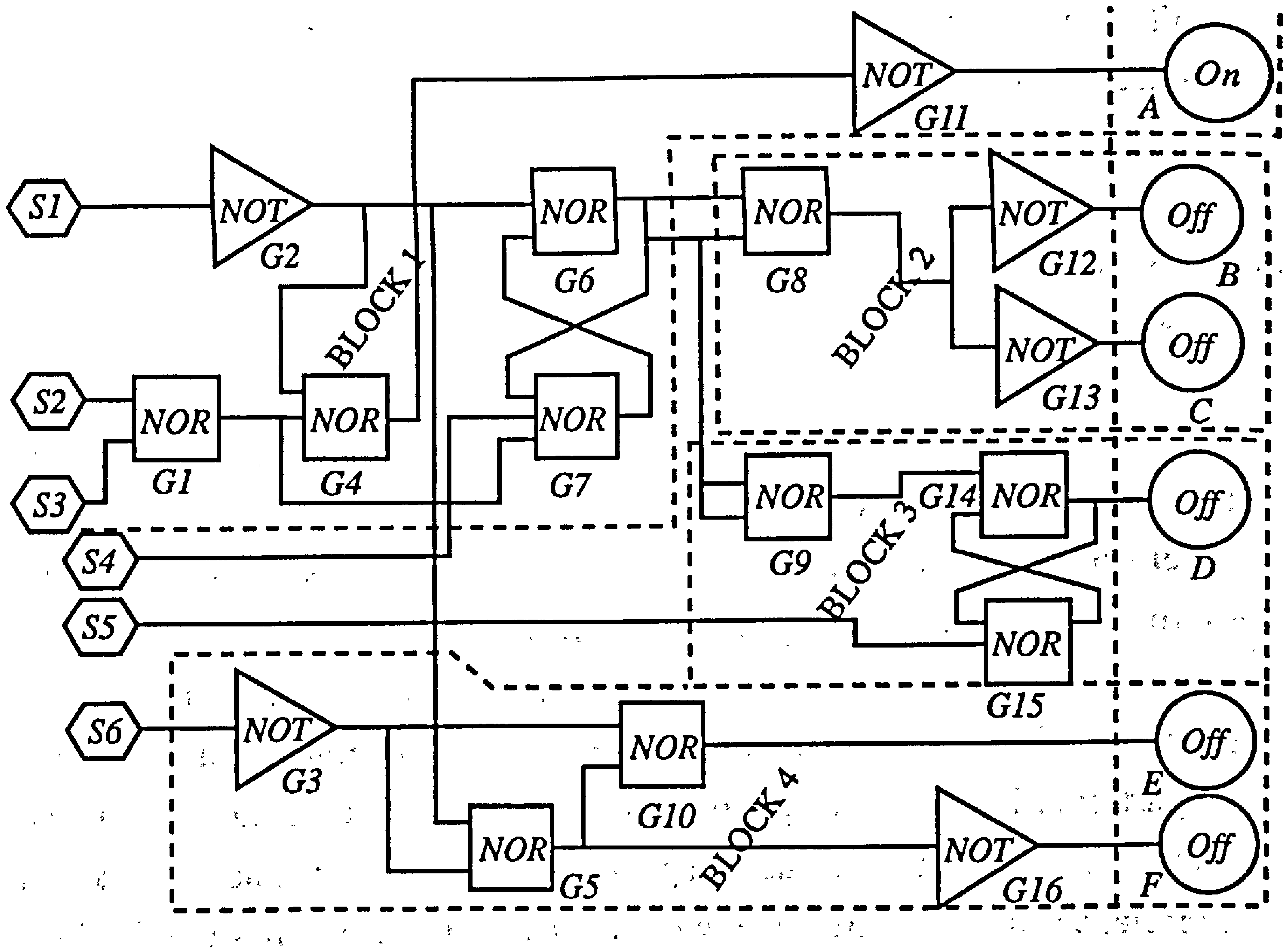


FIG. 14

EXERCISE 9

The line of linked units used for this exercise could be, for example, a frequency divider chain in which the input is 1 MHz from an oscillator. You can compare the number of tests needed if Input to Output technique is used compared with Half-Split technique. *

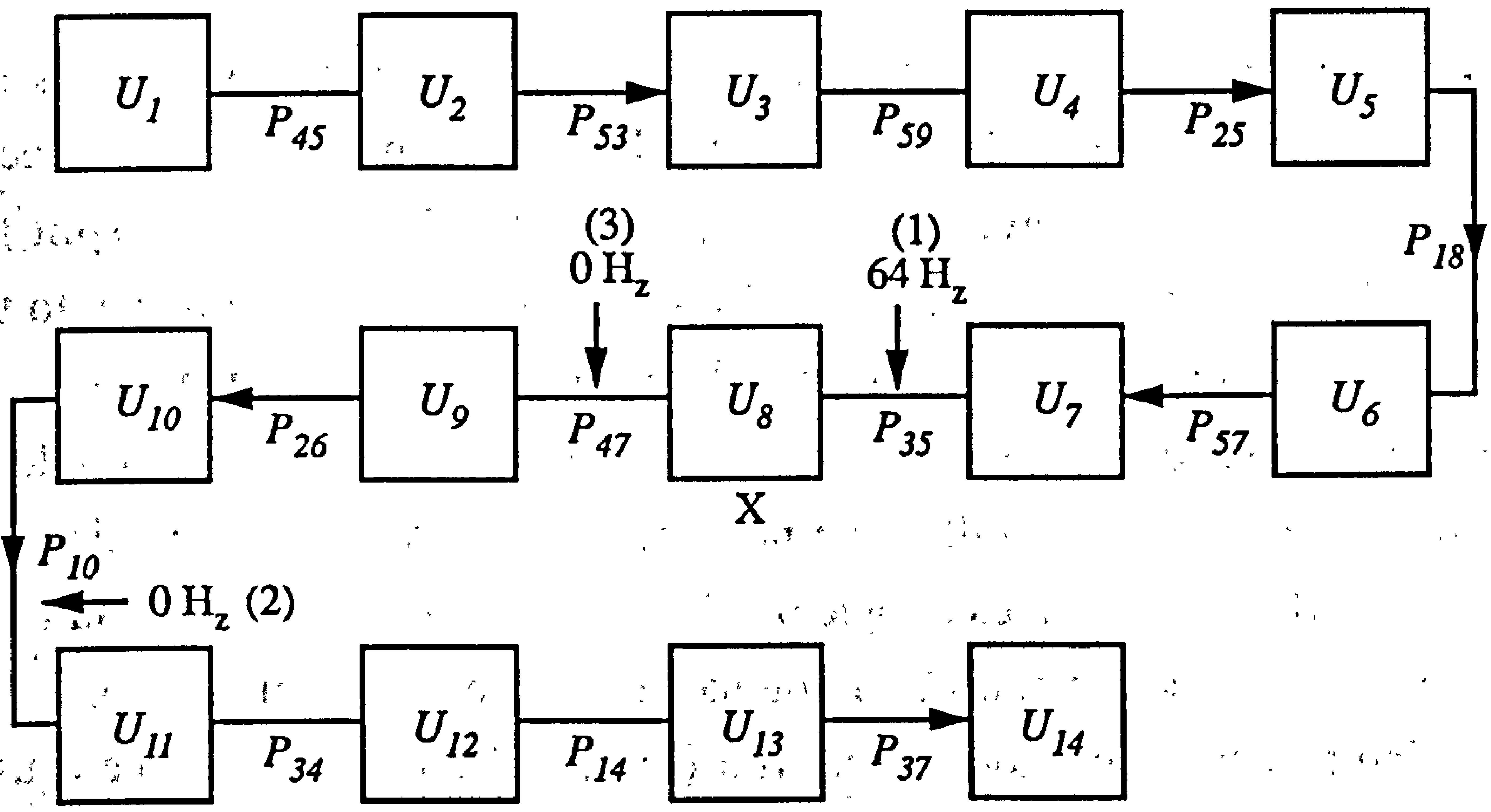


FIG. 15

* Formula for Input to Output is : $C = \frac{1}{2n} (n-1)(n+2)$

Where n = number of units, and C = means number of tests.

* Formula for Half-Split is $C = 3.32 \log_{10} n$.

EXERCISE 10

The circuit used in this exercise appears again below. This time we will use it to 'talk through' techniques in use.

The information that X is on tells us a good deal. It will help if you look back at Exercises 5 and 6 at this point on the use of negative information.

In this case the information is telling us that a number of logic gates are operating correctly. The dotted boundary line can simply be in your head rather than on paper. Having done this, you have effectively half-split the circuit. Now you ask, "What is it that I do not know?" This leads you to the area or 'block' outside the dotted line. Using input-to-output, the line E is tested and found to be at logic 1. The other line into G3 is an example of redundant information: it will make no difference to the output of this gate. The output when tested gives a logic 0, when it should be logic 1. A fault lies at T5, but is this also the cause? If you had tested the line from G2 to G3 you would find this at logic 0 too. There is a fault at T4 but this is not the cause. You should be able to see that fixing this will not make the two outputs change to ON. The fault and the cause is at T5.

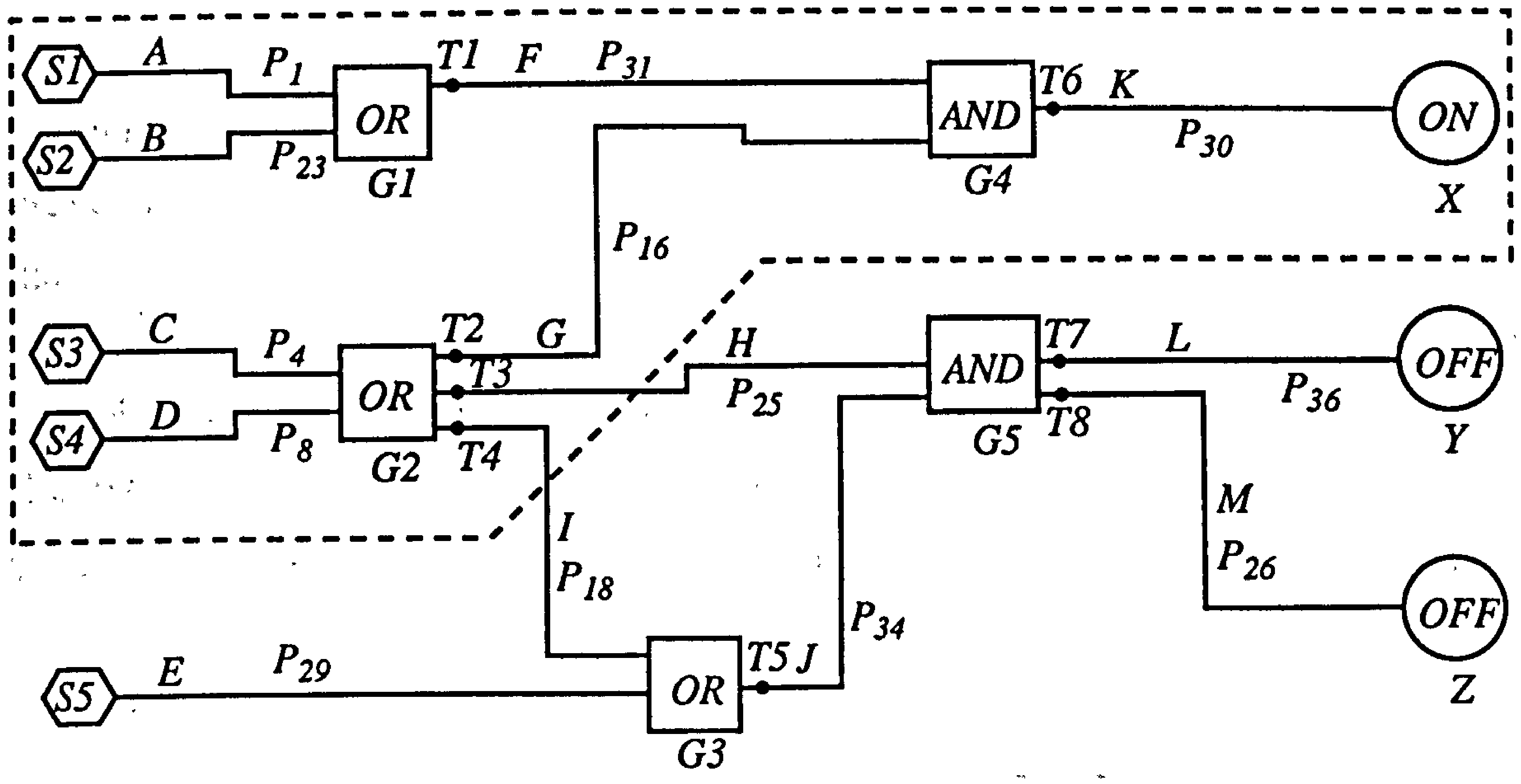


FIG. 16

EXERCISE 10

The aim of this exercise is simply to emphasise that the distinction between 'fault' and 'cause' is not always clear-cut. In other words, some events you marked as typical faults can, in certain cases, be seen as causes, and some causes can be seen as faults. The doubtful ones, if you had any, reinforce this point.

EXERCISE 12

The Tower of Hanoi can be, and most often is, solved by use of the Random Search Technique. It can, however, be solved using a Decision-Tree Technique. In the case of the three-disc version of the problem there are seven branches to the tree. This method of recording moves is similar to the action of a troubleshooter who records test results when the steps are too complex to hold in short-term memory. An example of a decision tree for the Tower of Hanoi problem is shown in FIGURE 17.

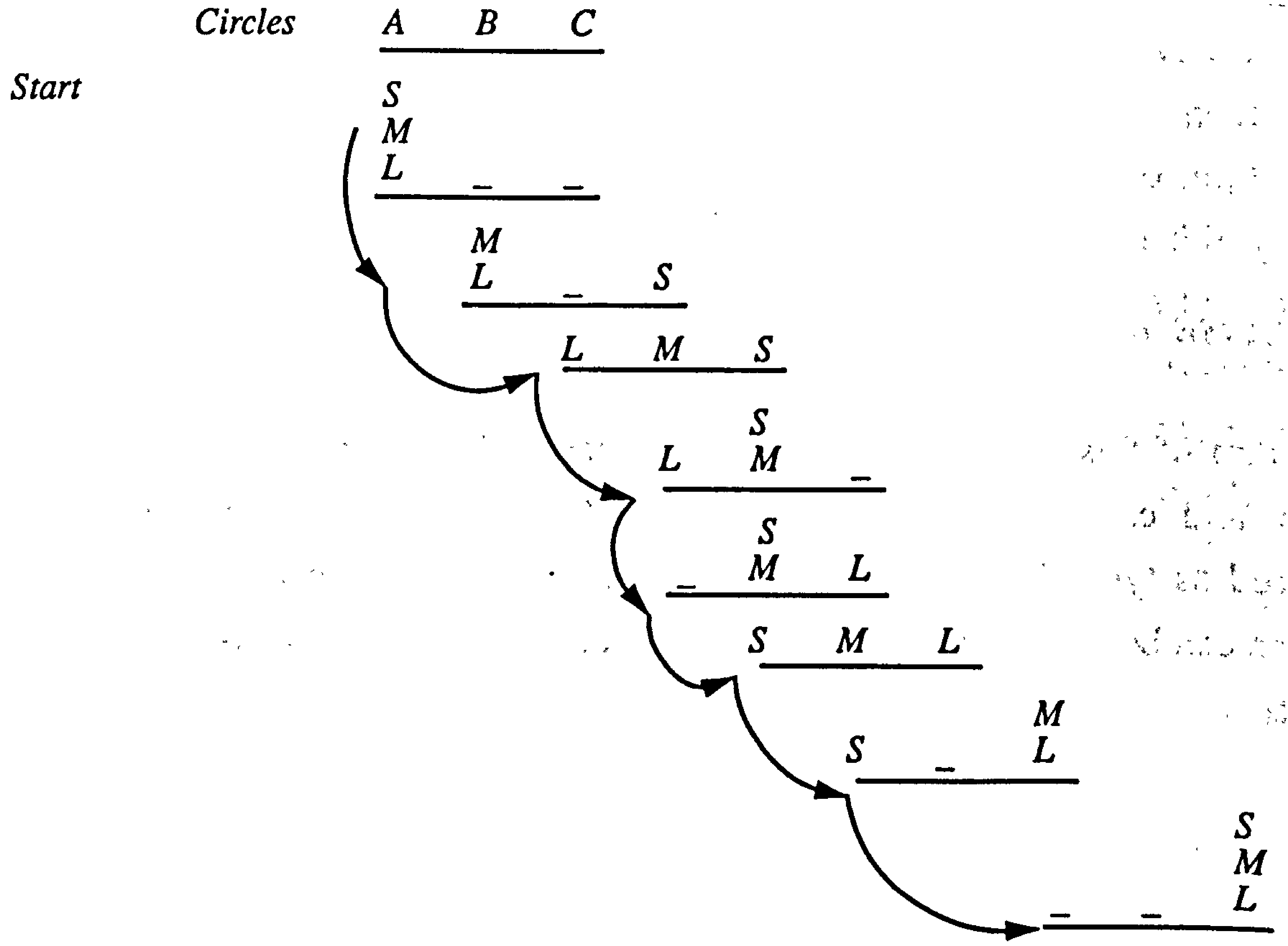


FIG. 17

EXERCISE 13

Although a simple exercise, this nine-dot problem does have an important message for people who must fault-find and diagnose. The message is that we so easily adopt what is called a 'mental set', that is seeing one or two ways to tackle a task and not being able to do something quite different in order to find a solution.

There are a number of opportunities where this can happen when doing fault finding and diagnostic tasks. When tried and tested methods let us down, it can be difficult to think of alternative explanations.

If you had difficulty solving this problem, it was probably because you were fixed on the idea that you had to remain in the area formed by the dots. Alternative thinking did not extend to going beyond this area.

There is both a message and a lesson to be gained from this simple exercise.

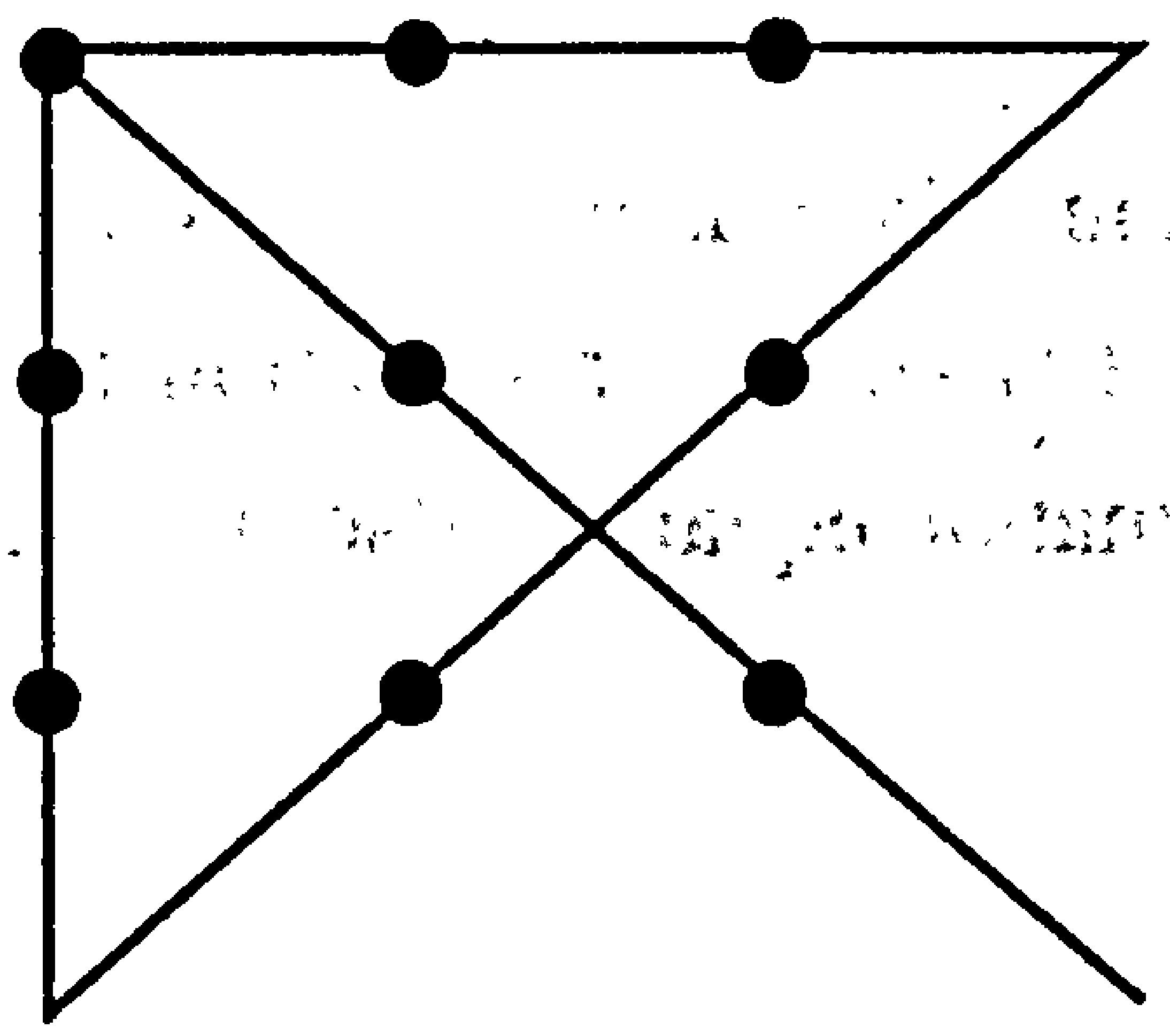


FIG. 18

EXERCISE 14

The circuit used for this exercise is given again in FIGURE 19.

The knowledge that output Z is ON does not give us much information on this occasion. We can, however, isolate out the bottom 'block' containing gate G3. Looking at the top 'block', we can make the expectation statement that line R must be at logic 1 if the gate G8 is working correctly. Testing line R we find that it is at logic 0. This means that gate G8 is not working correctly.

If gate G9 is working correctly, then line S must be at logic 1. Testing line S gives logic 1 as expected. The expectation can be stated that lines K and M must either be at logic 0 or only one is at logic 0. Testing gives line M at logic 1 and line K at logic 0, as expected. We can now say that if line K was at logic 1 instead of logic 0, the conditions would be right for output Y to change to ON. Checking input of gate G4 at line D gives logic 0. Therefore, with line L being at logic 1, gate G4 should be giving logic 1. This means that gate G4 is also faulty. Therefore, with both gates G4 and G8 working correctly, the two outputs X and Y should be ON.

The combination of techniques here is to see the circuit as a set of functional blocks. Asking at each test what that information is telling us gives us both positive and negative information equally. Also, you can use output-to-input at the individual gate level.

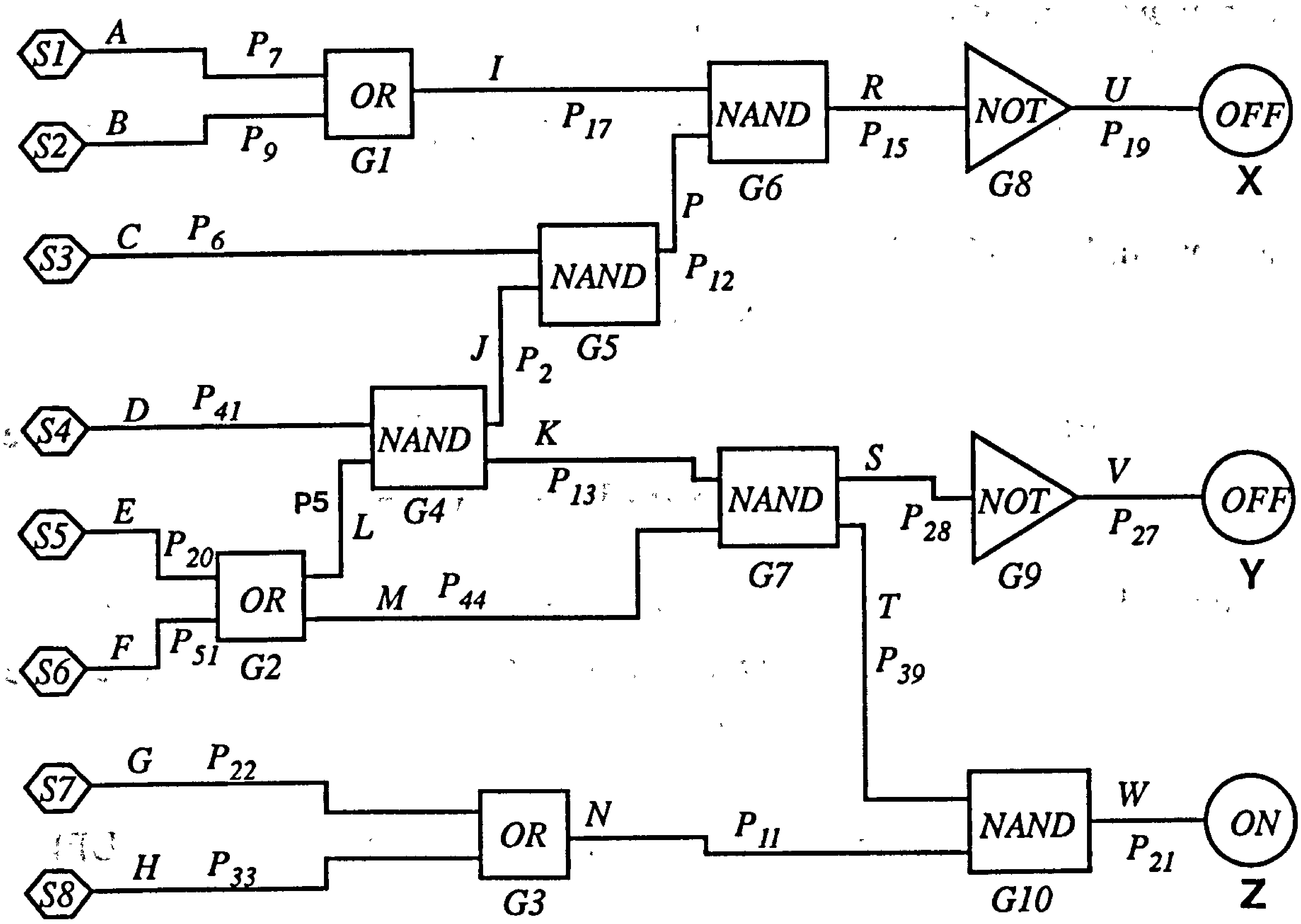

S1
A
P7
S2
B
P9
OR
G1
I
P17
NAND
G6
R
P15
NOT
G8
U
P19
OFF
X
S3
C
P6
NAND
G5
P
P12
J
P2
S4
D
P41
NAND
G4
K
P13
P5
L
S5
E
P20
OR
G2
S6
F
P51
M
P44
NAND
G7
S
P28
NOT
G9
V
P27
OFF
Y
T
P39
S7
G
P22
S8
H
P33
OR
G3
N
P11
NAND
G10
W
P21
ON
Z

FIG. 19

USEFUL REFERENCES

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Training
in
Fault Diagnosis

A Systems Approach

Module 3

Systems Thinking

Malcolm Craig.
1991.

CONTENTS

INTRODUCTION

Knowledge of systems-thinking is important for anyone who is involved in fault-finding and diagnosis.

The overall aim of this module is to raise your level of awareness about this way of thinking. This is because systems-thinking provides us with a ready means of seeing order in the complexity that troubleshooters, operators and management come across increasingly in the technology-driven workplace.

Put quite simply, systems-thinking is about 'wholeness', that is helping us to gain **a total picture** of the immediate system we are concerned with, and how this system affects and is affected by other systems.

Two thoughtful characters, some years ago, wrote about 'wholeness' in different ways:

Euclid:	"The whole is equal to the sum of the parts".
Aristotle:	"The whole is greater than the sum of its parts".

It is the second view, that of Aristotle, that we accept generally when talking about systems-thinking.

SECTION A: SELF-DIAGNOSTIC QUESTIONS

WHO SHOULD WORK THROUGH THIS SECTION?

- troubleshooters
- process/production engineers
- supervisors
- managers.

HOW MUCH TIME?

- You will need to allow between 30 and 40 minutes to complete this section.

WHAT YOU WILL NEED

- pen, notebook
- access to area of work for observation purposes.

AIM OF THIS SECTION

The aim of this section is:

- to help you to gain awareness about strategy use in fault finding and diagnosis.

OBJECTIVES OF THIS SECTION

At the end of this section you should be able to:

- recognise systems and sub-systems in your place of work
- see machines and/or processes as systems and sub-systems

- describe work-related systems in terms of their boundaries, environment and parts
- describe two types of relationship between parts of a system in your work.

INTRODUCTION TO SELF-DIAGNOSTIC QUESTIONS

Unlike other modules in this training series it is necessary here to give you a 'lead-in' to the self-diagnostic part – not a great deal of information, just enough to get you started.

This is because systems-thinking, as a subject, will be less familiar to you than the starting point of the other modules.

Each question in this section is preceded by background information.

BACKGROUND TO QUESTION 1

Thinking about Systems

Most people are familiar with the word 'system'. For example, typical comments to be heard are:

- "The system is to blame".
- "The system has gone down".
- "There are no systems in this place".
- "The system works against the poor".

When people make such comments it must be assumed that they, and the people spoken to, share a common understanding of what is meant by 'systems'.

QUESTION 1

What is your understanding of the system you work in?

Using the space below, write down a few details about why you would (or would *not*) call it a 'system'.

....

....

....

....

....

....

....

....

....

BACKGROUND TO QUESTION 2

Thinking about Types of Systems

There are many types of system. For example, here are a few common systems in everyday use:

- air traffic control system
- central heating system
- football transfer system
- university grants system
- office computer network system.

Can any list be more varied?

With respect to fault finding and diagnostic work, the possible systems are generally less varied. Here are a few possibilities:

- stores control system
- microprocessor control systems
- pneumatic layout system
- inward goods system
- plant maintenance system.

QUESTION 2

What systems do you recognise as affecting the work you do?

List the systems which affect your work directly or indirectly, using the space below.

....

....

....

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BACKGROUND TO QUESTION 3

Size of Systems

Systems can be extremely large in terms of area covered, number of people involved, and support needed. The European Community is an example of a very large economic and social system.

Systems can also be small: a computer programming home-working system is an example of a small system.

Systems can even be extremely small, for example a microchip operating system. Normally systems of this size are seen as sub-systems, but we will deal with this later.

QUESTION 3

In your work:

(a) what is the largest system?
(b) which system(s) would you describe as 'small'?
(c) which system(s) would you describe as 'extremely small'?

Write your answer in the space below.

....

....

....

....

....

....

....

BACKGROUND TO QUESTION 4

Systems and sub-systems

The simplest way to think of systems and sub-systems is to consider yourself for a moment. You represent what could be called a 'human-movement system' with lots of parts working together. Within this system there are a number of what can be called 'sub-systems', for example:

- blood circulation sub-system
- respiratory sub-system
- nervous sub-system
- digestive sub-system.

Going back to our earlier comment about 'wholeness' you could be said to represent more than the sum of the parts. It is, however, the **working together of these sub-systems** that produces the whole, or total system that is you.

An interesting point about diagnosis is that a medical general practitioner will recognise you as a whole system. On the other hand, a person who specialises in, say, the nervous sub-system would treat this part as though it was a whole system in itself. Similarly, troubleshooters who specialise in microelectronics tend to treat this part of the process as a whole system, rather than what it is, a sub-system dependent upon other parts of the whole system, and upon other whole systems in the organization.

QUESTION 4

Think about a machine or a process you know well, what are its sub-systems?

Write down a list, or draw a simple diagram to show the sub-systems of a machine or a process that you are familiar with in your work.

BACKGROUND TO QUESTION 5

Describing Systems

When thinking about systems for the purposes of fault finding and diagnosis, there are three basic things that a system must have:

- a boundary
- an environment
- people, goods, machines, processes.

These can act together in two ways.

1 One simply acts on the other, i.e. influences, directs, tells.

2 They interact, i.e. one acts with the other, and vice versa.

First, the **boundary** can be the factory walls, but does not have to be. The boundary can be an imaginary line that you can use to enclose all parts of the system as you see it; these parts do not have to be in one physical place. Think of your milkperson's delivery system: the boundary may well enclose not only the 'round', but also the vehicle depot, collection depot and office.

Next, the **environment** is composed of all the parts which affect, or can be affected by, our whole system within the boundary. These environment parts do not control and are not actually part of your whole system. They are out there in the environment, exerting influence.

Last, the parts that go to make up your system consist of **people (usually), goods, processes, machinery, etc.**

There are practical industrial examples of boundary, environment and systems parts in this module. The relationship between boundary, environment and parts is shown in FIGURE 1.

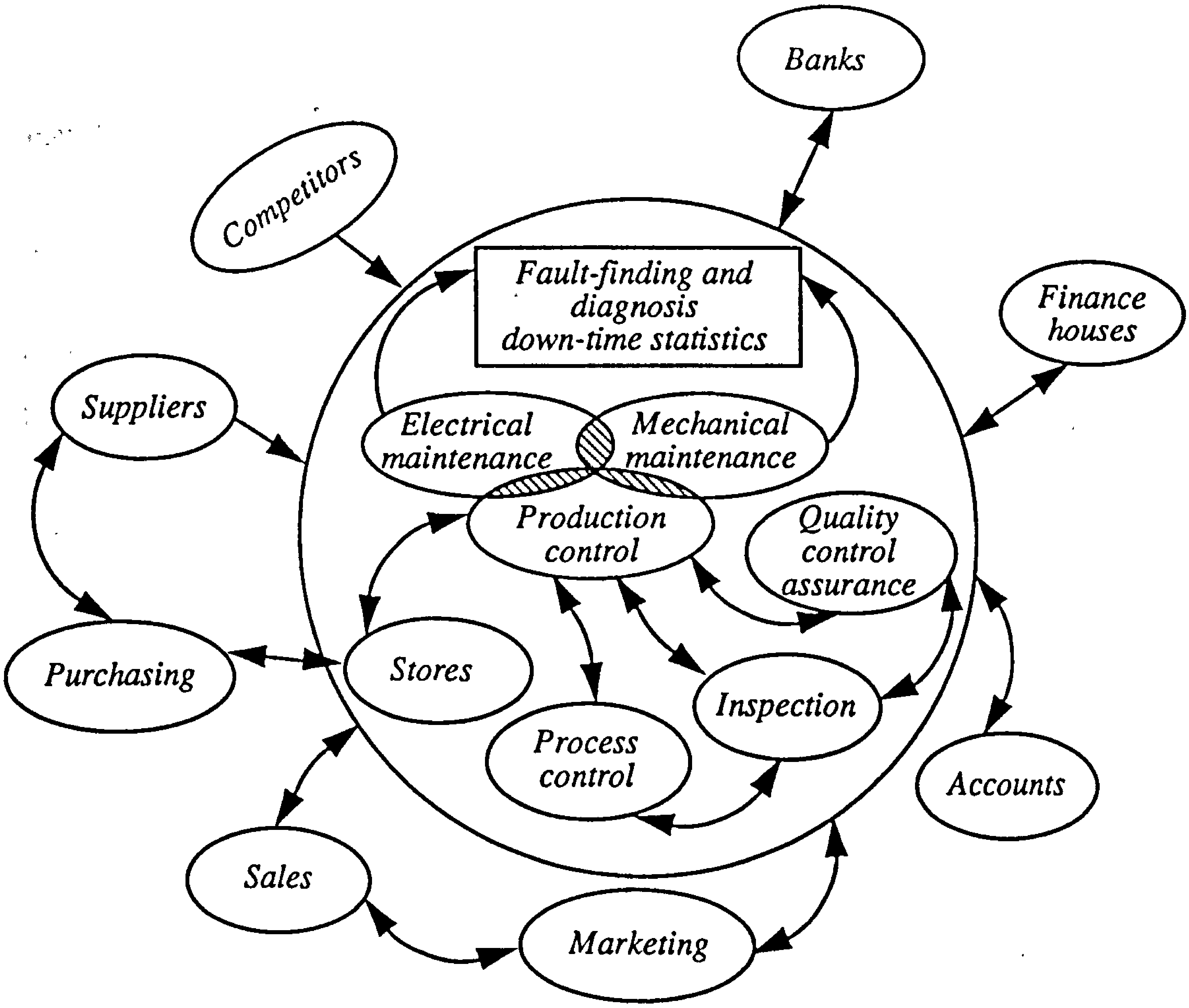

FIG. 1

If you worked in such a system it is possible that you would draw a different relationship. Other parts would be included, some taken out, parts in the environment included in the system and vice-versa. This is the purpose of such systems diagrams – to make you think about our own situation. Sometimes the end result is to trigger off changes or to provide new insight into how you work.

Look carefully at FIGURE 1 again before answering Question 5.

QUESTION 5

How would you describe the system you operate within at work, its boundary, its parts and its environment?

Draw a diagram, following the example of FIGURE 1.

BACKGROUND TO QUESTION 6

Influences

Every part of a system acts on other parts, or interacts with other parts. Also, most parts of any system act on or interact with parts in the system's environment. For example, a troubleshooter (mechanical) will typically interact with colleagues, operators, supervisors, managers, etc. He or she may also interact with outside contractors, fuel suppliers and customers, all within the system's environment.

When one part acts on another (i.e. influences, directs, tells, etc.) we draw a line and arrow to show the direction of influence. When one part interacts with another, we draw a line or two arrows. See FIGURE 2.

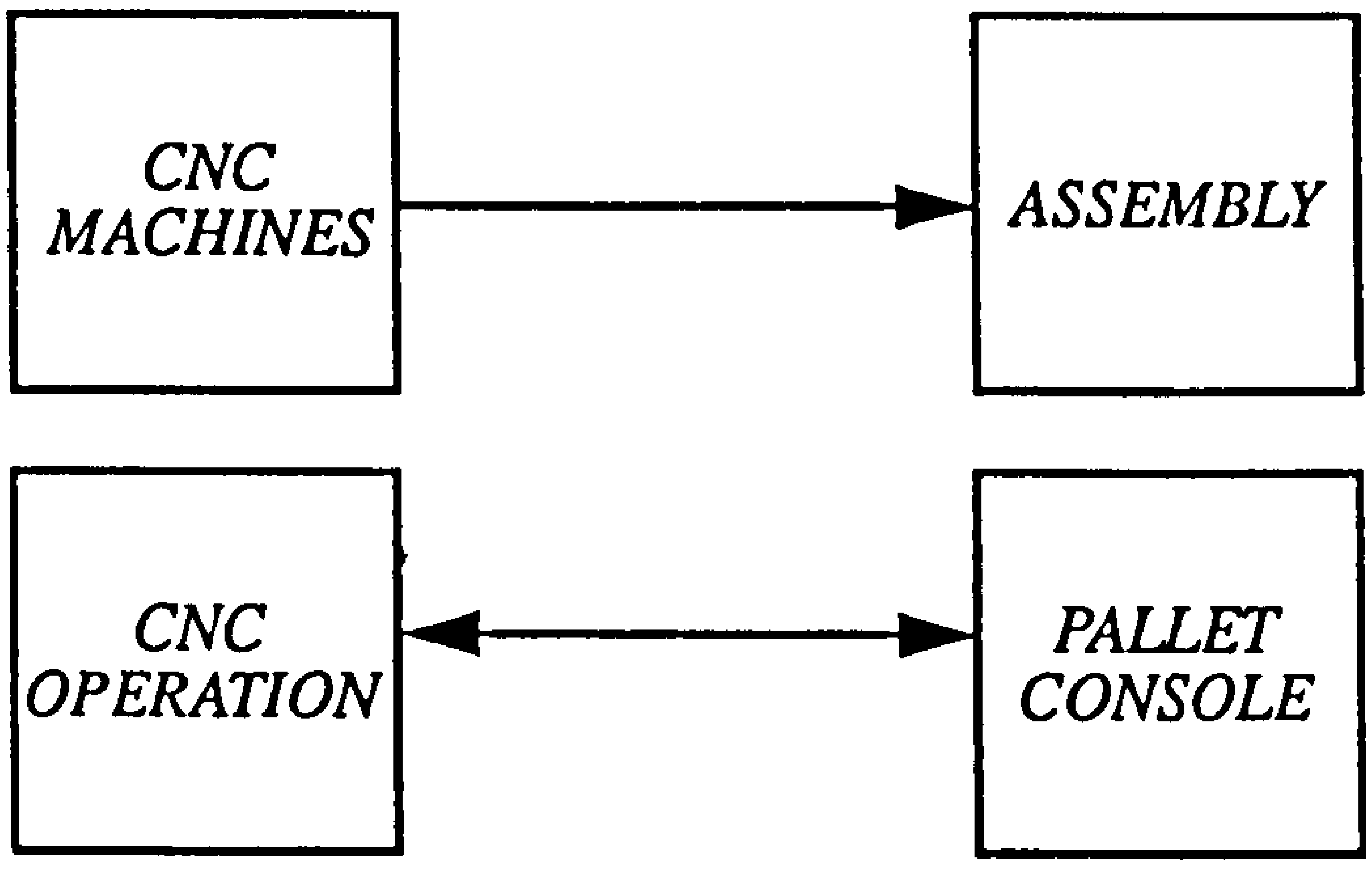

FIG. 2

QUESTION 6

(a) *Who, in your work, do you interact with?*

(b) *Who, in your work, <u>should</u> you interact with but do not?*

BACKGROUND TO QUESTION 7

A person who takes a systems approach to the organization that he or she works in, takes account of *all* the systems and sub-systems which contribute to the overall performance of that organization.

Similarly, a person who takes a systems approach to the specific area of work that he or she does, takes account of *all* systems and sub-systems which contribute to the performance of that area.

This final self-diagnostic question asks you to consider a list of twenty-one typical systems to be found in the manufacturing and service industries, and to indicate your level of contact with these systems, and any contact you do not have but feel you need.

Note: This is not a list of departments.

QUESTION 7

What is your level of contact with the following systems? (Please tick)

	REGULAR CONTACT	SOME CONTACT	NO CONTACT	SHOULD CONTACT
Company Marketing System	....	....	....	....
Customer Contact System	....	....	....	....
Inward Goods Control System	....	....	....	....
Machine Design System	....	....	....	....
Machine Purchasing System	....	....	....	....
Maintenance Supervisory System	....	....	....	....
Maintenance Scheduling System	....	....	....	....
Plant Design System	....	....	....	....
Plant Energy Control System	....	....	....	....
Plant Maintenance System	....	....	....	....
Process Design System	....	....	....	....
Production Design System	....	....	....	....
Production Management System	....	....	....	....
Production Supervisory System	....	....	....	....
Quality Assurance/Control System	....	....	....	....
Safety System	....	....	....	....
Spare Part Purchasing System	....	....	....	....
Stores Control System	....	....	....	....

You will find 'model' answers to these questions on page 55 – 57.

SECTION B: EXPLANATION OF SYSTEMS-THINKING IN FAULT FINDING AND DIAGNOSIS

WHO NEEDS TO WORK THROUGH THIS SECTION?

- troubleshooters
- operators
- process/production control engineers
- managers/supervisors.

WHAT YOU WILL NEED

- A quiet moment to absorb the explanation.

HOW MUCH TIME?

- You will need to allow between 5 and 10 minutes to complete this section.

AIM OF THIS SECTION

The aim of this section is to provide you with an overall explanation of systems-thinking as applied to fault finding and diagnosis.

OBJECTIVES OF THIS SECTION

At the end of this section you should be able to:

- describe how a shift in level of complexity has made systems-thinking necessary
- list at least ten things that someone who practises systems-thinking should be able to do.

WHO NEEDS SYSTEMS-THINKING?

The ability to practise systems-thinking needs to be developed by everyone **who is either directly or indirectly involved in fault finding and diagnosis.** The job titles in TABLE 1 are given as examples of what is meant by 'directly or indirectly involved'.

DIRECTLY INVOLVED	INDIRECTLY INVOLVED
Computer service engineer	Production manager/supervisor
Maintenance technician	Stores manager
Maintenance craftsperson	Storesperson
Production process engineer	Company buyer
Chef	Inward goods inspector
General medical practitioner	Quality assurance/control manager
Software writer	Product designer
Maintenance manager/supervisor	Machine designer
Machine/process operator	Process designer

TABLE 1

WHERE IS SYTEMS-THINKING NEEDED?

There are specific areas where systems-thinking has become essential, in particular the operating and maintenance of Flexible Manufacturing Systems (FMS), Office Computer Network Systems, or Hospital Acute Ward Equipment Systems. One of the major obstacles to learning when personnel transfer from non-automated to automated systems is **the failure to grasp the interactive nature of system working.** The skills and knowledge of systems analysts are not required, but what is needed is a sound grasp of basic systems ideas.

'OLD' VERSUS 'NEW' SYSTEMS

In older technologies, systems were far less complex. A boundary could be drawn around a steam train as a system designed to move goods and people. There was little to go wrong, and when it did the symptom, fault and cause could be located by using all human senses, and in most cases the causes were obvious. The same could be said for a traditional centre lathe, labour intensive spinning looms, hot metal printing presses or telephone strowger switching gear. In each of these cases, the present-day operation and control has become more complex. It is one price we pay for reducing labour costs.

TEN REQUIREMENTS FOR SYSTEMS-THINKING

People who must operate and maintain this 'new complexity' need to be able to do ten things in systems-thinking. These are listed below.

1 Recognise and describe the overall system in which they work.

2 Recognise and describe the sub-systems vital to their work.

3 Recognise and describe parts of their system which are critical to performance.

4 Know exactly the *inputs* and the *outputs* of the system, and of the sub-systems in which they work.

5 Understand how the inputs and the outputs are *controlled.*

6 Recognise and describe the kinds of influence that different parts of a system have on each other.

7 Be able to describe a boundary, either physical or in the mind, around important systems which affect their work.

8 Be clear about the difference between parts of the system in which they work, and parts outside the system (environment) which nevertheless affect their work in some way.

9 Be able to recognise how a change in some part of their system affects other parts too.

10 Appreciate how the practice of systems-thinking – of drawing boundaries, recognising inputs-outputs, seeing types of influence and understanding control – helps to simplify complex situations.

These ten requirements may appear to be daunting at first sight, but a step-by-step approach to basic systems-thinking will satisfy them in a short period of time.

The following sections aim to provide this step-by-step approach to the subject.

SECTION C: MACHINES AS SYSTEMS

WHO SHOULD WORK THROUGH THIS SECTION?

- troubleshooters
- operators
- process/production engineers

WHAT YOU WILL NEED

- pen, notebook
- access to machines/schematics.

HOW MUCH TIME?

- You will need to allow between 30 and 35 minutes to complete this section.

AIMS OF THIS SECTION

The aims of this section are:

- to introduce you to the main building blocks of systems-thinking: boundary, environment, inputs and outputs
- to enable you to base systems-thinking on practical examples
- to enable you to use in practice the idea of boundary, environment, and inputs/outputs
- to encourage you to describe machines as systems and sub-systems.

OBJECTIVES OF THIS SECTION

At the end of this section you should be able to:

- divide a machine or piece of equiment into sub-systems by drawing boundaries
- describe the environment of a typical system you know well
- describe what is meant by the term 'closed system'
- describe what is meant by the term 'open system'
- recognise, in a system you know well, the inputs and the outputs.

FIRST BASICS

The bicycle is a machine of beautiful simplicity. How you would describe a bicycle as a system is open to offers. It is not a 'transport system' in a true sense, and it cannot be described as a 'system' without including the rider because while it is a machine, it cannot act as a machine without the rider. Bicycle-plus-rider can be described as 'a system to provide forward motion'.

The **inputs** to this system are:

(a) the rider's energy

(b) oil

(c) spares.

The **output** is forward motion

There are two ways to consider any faults which occur in this system:

1 treat the machine like a 'black box' with simply inputs and outputs

2 consider the environment in which this machine operates and is maintained.

Attempts to fix a troublesome gear change fault could be made easier if it was known that the machine had hit the back of a car only days earlier and, in fact, had a twisted frame.

PRACTICAL EXERCISE 1

Draw a rough diagram to show how the bicycle can be troubleshooted as simply a machine with inputs and outputs. (Use your creative imagination). Then draw another rough diagram to show how other systems, or part systems, can affect any work done on this simple machine.

FIGURES 1 and 2 on pages 11 and 13 may be of help to you here.

A MORE COMPLEX SYSTEM

Now we will step up a level of complexity to a traditional centre lathe used in the manufacture (turning) of metal parts.

Again, like the bicycle, there must be close involvement of a person (centre lathe turner) before this machine can be described as 'a system for producing metal parts'.

The **inputs** to this system are:

- (a) turner's skill
- (b) electric power
- (c) oil/lubrication and cooling
- (d) raw material
- (e) cutting tools
- (f) measuring devices.

The **output** is turned parts to specification.

Normal practice was (is?) to have a number of these machines as part of a whole manufacturing system. If one failed, overall output from the whole system was affected but did not stop, unlike many modern complex systems.

In most cases this machine could be operated and maintained as a 'black box'. A boundary could be drawn around the machine and the skilled turner, and all faults could be diagnosed and rectified within that boundary. Even the influence of buying 'good' or 'bad' spares was minimal because normally they come from the one manufacturer. Causes of faults were through wear and tear or operating malpractice.

Within this area there was a clear boundary around the electrical power input and another boundary around the mechanical drive, so clear that there was no need to think about 'boundary'.

The next level of operation of machines provides less clear distinctions between inputs and drives. Microprocessor control of machines introduces a level of complexity that makes the idea of boundaries, input-output and control more meaningful. For example, what are the inputs and outputs of the microprocessor, where is the boundary, and when do the outputs become inputs to the process or machine that is being controlled?

PRACTICAL EXERCISE 2

Now is a good time for you to consider the inputs and outputs of your own system. Try doing this by making a list of inputs and a list of outputs.

If you find this difficult, the most likely reason is that in the workplace there is not just one recognisable 'system'. For each system there are some recognisable sub-systems which also have their inputs and outputs. Use the space below to write out your lists.

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Identifying your inputs and outputs is an effective way of starting the process of sytems-thinking. However complex the work situation, you must be able to describe *all* inputs and outputs.

At this stage you should be able to think of a machine or machines linked together, as in a flexible manufacturing system, and draw a boundary around the whole system as you see it. Also, you should be able to isolate out sub-systems within this boundary, and list all inputs and outputs of the whole system and of any sub-system.

If you can do this you have made a good start to systems-thinking.

THREE MINI-CASE STUDIES

Next, to give this work on boundaries and inputs/outputs a practical base, here are a few mini-case studies which illustrate increased complexity, systems and machines.

Case One

The manufacture of metal parts was done by rows of centre lathes, capstan lathes, planing machines, drilling machines, etc. Failure of any one item did not seriously affect overall production. Each could be treated as a 'black box' when fault finding and diagnosing.

Now there is the complexity of machine centres which perform the many operations previously done by different machines. One machine performs many operations and is linked into a manufacturing line in series so that failure of one item can mean failure of the line or whole system. Not only is there a complex relationship between the operations performed, but also there is a complex relationship with other parts of the process.

Case Two

In newspaper production there was a clear boundary between printing press operation and publishing (the preparing of newspapers in bundles for despatch). The two processes could be treated separately as 'black boxes' when fault finding and diagnosing.

Now the situation is quite differe[illegible] publishing includes automatic inserting of copy into the newspaper. This introduces a very complex system of machine operation which is linked to the actual printing press. Certain activity (and faults) on the press affects activity in publishing and vice-versa. Without an understanding of boundaries, and input-output, it becomes extremely difficult to understand the working of the new system.

Case Three

The making of cigarettes and the packaging of cigarettes were performed in quite separate departments; the boundary was clear. Fault finding and daignosis was reasonably straightforward, and could be easily divided between electrical power and mechanical movement. This applied to both manufacture and packaging.

The first move to increased complexity came with the introduction of microprocessor control of weight, moisture and density of product, and increased speed of output. The next move was to combine the manufacture and the packaging into one machine 'system'. There is now more interaction and complexity *between* manufacture and packaging. Not only the troubleshooters but operators as well need an understanding of how the new system and its sub-systems work.

In these three cases you can see how it is no longer enough to recognise and understand a machine or a piece of equipment. The systems at work amount to more than the individual bits and pieces that these systems contain.

THE SYSTEMS ENVIRONMENT

Building on the idea of boundary as a means of identifying our system, we will consider next the idea of **environment.**

When we have done this you will be able to see the relationship between parts of the system, its boundary, its inputs and its outputs, and the systems environment. Remember, all this still relates to machines.

Closed and Open Systems

To understand what we mean by environment in systems-thinking you need to have some idea about closed and open systems.

A closed system is a system with no environment. In practice this is not possible. It makes more sense to talk about systems being either 'more closed' or 'more open' than others. A very open system has free flow of information, people and goods across its boundary to the environment outside (e.g. Marks and Spencer). A more closed system has restricted flow across the boundary to its environment outside (e.g. Government Cabinet).

A systems environment is not, however, 'everything out there'. Any systems environment contains **people, goods, services, etc. which affect in some way the operation of that system.**

Now let's return to machines and machine operation. The traditional centre lathe was quite closed as a system; only raw materials crossed the boundary from the environment, and finished goods went back out over the boundary.

In contrast, the new machine centres are far more open as systems. The range of products to be manufacuted is more diverse, and therefore the operation of the system is affected by market forces. The operation depends upon software producers in the environment, and the designers of products have an influence on the operation of the machine system. (We now get designer-induced running faults). There are more flows and interactions across the system boundary to consider, to the extent that at times the boundary needs to be re-drawn.

PRACTICAL EXERCISE 3

Going back to your own system, what is the extent of your environment? Who and what is out there which affects your work?

Draw a rough diagram (similar to FIGURE 1, page 11) to show your system environment. Then draw lines with arrows (FIGURE 2 page 13) to show where the main influences are to be found.

Note. When we talk about 'your system', it is any system that you recognise as a 'whole' which is important in your job. It can be one troublesome machine, or it can be your department. Provided that you are clear about the boundary, it can be as large or as small as you wish.

Use the space below for your answer.

It is interesting that many misunderstandings in departments are due to lack of agreement between people about the actual position of boundaries, but that is another area of systems-thinking.

SUB-SYSTEMS

The whole system, whether taken to be one machine or a line of linked machines (including robots), can be seen as a collection of sub-systems. In the case of a flexible manufacturing system (FMS) these can be:

- conveyor sub-system
- robot control sub-system
- software sub-system
- manual operator sub-system.

For the purposes of fault finding and diagnosis it is necessary to be clear about these sub-systems, their inputs and the influence each has over others.

The ideas introduced in this section will help you to identify whole systems and sub-systems.

SECTION D: DEPARTMENTS AS SYSTEMS

WHO SHOULD WORK THROUGH THIS SECTION?

- troubleshooters
- operators
- process/production engineers
- managers/supervisors
- stores personnel
- buyers.

WHAT YOU WILL NEED

- organisational chart
- pen and notebook
- access to colleagues for discussion purposes.

HOW MUCH TIME?

- You will need to allow between 25 and 35 minutes to complete this section.

AIMS OF THIS SECTION

The aims of this section are to:

- introduce you to the idea of departments as systems
- emphasise the importance of department systems acting together as a means of contributing to greater fault finding diagnostic effectiveness.

OBJECTIVES OF THIS SECTION

At the end of this section you should be able to:

- describe, through an illlustration, your own department as a system
- identify the boundary of your own department system
- list possible reasons for difficulties in maintaining much needed contact between departments.

In the previous section you have considered machines as systems and sub-systems. A machine and its operator can be looked upon as a whole manufacturing system. One good example of this is a self-employed person operating a plastic extrusion machine in a small workshop.

A machine can also be seen as a sub-system within a whole system. One good example of this is a machine acting as part of a cell in a flexible manufacturing system; here the oputput of one machine can become the input of the next machine in line.

Finally, a machine can be in isolation, with its own inputs and outputs, but also part of a group of machines which again form the whole system. How such systems are organised (for example, machines in series or machines in parallel) influences the way that fault finding and diagnosis is carried out.

Departments within organizations operate in a similar way. Some departments operate in a kind of isolation, with members controlling the inputs and outputs and taking minimal account of the behaviour of departments outside their own boundary. Other departments have stronger links across their boundary to other departments while still maintaining a form of isolation. Finally, departments merge with others into a close integration while still retaining their own control and identity.

A good reason for looking at departments in this way is that in all fault finding and diagnosis it is necessary to take account of **interactions between departments.** This is especially so when seeking to make fault finding and diagnosis more effective.

The list in TABLE 2 (page 39) shows some sources of machine downtime, and in each case an example of the cause. The involvement of at least six departments can be recognised at work here.

All too often downtime is seen automatically as machine downtime, when the root cause is not related to a machine at all. On some occasions, for example, the word 'breakdown' should be changed to 'stoppage due to design fault'.

SOURCE	EXAMPLE OF CAUSE
Design	Recurring design-induced fault.
Process control	Operating at above optimum speed.
Production scheduling	Poor logistics of sequencing machine operations.
Purchasing	Using poor quality spares.
Stores control	Non-availability of made-up units.
Operator skill	Lack of appropriate training.
Operator availability	Poor cover/recruitment.
Fault-finding diagnosis	Lack of appropriate strategy.
Production/maintenance liaison	Poor maintenance response-time.
Manuals/schematics	Badly written or not available.

TABLE 2

PRACTICAL EXERCISE 4

Look, if you can, at an organisational chart for your department and ask yourself whether it represents a picture of:

(a) an isolated department
(b) an isolated department, but one which is still part of a larger system
(c) a department which is integrated with at least one other department.

PRACTICAL EXERCISE 5

This exercise is in two parts.

Part (a)

Look at FIGURE 3.

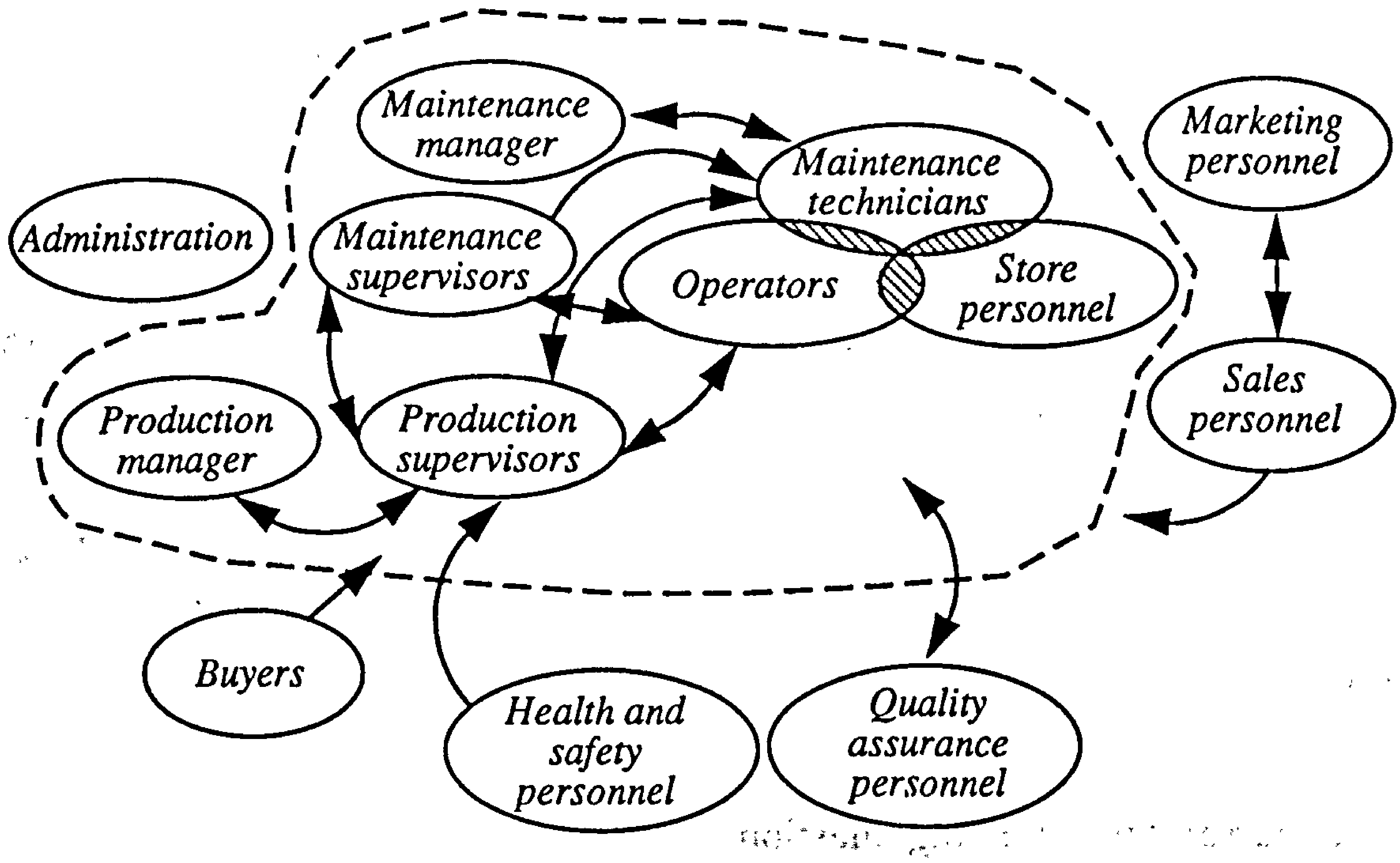

FIG. 3

Draw a similar diagram for your own department, showing where overlap exists and where links exist, either one-way or two-way.

Use the space on the next page for your diagram.

Part (b)

Now ask yourself the following question.

How easy is it for members of your department to work with members of other departments who have either a direct or indirect effect on fault finding and diagnosis? Tick the appropriate answer.

Very easy ....
Easy ....
Difficult ....
Very difficult ....
Not possible ....

PRACTICAL EXERCISE 6

There can be many reasons why much needed contact is difficult or impossible to maintain. For example:

- physical lay-out of the plant
- manager personality clashes
- grading structure: grade 1 not able to speak to grade 3, etc.
- work protection
- lack of awareness of need to maintain contact
- work priorities.

If you recognise similar difficulties in your own work situation, list the reasons you see for blocks to improved contact. A systems approach to fault finding and diagnosis demands that 'everyone who needs to know, gets to know'.

Use the space below for your answer.

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FOLLOW-UP ACTIVITY

If a troubleshooter repeatedly fixes a recurring design-induced fault, he or she needs ready access to a person or persons ultimately responsible, instead of simply grumbling about "designers who do not understand production needs".

If access to other people is seen to be difficult in your work situation, draw a diagram of your department in relation to others to see where uncrossable boundaries exist.

Put your finger on the reason or reasons, and act!

SUMMARY OF THIS SECTION

1 Your organisation can be recognised as a system, and outside the organisation's boundary lie:

banks)
finance houses)
suppliers) your organisation's
Health and Safety Executive) environment
competitors)
etc.)

2 Your department can be recognised as a system, either quite isolated within the whole organization system or integrated with one or many other departments.

3 Fault finding and diagnosis is rarely the sole responsibility of one department. In practice there can be as many as six departments involved.

4 Boundaries that act as blocks to free contact between people need to be breached.

5 Out-dated grading systems which act as blocks to free contact between people need to be abolished.

6 "Sorry" to the status-conscious among you.

7 Everyone who needs to know, should know.

SECTION E: FEEDBACK

WHO NEEDS TO WORK THROUGH THIS SECTION?

- troubleshooters
- process/production control engineers
- managers/supervisors
- stores personnel
- purchasing personnel
- designers.

WHAT YOU WILL NEED

- pen and notebook

HOW MUCH TIME?

- You will need to allow between 15 and 20 minutes to complete this section.

AIM OF THIS SECTION

The aim of this section is to increase your level of awareness about the use of feedback as applied to information in fault finding and diagnosis.

OBJECTIVES OF THIS SECTION

At the end of this section you should be able to:

- describe and recognise examples of both negative and positive feedback
- identify, through illustration, the type of feedback in use in your own situation.

FEEDBACK IN SYSTEMS-THINKING

Although in Module 4 we will be examining the necessary materials for and the mechanics of feedback, in this section we will look at feedback as part of systems-thinking. We will consider here the part that feedback plays when we are thinking about machines as systems, departments as systems, or even individual circuits as systems.

Positive and Negative Feedback

There are, broadly speaking, two kinds of feedback:

- positive feedback
- negative feedback.

In systems-thinking we see negative feedback as being just as desirable as positive feedback when it is used in the appropriate place.

In other words, you must overcome the mental block some people have that negative is 'bad' and needs to be avoided, and that positive is 'good' and needs to be encouraged. Both are good in the right place.

Feedback as a Control

Feedback is normally linked to some kind of control. When using feedback we either seek to keep a machine, a process or some event within bounds (negative feedback), or we seek to encourage more and more output (positive feedback).

The Chancellor of the Exchequer uses forms of negative feedback to keep spending within bounds, and a form of positive feedback to encourage savings. Both can be effective and right when used wisely.

With regard to fault finding and diagnosis, we can use negative feedback to control the relationship between inputs to and outputs from a machine or process. If a plastic extrusion machine is producing too many blemishes, there needs to be a form of negative feedback to control the operation and make necessary adjustments. Such feedback can be automatic or manual.

On the other hand, if it is found that the keeping of good machine histories (records) results in more production time, then positive feedback to produce even better records will result in even more production time.

The most vital part that feedback plays in fault finding and diagnosis is in giving everyone concerned 'knowledge of results'.

If, for example, a process engineer finds that a newly installed system for statistical process control (SPC) is giving useful information related to machine faults, then feedback to maintenance personnel (who may not be using the new system) becomes necessary. This can be seen as an example of positive feedback.

If a maintenance technician finds that output targets set by production control are beyond the limits of optimum effective machine operation, then feedback to achieve the correct level is necessary. This is an example of negative feedback.

There are also feedbacks on machines and processes, normally negative in each case. The best known are:

- governors to control machine speed
- thermostats to control output temperature
- loops in flip-flop logic gates.

These types of feedback are covered in Module 2, and in technical training generally. The feedbacks crucial to present-day fault finding and diagnosis are information feedback loops.

In FIGURE 4 there is a control model showing a feedback loop. It is possible to see that any problems uncovered at the sensor could be traced back to either one (or more) inputs, or to the actual process in the black box, that is, *how* the job was done. (Note: this is simply a hypothetical example).

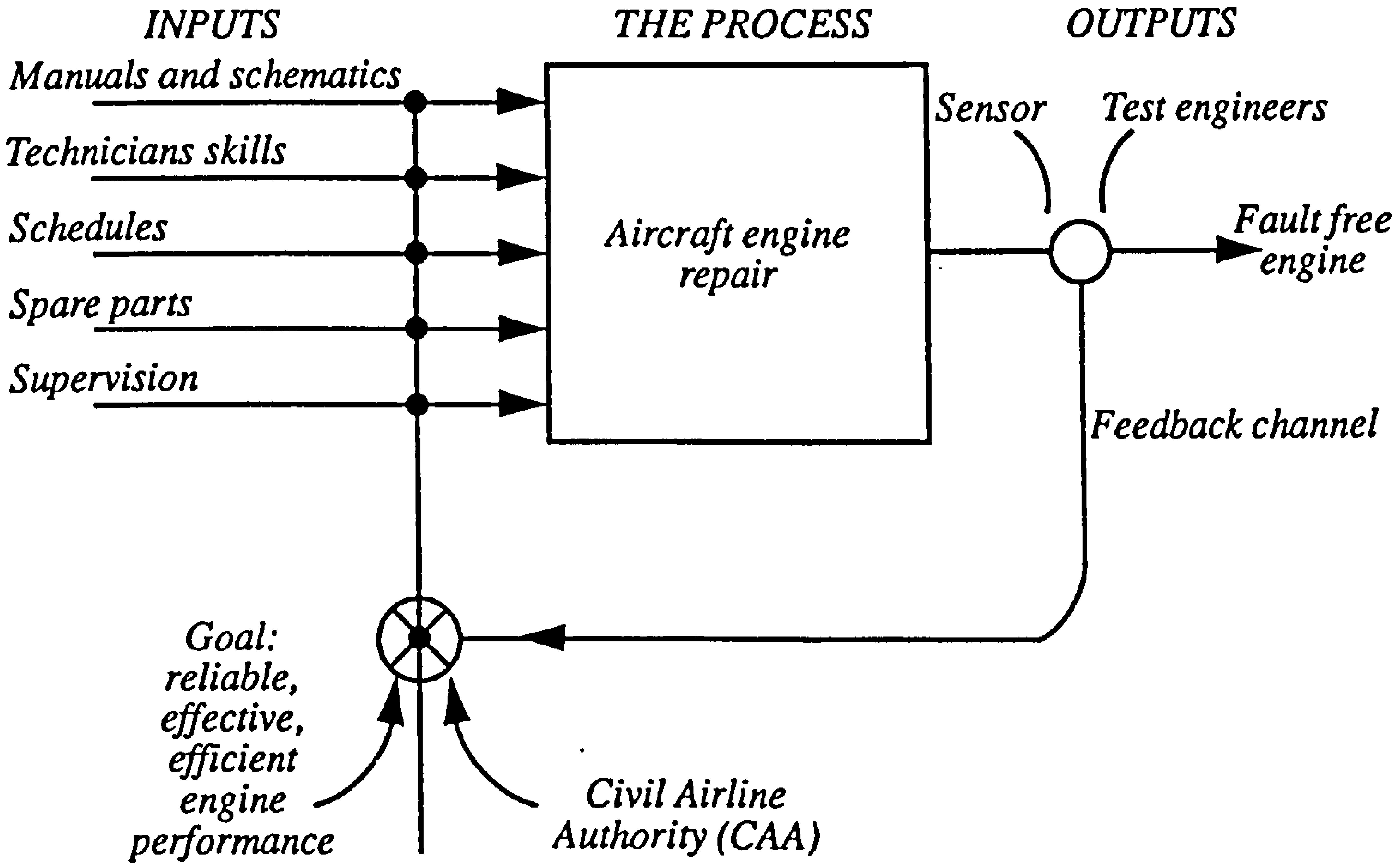

FIG. 4

Refer to this diagram when doing Practical Exercise 7 on the next page.

PRACTICAL EXERCISE 7

Think of a process that you are closely involved with, and draw a similar control, putting in your own inputs and outputs and methods of using feedback.

Note

Remember that the drawing of such diagrams is not important. What is important is that the act of drawing makes you stop and think about how the system you work in actually operates. Such diagrams are simply tools for thought.

Use the space below for your diagram.

The diagram you have produced on the previous page is an example of closed loop control.

An open control would be the same model but without the feedback loop. In other words, the quality and the reliability of the inputs, and of the process, would be designed to ensure correct output every time. An example of this is the zero-defect goal of Japanese electronics lines, where quality and reliability are built into the inputs and the actual process, dispensing with inspectors at the sensor.

Probably the best guarantee of effective information feedback for fault finding and diagnosis is through the maintenance of machine and/or process histories. This is covered in Module 4.

SECTION F: PRACTICAL EXAMPLES OF SYSTEMS-THINKING

There are no aims and objectives to this section in the formal learning sense.

Look at FIGURES 5 and 6 overleaf. These are two illustrations of systems-thinking in use. They roughly show the workings of two systems if the observer was thinking about the process in systems terms.

Drawing diagrams like these raises important questions and issues. Here are some examples.

- What exactly is the whole system?
- What is part of this system and what is not?
- What outside effects are there on this system?
- What are the inputs and the outputs?
- Is one part more critical than any other?
- Does failure of *any* part mean failure of the whole system?
- Should maintenance personnel be totally dedicated to this system, or are they to operate outside the boundary of this system, only coming in when there is a problem?
- Who actually controls feedback?
- How is feedback achieved?
- Who needs to know about faults and causes apart from people shown within this system?
- Are there feedback channels to people who need to know?
- Can these system boundaries and sub-system boundaries be used in the symptom-function technique?

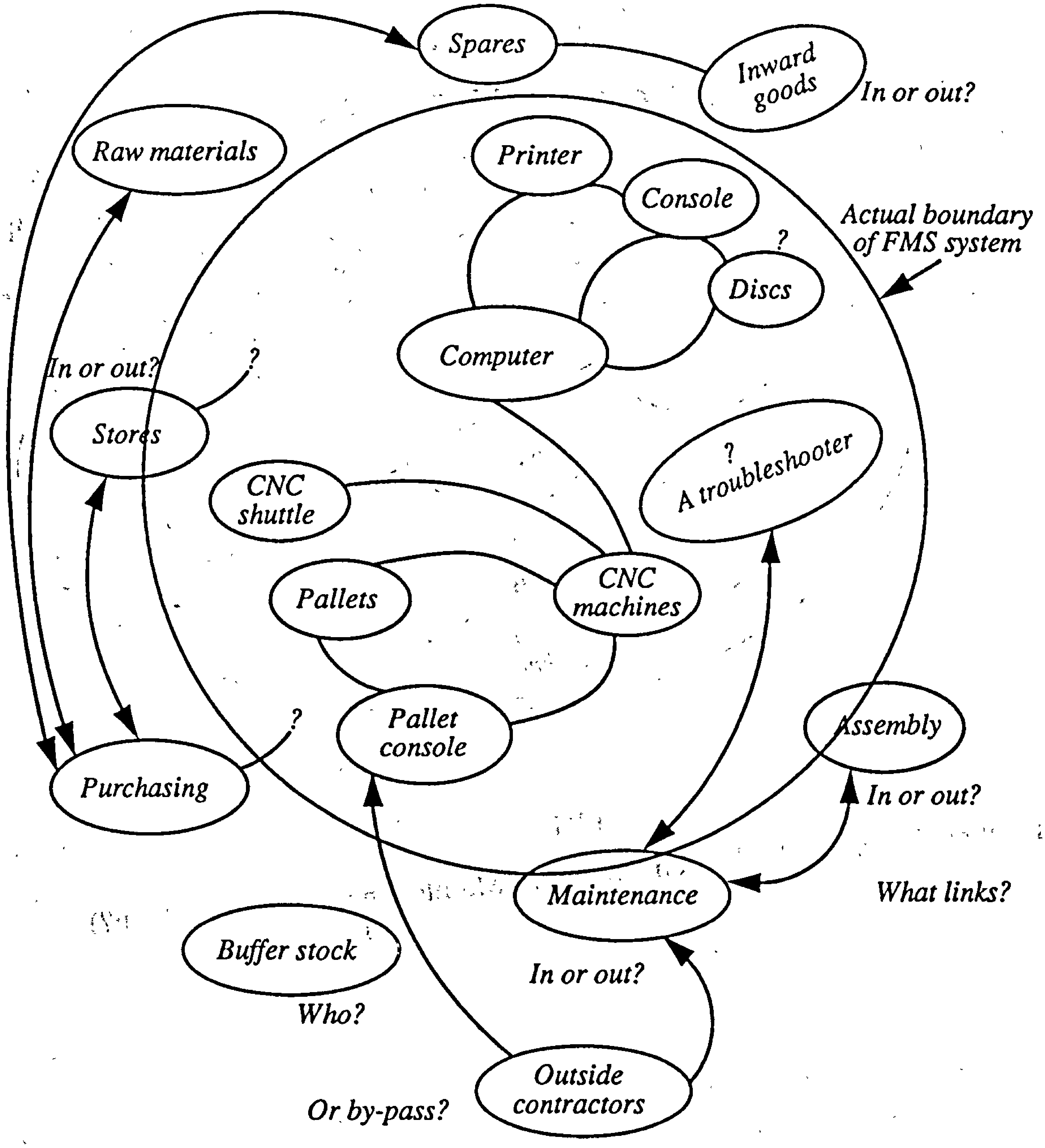

FIG. 5
Organisation of FMS System and Maintenance

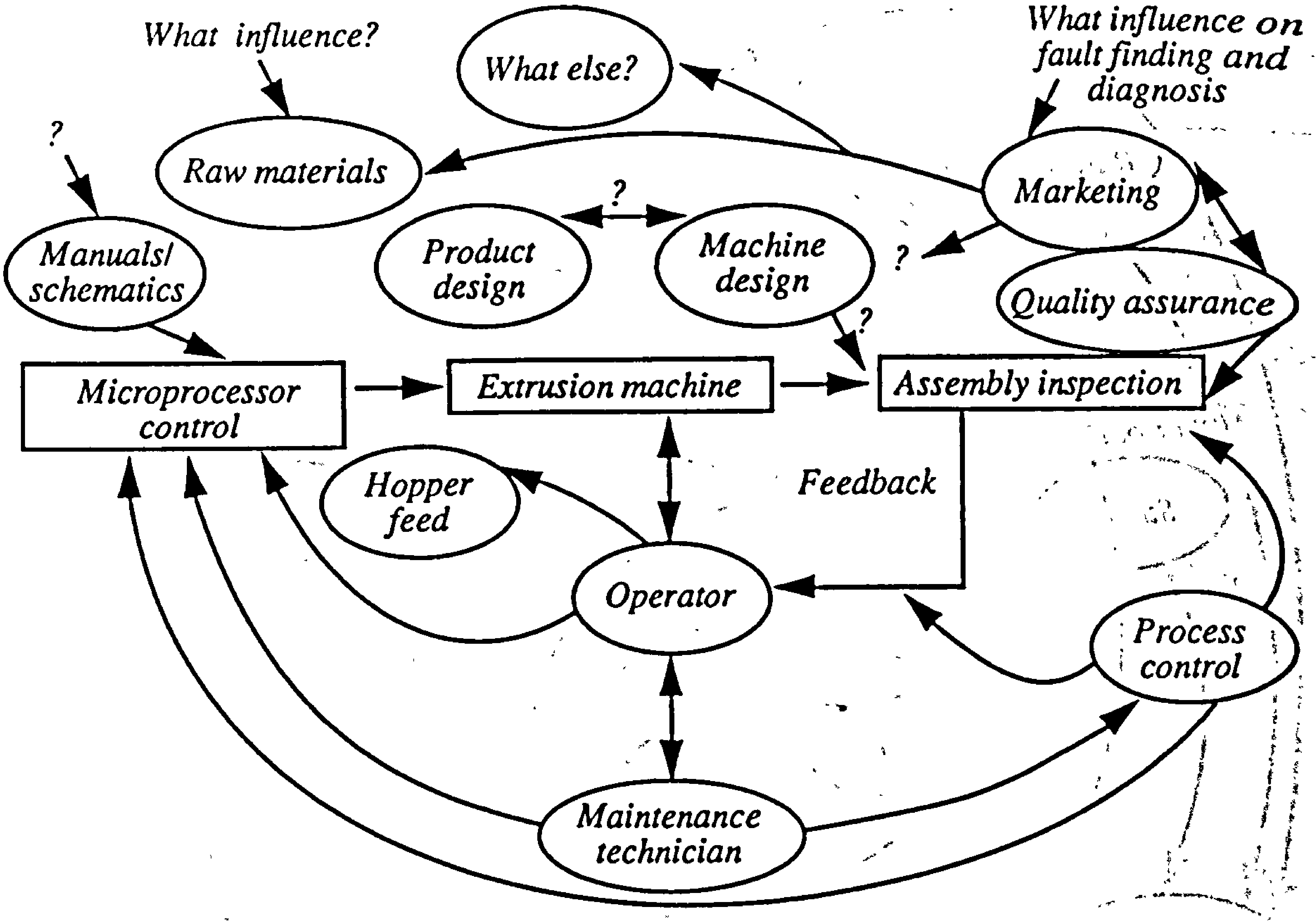

FIG. 6

Plastics Extrusion Production System or Maintenance System (or both?)

MODEL ANSWERS TO SELF-DIAGNOSTIC QUESTIONS

QUESTION 1

You may have seen only the department or the overall organization as a system. All systems contain parts: these can be people, components, machinery, materials etc.

All systems have boundaries, that is, a line that separates the systems from its outside environment.

All systems *do* something, i.e. there are inputs and outputs, and some activity takes place.

You may have recognised yourself as being in a smaller system than your department, say a team of specialists within the department. (For example, a test rig system.)

QUESTION 2

You may have recognised one, two or even many other systems which affect your work. After working through this module you may come to recognise even more. For example, a mechanical technician may recognise an outside manufacturer's system, an outside contractor's system, a factory energy-saving system, a stores requisition system, etc.

QUESTION 3

The largest may well be the total company; if it is a multinational this may be too large to recognise as a system. This is an interesting point to ponder. How you draw the boundary around what you recognise as your largest system makes you think about the organization in a different way. Is it 'large' according to the number of people in the system? Or according to output? Or according to turnover? And so on.

The smallest could be a pneumatic control system.

Again, this helps you to be clear about where the boundaries lie.

QUESTION 4

It is important for effective fault-finding and diagnosis that you can see whole systems as sub-systems, especially in areas such as Flexible Manufacturing Systems, Office Network Systems, and Newspaper Insert Systems. In each case there are important sub-systems linked together and interacting with each other. You should be able, given that you know the whole system, to recognise obvious boundaries around smaller operations within the whole system. Each of these sub-systems will have inputs and outputs.

QUESTION 5

A first atttempt at a diagram of this kind can be difficult. However, the picture you have come up with is <u>your</u> view of the system in which you operate. A colleague may independently arrive at a different picture. Therefore this way of systems-thinking allows you to resolve these differences if they exist. Many misunderstandings are caused by having different views of a system.

SELF-DIAGNOSTIC QUESTIONS 6 AND 7

Both questions are designed to help you reflect on your current position within the system, and to what extent a free flow of information is possible.

USEFUL REFERENCES

Bertalanffy, L von (1956)	*General Systems Theory* (New York, Brazillier)
Bignell, V (1985)	*Manufacturing Systems* (Oxford, Open University, Blackwell Ltd)
Bonetto, R (1988)	*Flexible Manufacturing Systems in Practice* (London, Kogan Page Ltd)
Checkland, P (1981)	*Systems Thinking, Systems Practice* (Chichester, John Wiley)
Open University	The Open University offer three courses in systems which can be studied as part of a degree programme or as an associate student without taking a degree. In all three courses there is strong emphasis on industrial systems.
Rathmill, K (1986)	*Flexible Manufacturing Systems* (Bedford, IFS Publications Ltd)

Training
in
Fault Diagnosis

A Systems Approach

Module 4

Fault Diagnostic Recording

Malcolm Craig.
1991.

CONTENTS

INTRODUCTION

> *Information is as essential to maintenance as engineering drawings are to manufacture.*
>
> Dr R H Baulk, British Steel Corporation

There is some truth in the saying that the task of fault-finding and diagnosis consists of 90% information and 10% engineering (or medicine, as the case may be). In most fault events, a high proportion of the delay is caused during fault-diagnosis rather than time spent in repairing. The finding and use of information plays a crucial part in fault-diagnosis tasks, and accounts for a high proportion of diagnostic time. Information, whether held on a computer data base, recorded in a dog-eared notebook or noted on cigarette packets is essential to the present-day troubleshooter and operator.

Unfortunately, the old practice of storing this information in peoples' memories is possibly still the most used method of fault-diagnostic recording. The increasing complexity of machines and systems, however, makes this 'memory method' no longer viable. There must be effective recording systems capable of matching the complexity of current manufacturing and service operations.

In medicine, unlike engineering, the practitioner feels unable to perform his or her work effectively without the use of a comprehensive symptom-sign-problem-diagnosis recording system. The young medical professional is drilled in the taking of histories, which later become valuable diagnostic aids. Many practitioners in engineering on the other hand do not readily see the considerable value to be gained from taking machine histories.

The aim of this module is to present a range of history-taking methods, provide examples of their use, and make a strong case for their adoption in areas where a pay-off can be demonstrated.

This module has close links with the other five modules in the programme. The main relationships are shown in FIGURE 1.

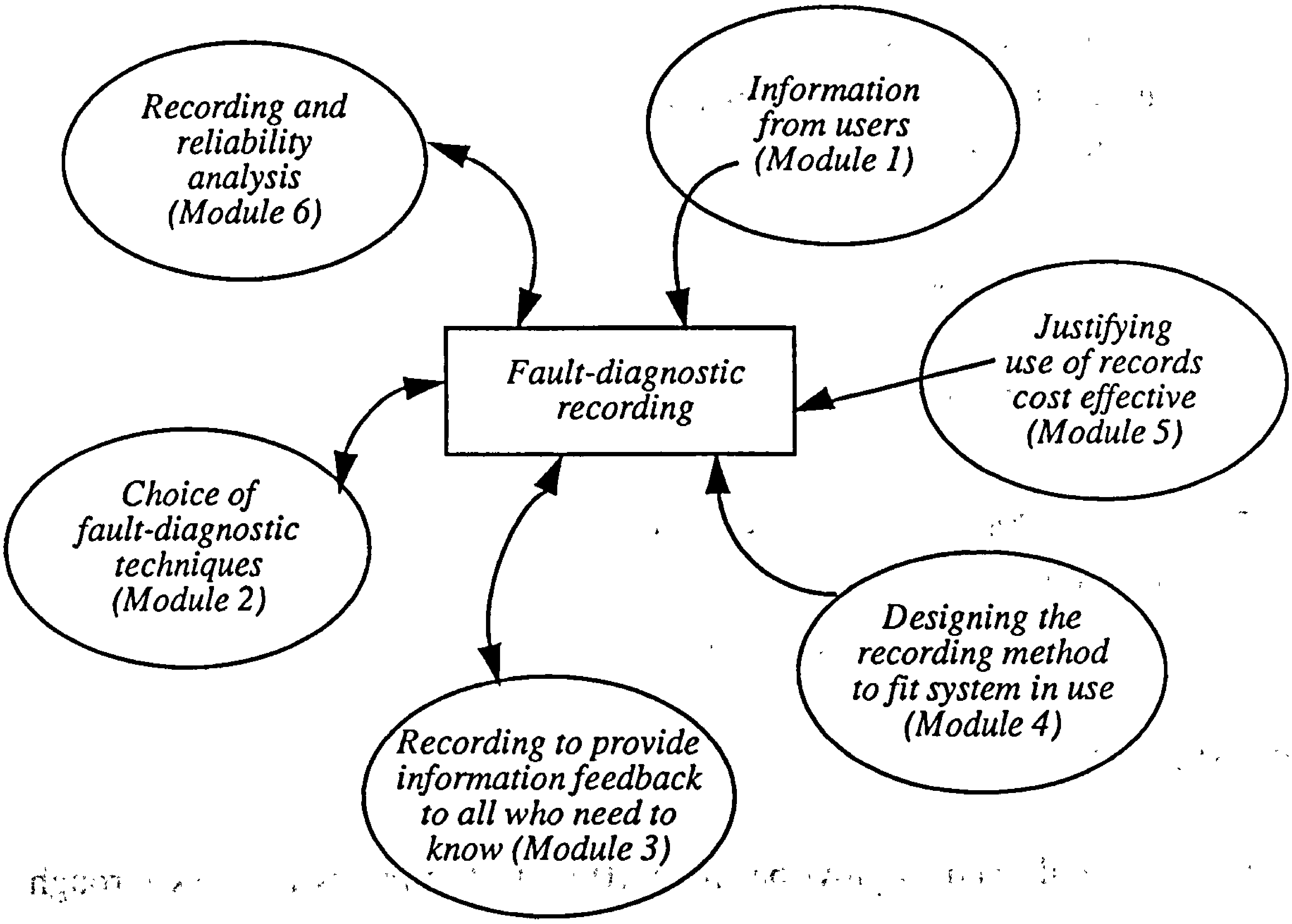

FIG. 1

Showing this relationship in this way helps to provide an overview. It can, however, suggest that fault diagnostic recording is a rather complex business, when in practice it must be simple. The golden rule throughout this module is 'Keep it simple, or as simple as possible'. Some methods of recording are more complex than others. The aim is to use the simplest that your situation can tolerate.

SECTION A SELF-DIAGNOSTIC QUESTIONS

WHO SHOULD WORK THROUGH THIS SECTION?

- service/maintenance managers
- service/maintenance supervisors
- troubleshooters
- operators
- stores personnel.

WHAT YOU WILL NEED

- existing copies of fault recording methods
- notebook and pencil
- access to at least one colleague.

HOW MUCH TIME?

- you will need to alow between 10 and 15 minutes to work through this section.

AIMS OF THIS SECTION

The aims of this section are:

- to raise your awareness about the importance of fault recording
- to introduce you to a range of fault recording methods
- to demonstrate to you the value of effective recording.

OBJECTIVES OF THIS SECTION

At the end of this section you should be able to:

- describe at least three accepted and proved fault recording methods
- identify who should be involved in fault recording
- state how feedback can be built into a fault recording system
- state the minimum headings required of a fault recording document.

QUESTION 1

What are the reasons you would give for keeping records of faults and their diagnosis?

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QUESTION TWO

Which methods can you name and describe for the recording of fault and diagnostic information?

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QUESTION 3

If you were given the task of designing a new form for the purpose of gathering fault and diagnostic information, what headings would you use?

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QUESTION 4

Who in your view, should be involved in the collection of fault diagnostic information?

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QUESTION 5

The following terms are used either in relation to fault-finding, diagnosis information or used to describe types of recording systems. Can you identify them and say what they mean?

FIMS

FSD

MTTF

MTTR

FMECA

FTA

LCC

DOM

MTBMA

MDT

Now turn to the Model Answers on page 82

SECTION B FAULT DIAGNOSIS RECORDING METHODS

WHO SHOULD WORK THROUGH THIS SECTION?

- troubleshooters
- operators
- supervisors
- production/process engineers

WHAT YOU WILL NEED

- access to any current methods of recording
- notebook and pencil
- access to at least one colleague

HOW MUCH TIME?

- You will need to allow between 80 and 110 minutes to work through this section

AIM OF THIS SECTION

The aim of this section is to introduce you to standard methods of fault event recording.

OBJECTIVES OF THIS SECTION

At the end of this section you should be able to:

- recognise essential items of information to be included in a tailor-made record system
- describe the use of at least six recording methods
- list advantages and disadvantages of the respective methods.

STANDARD METHODS

These are a number of what can be called 'standard methods' in use:

- SIMS
- SIMM
- FIMS
- FSD.

One of the earliest to be used was Symbolic Integrated Maintenance System (SIMS). This was developed in the U.S.A. by Technical Operation Inc. From this beginning, the United States Navy developed the Symbolic Integrated Maintenance Manual (SIMM). The Royal Navy subsequently adapted this work to produce Functionally Identified Maintenance System (FIMS). This again was adapted for use by the British Steel Corporation and called Functional System Documentation (FSD).

An important message to come out of these developments is that record systems need to be tailor-made to fulfill the needs of the particular organisation. Each one involves the maintenance of effective fault-diagnostic recording, and uses a method which is appropriate for the systems in use.

In this section we are going to look at methods and consider the basic building blocks of an effective recording system. At the end of this section you should have ideas about designing your own system, modifying the method you use, or you may simply say to yourself "I can do better than that!"

Now do Exercise 1

Exercise 1

A Our fault diagnostic recording system is (tick as appropriate):

(a) computer-based
(b) log book-based
(c) card system-based
(d) 'chit'-based
(e) personal notebook-based
(f) cigarette packet-based
(g) word of mouth-based
(h) memory-based
(i) other.

B Our fault diagnostic recording system is (tick as appropriate):

(a) highly effective
(b) effective
(c) could be better
(d) poor
(e) awful.

If, in Part A, you have ticked either (a), (b), (c) or (d), and then (a) in Part B you need only skim read this section to see whether you can pick up some useful points.

BASIC BUILDING BLOCKS

Unfortunately for engineers, the recording of fault diagnostic information is tainted by that most deadly boring of tasks – 'administration'. Therefore, given that it needs to be done we must keep our recording to a minimum. So, what is 'minimum'? In other words, what are our basic needs?

Exercise 2

You are allowed to record only six items of information about a fault you have fixed. Which items from the list below would you choose? Place a tick alongside the letters of your choice.

(a) Time taken to respond to the fault
(b) Time taken to diagnose
(c) Time taken to repair
(d) Time taken to check out
(e) The symptom reported
(f) The actual symptom if different from (e)
(g) Signs
(h) Fault (or faults)
(i) Cause (or causes)
(j) Spare parts used
(k) Removed parts faulty
(l) Removed parts not faulty
(m) Time since last breakdown
(n) Time since last reporting of that fault
(o) Initial people working on the fault
(p) Additional people brought in
(q) Effects on other parts of the system
(r) Any back-up procedure used
(s) Outside contractor involvement (who)

(t) Outside contractor involvement (time)
(u) Technique used to diagnose successfully
(v) Method used to repair
(w) Module replacement or part replacement
(x) Evidence of operator-induced fault
(y) Evidence of design-induced fault
(z) Detailing who needs to know about fault.

(There are more, but we have run out of letters. These, however, are the most vital items of information).

Obviously this is not an easy decision to make, yet any recording documentation which contains more than six requests for information will quickly become too complex and too cumbersome for use by most practitioners, such as troubleshooters, operators, supervisors, etc.

Now prioritise your choice of information made from (a) to (z) on the previous page.

Most important information ....

2nd most important information ....

3rd most important information ....

4th most important information ....

5th most important information ....

6th most important information ....

The next thing to consider when attempting to get down to basics is **the reason for keeping records.**

Using the list of information items in Exercise 2, here are some **possible** scenarios and the information that is likely to be needed.

POSSIBLE SCENARIOS	INFORMATION NEEDED
1 Car assembly robot line. Response and diagnostic time most crucial.	a + b c h i j n
2 Maintenance workshop bench diagnosis and repair of modules, units, parts.	h i j v w x + y

The message here is quite clear.

Before designing a fault diagnosis record system you must identify only the essential basic building blocks of information.

Here is a step-by-step approach in identifying those key items of information.

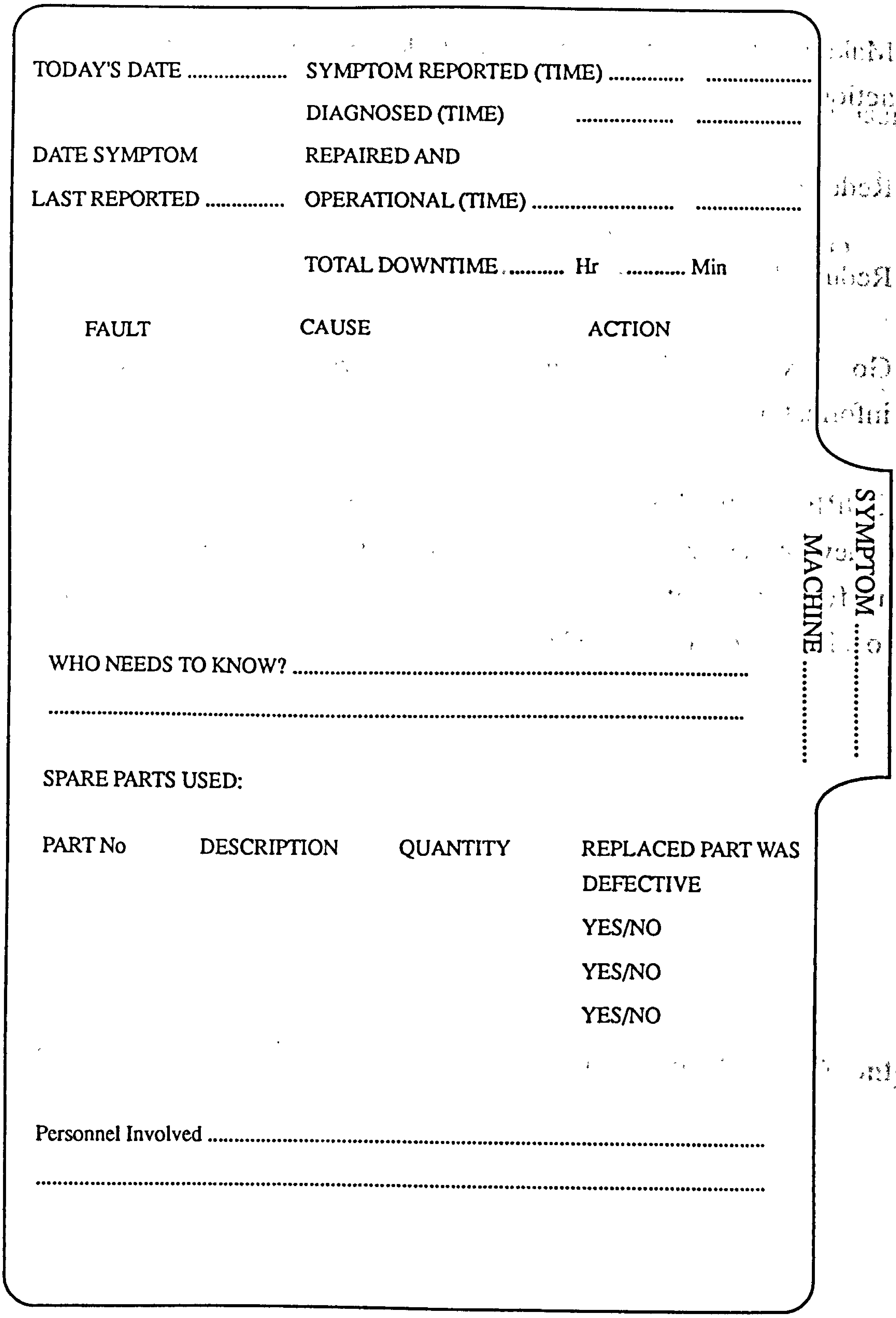
1 Make a list of what would be **nice to know** about faults, their cause and action taken.

2 Reduce this list to what is seen as **really useful.**

3 Reduce this list to what is **essential.**

4 Go back to 2 and make sure you can do without certain useful bits of information.

In FIGURE 2 on the next page is shown a fault diagnostic recording form that, in the view of the writer, is a 'model' – the 'best' – and serves as a core record system for any situation. The aim of providing this model is that only additional bits need to be added as required.



TODAY'S DATE .... SYMPTOM REPORTED (TIME) ....

DIAGNOSED (TIME) ....

DATE SYMPTOM LAST REPORTED .... REPAIRED AND OPERATIONAL (TIME) ....

TOTAL DOWNTIME .... Hr .... Min

FAULT	CAUSE	ACTION

WHO NEEDS TO KNOW? ....

....

SPARE PARTS USED:

PART No	DESCRIPTION	QUANTITY	REPLACED PART WAS DEFECTIVE
			YES/NO
			YES/NO
			YES/NO

Personnel Involved ....

....

SYMPTOM ....

MACHINE ....

FIG. 2

As a result of completing Exercise Two on page 12, you should be able to appreciate that record systems must be tailor-made to fit your situation.

Adopting a 'record system' from elsewhere and adapting it to fit your circumstances can result in having requests for information which are not needed. This is the 'kiss of death' for a record system. To be effective, a record system must contain essential, *and only essential*, requests for information.

METHODS USED FOR RECORDING FAULT DIAGNOSIS INFORMATION

These are a number of methods used to record fault diagnosis information:

(a) symptom cards
(b) traffic lights
(c) chits
(d) log book
(e) computer input
(f) notebook
(g) memory.

These methods will now be described.

(a) Symptom Cards Description

This method, as the title suggests, begins at the point when a symptom is reported.

Imagine one of the most basic electrical faults, a failed lamp in a room. A Symptom Card for this event would look something like the one shown in FIGURE 3.

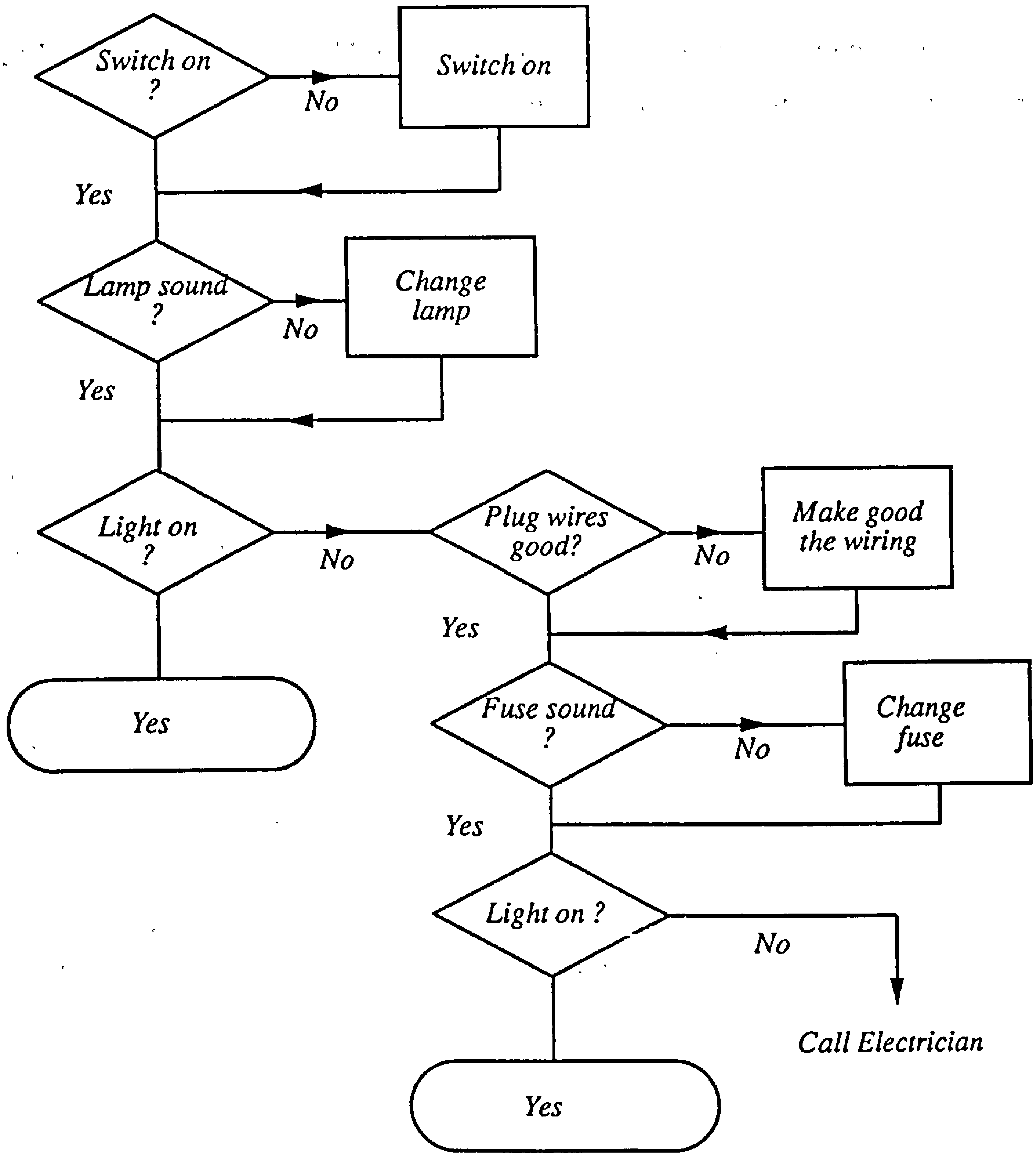
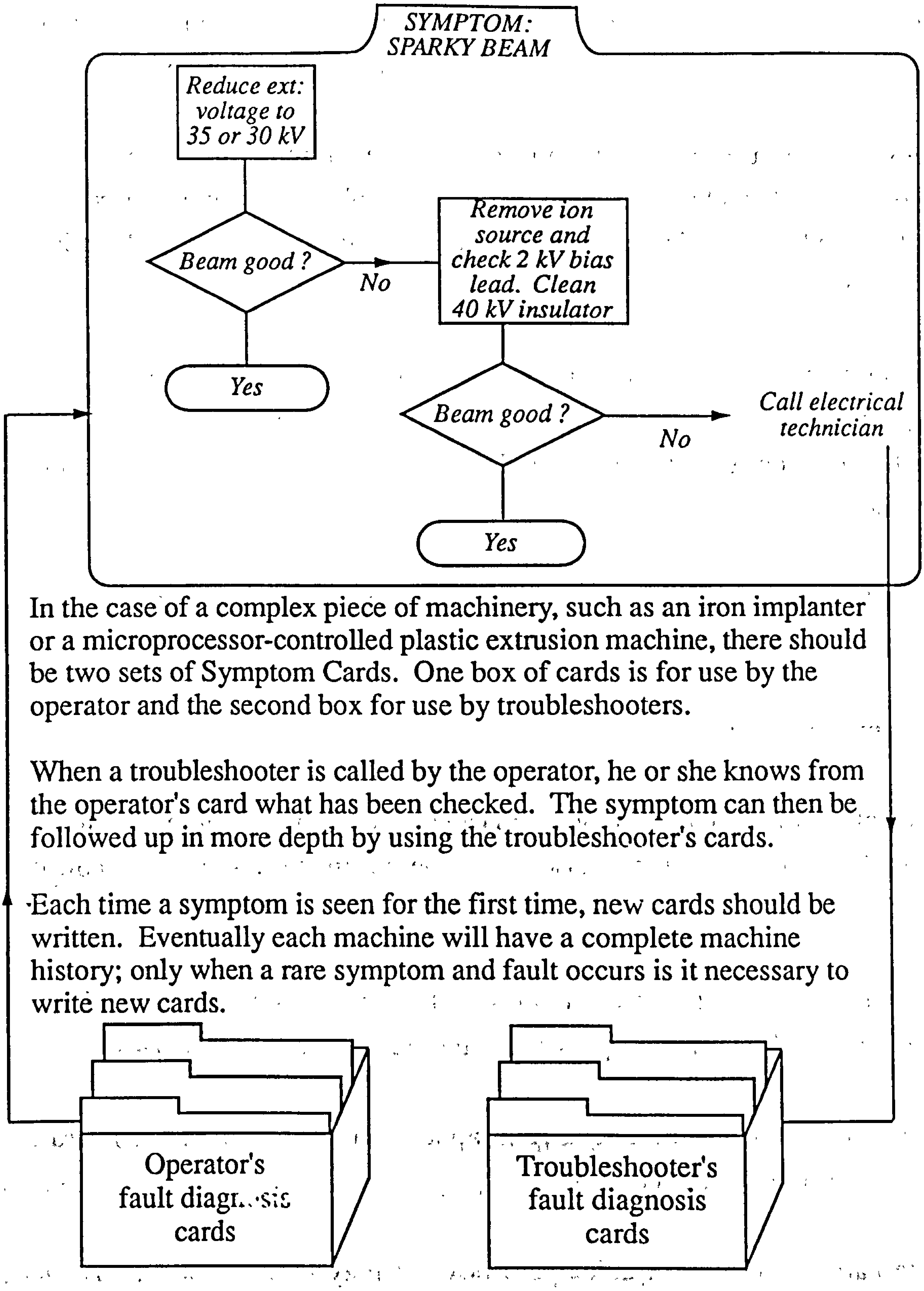


FIG. 3

From this simple example you should be able to see how a machine operator could use a card of this kind.

When he or she recognises the symptom of a machine problem, the card for that symptom is inspected. The checks that an operator can make are then followed until the point is reached where more expert help is needed. The card instructions would end with 'call electrician', 'call mechanical fitter' or 'call process engineer'.

A more job-related Symptom Card is shown in FIGURE 4. This is related to an Iron Implanter in use at Philips, Hazelgrove.



In the case of a complex piece of machinery, such as an iron implanter or a microprocessor-controlled plastic extrusion machine, there should be two sets of Symptom Cards. One box of cards is for use by the operator and the second box for use by troubleshooters.

When a troubleshooter is called by the operator, he or she knows from the operator's card what has been checked. The symptom can then be followed up in more depth by using the troubleshooter's cards.

Each time a symptom is seen for the first time, new cards should be written. Eventually each machine will have a complete machine history; only when a rare symptom and fault occurs is it necessary to write new cards.

FIG. 4

In practice, of course, operators will react to familiar symptoms by making checks without reference to the cards, and so too will the troubleshooters.

However, a feature of new technology is the increasing reliability of components, and this brings new problems. A number of symptoms occur far less often, and memory in this situation becomes much less reliable. Machine histories overcome this problem.

A further point is that when operators and troubleshooters arrive new to a job, there is much less need for them to go through the learning of symptoms as and when they occur. Effective records accelerate the time spent in gaining experience.

For complex machines and/or systems there can be no argument against the use of symptom cards. You know they make sense.

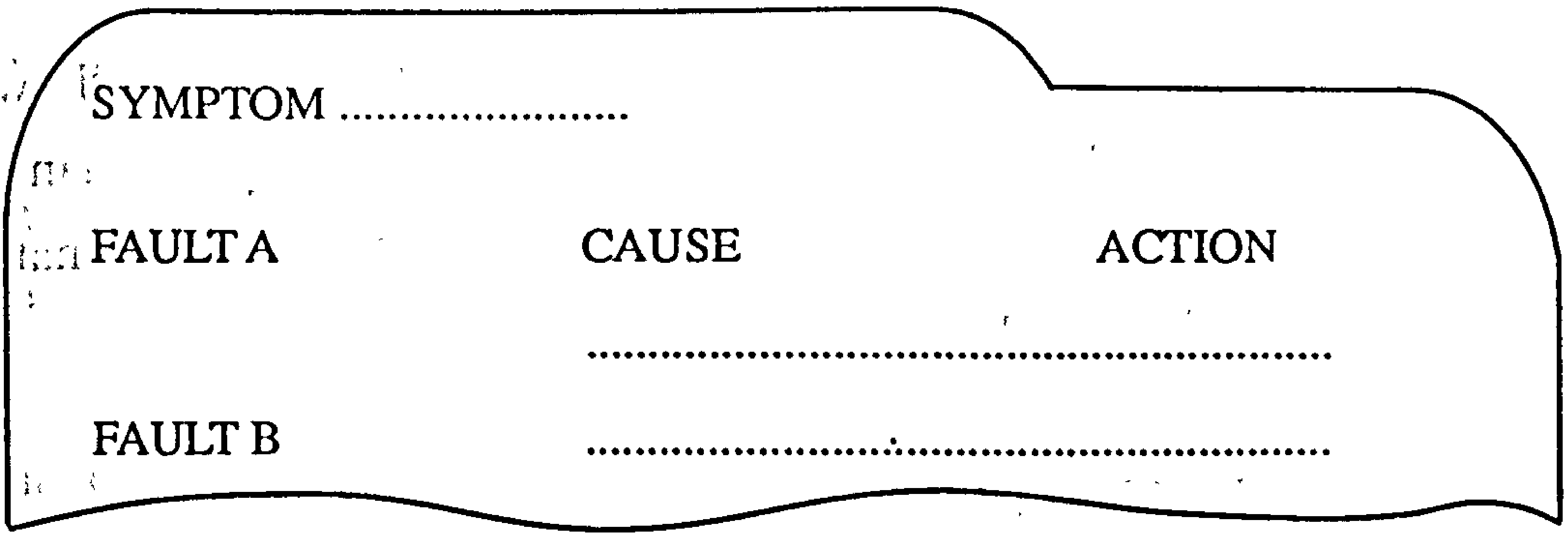
Symptom cards in use

The actual information held on each card can be recorded in algorithm form, as in FIGURES 3 and 4. You may also record the information serially, as shown in FIGURE 5.

People tend to divide up between those who like diagrams such as algorithms (we call them 'holists'), and people who prefer lists (we call them 'serialists').

The cards can be held in a strong ring binder so that the tab of each card, showing the symptom, can be seen.

An alternative is to use an index card box. It may be necessary to use a purpose-made box large enough to take around two hundred cards.



SYMPTOM ....

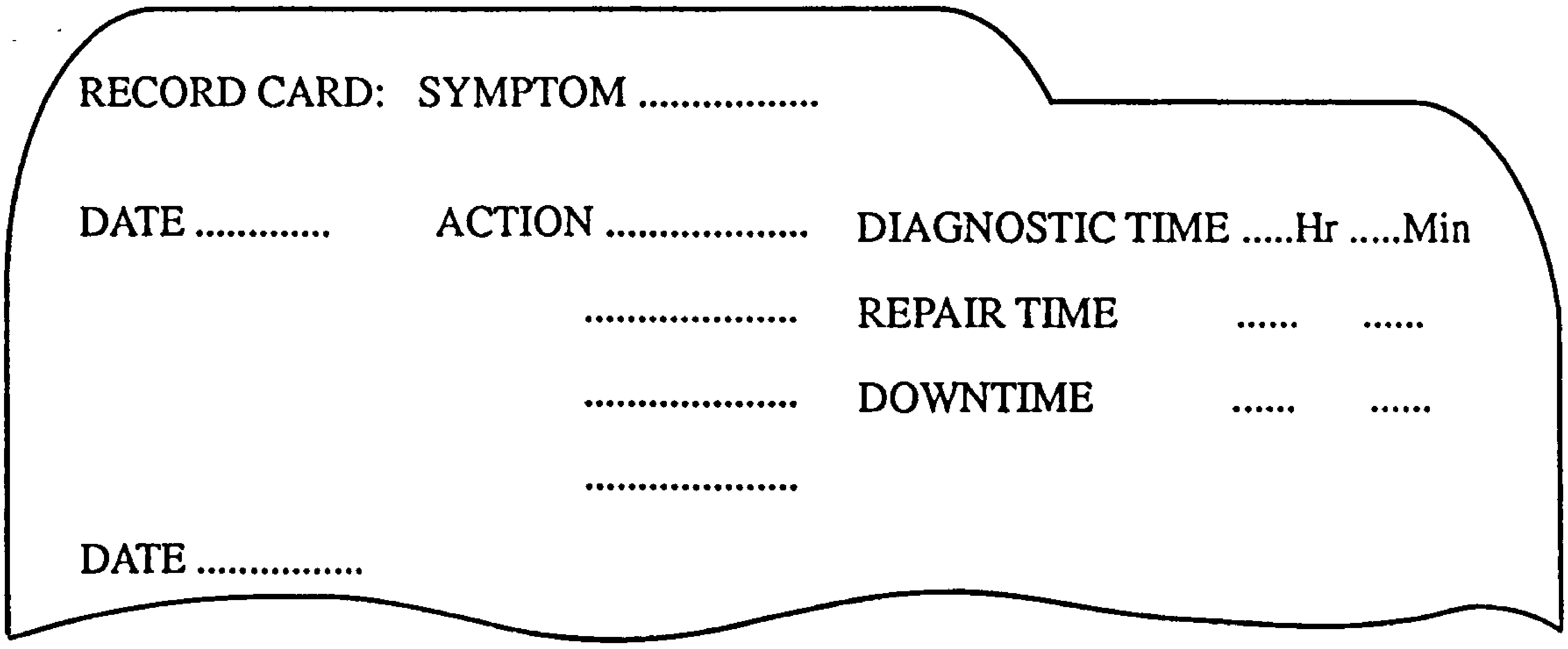
FAULT A CAUSE ACTION

....

FAULT B ....

FIG. 5

With each symptom card there is a fault diagnosis record card relating to that symptom. A sample of this type of card is shown in FIGURE 6.



RECORD CARD: SYMPTOM ....

DATE .... ACTION .... DIAGNOSTIC TIME ......Hr ......Min

.... REPAIR TIME ....

.... DOWNTIME ....

....

DATE ....

FIG. 6

A box or binder of well-maintained symptom cards can be analysed for trends and patterns in machine downtime, such as most common symptoms, faults and their causes, and frequency of fault events related to causes. The use of such information is covered in Section D.

You can, incidentally, generally ignore the frequently heard comment that "there are thousands of different faults on this machine". The use of a symptom card system will indicate otherwise.

An important point to make here is that machine manufacturers would do well to supply, as standard, a set of symptom cards rather than machine manuals which are often difficult to follow, and which contain far more information than is needed to maintain and operate the machine.

Now do Exercise 3 on the next page.

Exercise 3

Think about the use of Symptom Cards in your own situation and ask yourself whether the method is of value or not.

To make sure that you are making this decision for sound reasons, do a simple evaluation by listing advantages and disadvantages as you see them. Use the space below.

ADVANTAGES OF SYMPTOM CARD USE	DISADVANTAGES OF SYMPTOM CARD USE

Listed below are possible advantages and disadvantages of Symptom Card use:

ADVANTAGES

- Provides close control over reasons for downtime.
- Allows quicker access to possible faults than other system in use.
- Provides more responsibility (job enrichment) for operators.
- Reduces the negative effects of 'experts' leaving the organisation.
- Provides more efficient transfer of fault information between shifts.
- Provides analysts with feedback to help improve maintenance/operating procedures.
- Encourages closer working between operators and troubleshooters.
- Provides feedback to machine design.
- Reduces downtime by reducing time spent on fault finding and diagnosis.

DISADVANTAGES

- Reduces the need for personally valued 'experience'.
- Engineers dislike administrative tasks.
- Reduces skill level, in terms of diagnosis, to an automatic process.
- May encourage operators to go beyond limits of responsibilities.

It is not difficult to see from these possible advantages and disadvantages that most advantages are 'organisational' advantages, and most disadvantages are 'individual'-linked disadvantages. This may go some way to explaining the reluctance of practitioners in industry to design and maintain effective record systems.

This is not the place to enter into this debate. The aim here is to raise your awareness about fault diagnosis recording methods.

Whether, at this stage, you have accepted or rejected the symptom card method, it is hoped that your decision has been made for valid reasons.

Now let's move on to the next method of recording fault diagnosis information.

(b) Traffic Lights Description

This method of fault diagnosis recording has, apart from the recording of information, an in-built systematic control.

The principle of traffic light sequence, red-amber-green, is used. This is achieved by having three sheets of NCR paper (No Carbon Required), the top sheet red, middle sheet amber and bottom sheet green. When the operator or the supervisor reports a symptom the details are recorded on the sheet. The troubleshooter arrives and after initial questioning, observation and checks of obvious areas, he or she records on the top sheet either that the fault and the cause have been found and fixed, or that further work is needed.

If the problem has been cleared quickly, the troubleshooter leaves the bottom green sheet for production records, and takes the middle and top sheet. The middle sheet can be used to alert others on the site to whom the fault may be relevant, such as design, production control, stores etc. The red sheet remains with maintenance records.

If the problem requires further work, the remaining parts of the top sheet are completed.

There can be an extension of this control by record sheets, and that is to use red amber and green lights above the machine, or above the line in the case of FMS. Red shows that troubleshooting help is needed. Amber shows that fault diagnosis/repair work is in progress. Green shows that all is well.

Traffic Lights in use

This method can be combined with the symptom card system by having only the symptom cards available and not having the control cards.

A preferred alternative to this is to have a binder in production to take the green sheets. The sheets are entered under symptoms as in the symptom card system.

The traffic light sheets need to be on a frame or rack prominently displayed at the site of the machine or at the line.

Exercise 4

As before, think about this method and list the advantages and disadvantages as you see them. Use the space below.

ADVANTAGES OF TRAFFIC LIGHT USE	DISADVANTAGES OF TRAFFIC LIGHT USE

Here are some likely advantages and disadvantages of traffic light use.

ADVANTAGES

- Makes current machine state obvious to all concerned.
- Production Supervisor can read the situation from the top sheet and plan alternatives accordingly.
- The control can make record keeping a habit by both production and maintenance.
- The method assures a chronological order to fault information.
- The use of a middle sheet alerts others to certain problems without too much conscious effort on the part of troubleshooters.
- Inspection of previous green sheets held under the symptom that has just been reported can be of value as a fault diagnostic aid.

DISADVANTAGES

- Has taint of 'paperwork', even more than symptom card system.
- Can be viewed by troubleshooters and operators as a monitoring or 'checking on work' device.
- Failure to remove sheets at end of the repair can mislead production.
- May be seen as substitute for production-maintenance verbal communication.

Again, the advantages can be seen as 'organisational' advantages, and the disadvantages all have a strong 'individual' element in them.

The method, particularly when combined with the overhead light system, can be a powerful tool in the drive towards reducing downtime.

(c) Chits Description

A chit is a chit is a chit! That is to say, it is a piece of paper normally taken from a pad of chits.

The information contained on a chit tends to be limited to symptom, time reported, what was wrong, spares used, hours/minutes downtime and who did the repair.

There is rarely information about:

- cause of fault
- difference between diagnosis and repair time
- spares replaced, whether faulted or not faulted
- symptom correctly or incorrectly reported
- response time to call-out.

Chits in Use

The most important factor in the use of chits is 'who controls?' For example, in some situations the troubleshooter cannot respond, even if told about the problem, without being given a chit by a supervisor. This can cause considerable delay. The amount of autonomy allowed to operators and troubleshooters to ensure that they can work together is at question here.

Ideally the troubleshooter should control the chit system, that is recording information soon after responding to the request for help. The supervisor is then informed verbally of the fault event.

The chit system does not have the clear control of the traffic light system, even if the chits are duplicated on NCR paper. This is because it is difficult to share the recording task between production and the troubleshooter.

Exercise 5

List advantages and disadvantages of the chit system as you see them. Use the space below.

ADVANTAGES OF CHIT SYSTEM	DISADVANTAGES OF CHIT SYSTEM

Here are some likely advantages and disadvantages of the chit system.

ADVANTAGES

- Can be carried around; convenient.
- Paperwork kept to minimum.
- More chance of being used than more sophisticated methods.

DISADVANTAGES

- Information limited; some essential detail can be lost.
- Only one person controls and is involved in recording.
- Use of only one chit limits sharing of information.
- Easily lost.

The chit method of recording fault diagnosis information is possibly one of the most common in use. There are, however, serious flaws in the method. In addition to the disadvantages listed above, chits serve as a poor means of communication. They tend to be held by the person doing the troubleshooting, that is if they are not lost in transit. It is difficult to control their movement and even more difficult to pass the information on to a range of people within the organisation, including people who have some influence on the ultimate cause of faults.

Chits can be seen essentially as an extension of the 'fag packet' approach which we will look at later.

Finally, the use of chits as the means of fault analysis leads to the passing of the chits to 'someone upstairs', going into a black hole never to be seen again. A not uncommon comment from troubleshooters is "I do not know what they do with this information".

By contrast, a machine or line-based recording, such as symptom cards or traffic lights method, can more easily be returned to source, preferably with a report from the analyst for all to see.

(d) Log Book Description

A feature of log bocks, when they are maintained, is that they are more likely to be used by troubleshooters than by production staff.

Fault diagnosis information is entered in the log book in the form of a short account of the fault and what was done to fix the problem.

Usually the pages are ruled into three or four sections: Date; Time; Fault; Name of Troubleshooter.

The log book is normally kept in a workshop, competing for space with many other bits and pieces.

Log Books in Use

The use of log books can vary considerably between troubleshooters and between shifts.

The quality of information varies too, depending upon the ability of the person recording to write some kind of prose.

Given that a log book is used conscientiously by all concerned, the method has more advantages than disadvantages, and can be a powerful fault diagnosis aid.

Log book use can only be a valid reliable method of recording if two things are done.

1 The log book must be designed and printed in accordance with guidelines shown in Basic Building Blocks; see pages 12 – 14.

2 All relevant staff must be trained in its use.

Exercise 6

List the advantages and disadvantages of log book use as you see them. Use the space below.

ADVANTAGES OF LOG BOOK USE	DISADVANTAGES OF LOG BOOK USE

Here are some likely advantages and disadvantages of log book use.

ADVANTAGES

- Valuable communication link between shifts.
- Concise, easily accessed information contained in one place.
- Format can readily be changed to suit changing circumstances.
- Can be easily transported for analysis, or in the event of safety enquiry.
- Can be used on-site for reference during diagnosis.
- Completed copies can be stored as easily accessible fault diagnosis data.

DISADVANTAGES

- Recording can be 'patchy' due to lack of formal structure in respect to information requested.
- Can be 'swamped' in a workshop.
- Reliability affected by inconsistency between shifts of troubleshooters.
- Not easily shared with production; in this respect it can be one factor in the isolation of Maintenance.
- Difficult to know who actually controls this type of recording.

(e) Computer Input Description

The power of the microcomputer as a fault diagnosis recording tool is considerable. In time, there will be few organisations without the facility to enter fault diagnostic information into a computer network system.

Special Note

At present, there may be some reluctance to adopt a fully computerised system. This is not for reasons of cost because the pay-back time on both hardware and software is, in most cases, little more than twelve months. A major concern is **the danger of de-skilling the troubleshooter's role.** While this is not the place to discuss concerns of this kind, it is necessary to keep in mind what the full implications of computer use can be.

The use of microcomputers, linked together in what is commonly called a local area network (LAN), provides the facility to record day-to-day fault diagnostic events, and to include information about use of spares, manpower, reasons for downtime. This information can then be made available, through local terminals, to stores, maintenance and production management, and to operators and troubleshooters.

Computer Input in Use

The most sophisticated computer system available acts only as a tool for *recording* information. The network itself will not ensure effective, efficient fault diagnostic recording. The continued practice of sloppy recording on bits of paper or in memory, if transferred to computer software, will still result in sloppy records.

The use of computer networks allows effective recording systems, such as symptom cards, to be operated even more effectively. To do this, it is necessary for practitioners to be skilled in using an effective manual system before attempting to use a computer system.

The normal starting point, apart from availability of suitable hardware, is to use an off-the-shelf software package which allows for the total management of maintenance information, of which the recording of fault diagnosis is a part.

A survey of this type of software is available from Conference Communications, Tilford, Farnham, Surrey GU10 2AJ.

An alternative is to use an existing Management Information System (MIS), and to record fault diagnosis in a form most appropriate to your company, possibly modelled on recording techniques described here.

Computer System in Use

In use, it is normal for the operator to name a symptom and request troubleshooter help. A supervisor raises a work card and logs on the request to a line VDU. The troubleshooter takes the card details from a printer, and after diagnosing and fixing the fault, enters the fault diagnosis information to the computer. In this way, each symptom has a databank of:

- faults
- causes
- time to diagnose
- time to repair
- spares used
- personnel requirement
- other comments

(See Section D, page 52).

Exercise 7

List advantages and disadvantages, as you see them, of a computer-based system. Use the space below.

ADVANTAGES OF A COMPUTER-BASED SYSTEM	DISADVANTAGES OF A COMPUTER-BASED SYSTEM

Here are some likely advantages and disadvantages of a computer-based system.

ADVANTAGES

- Supports a systems approach; that is, everyone whether directly or indirectly involved with fault events, can get access to vital information.
- Maintenance of machine and plant histories is made easier.
- Transfer of information to other software, such as statistical packages, makes analysis of fault diagnosis methods easier to do and easier to control.
- Access to fault diagnosis information is readily available.
- Information is available on site and overcomes the problem of keeping clear paper records in dirty environments.

DISADVANTAGES

It is difficult to identify any really genuine disadvantages. However, the following can arise.

- The resistance of 'experts' to having their memory store transferred to a screen for others to access. (This also applies to effective manual records on cards). The computer simply makes ready access more obvious.
- Older troubleshooters may have problems in adapting to the computer network system. (This is simply a generation problem; the effects are temporary).

(f) Notebook Description

This method is closely related to the log book method; there are, however, some important differences.

The notebook method is personal. In one organisation used in research for this module material, a *past employee* was asked for sight of his notebooks which contained the only comprehensive record of fault diagnosis on a particularly complex machine. In many cases, the notebooks travel with the company leaver.

Only in rare cases do troubleshooters or operators make their notebook records generally available. In one of these cases a troubleshooter on a flexible manufacturing line (FMS) kept comprehensive fault diagnostic records in a set of hard-backed notebooks. These books were available in what amounted to a main library on the line. While such practice can be extremely effective, it goes without saying that the company is in a vulnerable position.

A further problem is that such records can reflect a personal way of working which may be quite inefficient.

Finally, and of great importance, is the fact that notebook information, while useful for use in fault finding, is not linked to the needs of different sections of the organisation as good records should be.

The Notebook in use

One of the key functions of notebooks of this kind is to record details about machine settings. For example, if a problem was cured by the addition or removal of shims, a notebook record of when and by how much the change was made will be of value next time round.

Most fault diagnostic information consists of records about unusual faults and how they were fixed.

The symptom does not appear too often in notebooks because troubleshooters are 'fault orientated' and not 'symptom orientated' like operators. The result is that faults, and action used to cure, feature strongly. More comprehensive (and effective) recording of symptom, signs, fault(s) cause(s), action, feedback comes through formal record systems supported by training in their use. Seldom is such thoroughness found in a notebook system.

The control of this system is difficult. Ineffective practices logged into a notebook stand a good chance of being repeated many times over. It is rare for notebook information to be seriously analysed; therefore the feedback information necessary to monitor and control fault diagnosis is missing.

Exercise 8

List advantages and disadvantages of the notebook method.

Use the space below.

ADVANTAGES OF NOTEBOOK METHOD	DISADVANTAGES OF NOTEBOOK METHOD

Here are some likely advantages and disadvantages of the notebook method.

ADVANTAGES

- Very much better than badly maintained formal systems, or than no recording at all.
- Can provide valuable insight into the more effective troubleshooters' methods.
- Can highlight reasons for unacceptable downtime statistics.
- Can provide useful 'crib' information for people new to the job.,
- Can form the base of a computerised knowledge-based system.

DISADVANTAGES

- Leaves the company vulnerable to the movements of employees.
- Difficult to link information to corporate and departmental objectives.
- Seldom in a form sufficiently thorough to provide a really effective fault diagnostic aid.
- Not easily analysed.
- Control is difficult, if not impossible.
- Can be maintained in the place of a formal, more effective system on-site.

(g) Memory

This is possibly the most frequently used method of recording fault diagnosis information.

In the past, older technologies such as mechanical switching gear, relays and mechanical controls all provided their own three-dimensional models in which parts were easily recognised. This ease of recognition greatly helped the use of memory. The sight of each part acted as a prompt to our memory store.

Another significant feature of older technologies was that any chain of possible fault events was less complex than is generally found on current systems.

Nowadays troubleshooters need to hold more and more information in working memory while diagnosing, that is unless formal records are maintained and used.

This increase in tasks for our working memory is not unlike the way we now have to use longer telephone numbers, to a point which exceeds the capacity of our working memory. People over forty years of age will remember when a combination of three letters and three or four numbers formed an easily memorised telephone number.

What is called 'experience', in relation to fault diagnosis, is fault event information held in long-term memory(LTM).

The prompts used in the past helped us retrieve this information from LTM. But now that prompts are much less clear, the use of this memory can lead to problems and long delays spent in fruitless searches through a system or a machine.

There does, however, appear to be benefit in memory use. There is value in having someone who can diagnose from information held in LTM, without the use of fault aids, manuals, schematics, etc. There are also, however, disadvantages which far outweigh any benefits, which in today's fast changing technology can only be short term anyway.

Take the example of when a troubleshooter approaches a symptom and says, "I remember last time it was ....XYZ." No matter how inefficient the solution may be, it will not be assesssed or reviewed while stored in memory.

A more serious problem with memory use is that it can never be a company fault diagnosis system. If the expert leaves, the memory store of faults goes too.

SECTION C WHO SHOULD RECORD?

WHO SHOULD WORK THROUGH THIS SECTION?

- troubleshooters
- operators
- supervisors
- managers.

WHAT YOU WILL NEED

- Access to at least one colleague.

HOW MUCH TIME?

- You will need to allow between 5 and 10 minutes to complete this section.

AIM OF THIS SECTION

The aim of this section is:

- to encourage you to consider who needs to be involved in fault recording.

OBJECTIVES OF THIS SECTION

At the end of this section you should be able to:

- name job roles that have within them responsibility for recording
- state whether existing choice of job roles is appropriate in your situation.

INTRODUCTORY NOTE

This is a short but important section.

TYPICAL RECORDERS OF FAULT DIAGNOSTIC INFORMATION

We shall begin by simply listing the people who could typically act as recorders of fault diagnostic information. These are:

- troubleshooters
- operators/users
- manufacturing/service supervisors
- maintenance supervisors
- designated technicians
- clerical recorders
- machine/system-suppliers' troubleshooters.

The troubleshooter is an obvious person to include here. However, a key question to ask is whether he or she should have sole responsibility. Should the troubleshooter share recording with an operator or user of the equipment, or with someone who has the specific task of maintaining such records?

To avoid the natural resistance to recording, shown by troubleshooters, one ploy is to require them to enter only the briefest of comments and to use box-ticking. The record is then written in a more comprehensive form, suitable for analysis by technicians.

This approach is used especially in situations where a company is building up a fault diagnostic knowledge-based system (sometimes wrongly called an 'expert' system). When the point is reached that only the most unusual symptom and related fault needs to be recorded, the technician can hand over the system to the troubleshooters and then go off to do other things.

As an alternative to this designated recording role, it is possible for supervisors to include fault diagnostic information as an input along with other management information. Again this recording would be done, either manually or in computerised forms from the troubleshooters and/or operator's notes.

The use of clerical personnel to maintain effective fault diagnostic records is not common but has distinct advantages. There is a good chance that the methodical rule-based approach of clerical people can achieve better results than when recording is done by people who wish only to tackle the next problem.

The people who recognise symptoms, look for signs, locate faults, diagnose causes and then provide feedback, must maintain some record of their work. In a world of increasingly complex technology, the recording of such data is essential. The people who actually maintain this information in a usable form may or may not be the same people who actively troubleshoot. The minimum requirement of troubleshooters, however, is to provide essential details about their fault-finding diagnostic actions.

Exercise 9

Answer the following questions concerning your own work situation.

1 In my situation the people who do *first line recording* of fault diagnostic information are (tick as appropriate):

- troubleshooters
- operators
- supervisors
- technicians (designated).

2 The people who *maintain* fault diagnostic information are:

- troubleshooters
- operators
- supervisors
- technicians (designated)
- clerical personnel.

3 The people who, at present, *record* fault diagnostic information are:

- appropriate
- appropriate, but need additional support
- not appropriate; new system needed.

SECTION D USE OF RECORDED INFORMATION

WHO SHOULD WORK THROUGH THIS SECTION?

- troubleshooters
- operators
- supervisors
- managers
- stores personnel.

WHAT YOU WILL NEED

- notebook and pencil
- access to at least one colleague
- access to reliability data.

HOW MUCH TIME?

- You will need to allow between 15 and 20 minutes to complete this section

AIMS OF THIS SECTION

The aims of this section are:

- to enable you to recognise the use of recorded information for reliability analysis
- to enable you to recognise the use of information as a direct fault diagnostic aid during diagnostic tasks.

OBJECTIVES OF THIS SECTION

At the end of this section you should be able to:

- state two main reasons for recording faults
- describe how explanation of MTTF can be improved through effective fault recording
- use fault recording as a direct diagnostic aid and demonstrate how history of fault events can help predict future events
- share fault information among troubleshooters and operators to demonstrate how sharing can reduce unexpected 'novel' faults.

WHY DO WE RECORD INFORMATION?

A major criticism of fault recording, made by people who are called upon to record, is that the reasons for wanting the information are not made clear.

Everyone who is asked to record information should understand fully why each bit of information is needed.

There are two broad reasons for recording fault diagnosis information.

1. To demonstrate the level of reliability of a machine, a piece of equipment, a production line, or a total system.

2. To provide, through recorded histories of fault events, an aid to fault diagnosis. A comprehensive record of what has happened provides the best guide and solution to future events.

As in all other areas of life, an awareness of history is of enormous value to problem solving and decision making. Very little is, in fact, totally new to us.

We will now consider these two broad reasons for fault diagnosis recording.

RECORDING AND RELIABILITY

How reliable? How dependable? We can ask this of any piece of equipment or system. We can only give a measured, quantifiable answer if a record of reliability is available.

What is "reliability"?

Reliability is defined as the probability that an item of equipment or a system will perform a planned function for a specified period of time under given conditions.

Therefore, a component may not be reliable because of:

- unsuitable functions
- unsuitable time of continuous use
- unsuitable design for performance
- unsuitable manufacture for performance
- unsuitable operating conditions.

System reliability

When we consider a system, rather than a component, the situation is different. (See Module 3). System reliability must include the following:

- design of the system
- how people operate the system
- how people maintain the system
- how people provide spares to the system.

Mean Time to Failure (MTTF)

A standard measure for reliability is mean time to failure (MTTF). If this equalled the performance time required, reliability would be 100%. However, this is misleading and too simplistic. All machines and systems develop failures. The MTTF is a measure of how well the last fault was diagnosed (i.e. the cause was found as well as the fault) and the effectiveness of the repair.

Without effective records it is not possible to say whether an unacceptable MTTF is due to:

- unsuitable operation conditions
- unsuitable spares
- poor diagnosis

- poor diagnosis
- poor operator skills
- poor repair
- fault caused during repair
- unreliable equipment
- design-induced fault.

It is not possible to hold such data in memory in a form that allows for analysis of reliability.

Mean Down Time (MDT)

Another measure that comes into reliability is mean downtime (MDT).

MTTF + MDT = TOTAL AVAILABLE TIME (AVAILABILITY)

Without effective records it is not possible to say whether MDT is due to:

- availability of labour
- availability of raw materials
- repair time
- fault diagnosis time
- spares requisition time
- response-to-fault time
- machine setting time
- checking out time.

Only by identifying reliability in this way is it possible to target the cause or causes of poor mean time to failure (MTTF).

Exercise 10

Complete the following statements based on your own work situation.

(a) In my situation:

the reliability* of our most reliable machine is ....%
the reliability* of our least reliable machine is ....%
the reliability* of our most reliable production line is........%
the reliability* of our least reliable production is ....%

$$* \text{ use: } \frac{\text{MTTF (hours)}}{\text{Availability (hours)}}$$

(b) The reliability of our total system is.....................

(c) This situation is (tick as appropriate):

....very good
....good
....acceptable
....poor
....very poor.

(d) Our recorded fault diagnosis information can provide a measure of reliability and can predict reliability.

Effective records tell you how well you are doing. If you are not doing too well, they tell you where the causes of the problem are to be found.

For more detailed information about reliability, beyond its relationship to record keeping, a book by David Smith is recommended. (See Useful References on page 83).

RECORDING AS FAULT DIAGNOSIS AID

The best aid to fault diagnosis is having detailed accurate knowledge about past fault events.

The experienced effective troubleshooter draws on past fault events, and repeats his or her most effective behaviour which resulted in good diagnosis.

The experienced *in*effective troubleshooter draws on past fault events and repeats ineffective behaviour which resulted in poor diagnosis.

If effective troubleshooters do not record their fault diagnosis experience; there can be no means of making this valuable expertise generally available. The alternative is by word of mouth which is a slow process, and open to misunderstandings.

For any machine, piece of equipment or system there can only be *n* number of possible symptoms; in other words there must be an exhaustive list. For each one of these symptoms there can only be *n* number of possible faults, another exhaustive list. For each of these faults, there can only be *n* number of possible causes, an exhaustive list again.

Every fault diagnosis task, whether on a nuclear power plant, a patient, a washing machine or a bicycle, begins with a symptom and ends with a cause.

Providing ready access to symptom-fault-cause information greatly reduces the time, expensive time, spent in diagnosis.

Example

Troubleshooter A liaises with operator B on shift X and consistently finds the cause of a given symptom in around six minutes.

Troubleshooter C liaises with operator D on Shift Y and consistently finds the cause of the same symptom in around twenty minutes.

This is not an unlikely scenario, and there is an important question to ask here.............

"Why cannot one learn from the other?"

In most cases such learning does not take place because the sum of effective diagnosis becomes part of *personal experience alone*, and is not shared.

An alternative to this situation is the use of fault diagnosis records.

The 'model' fault diagnosis aid, which is almost foolproof, is to have for each possible symptom a record of the best strategies taken which identified the cause.

With such a record system a troubleshooter or operator could walk into a company for the first time, be given a symptom, and diagnose the cause using the aid in optimum time. This should be one goal of an effective fault diagnosis record system.

We have just said 'almost foolproof'. There will always be the unexpected fault event, but contrary to popular belief the unexpected does not happen every day. The unexpected rarely happens. Events *appear* to be unexpected or unusual because memory fails. People (or one person) happen to keep missing a particular fault event. If the combined fault events experienced by everyone are readily accessible, it can be seen that unusual events are, in fact, rare.

SECTION E DESIGNING A FAULT DIAGNOSIS RECORDING SYSTEM

WHO SHOULD WORK THROUGH THIS SECTION?

- troubleshooters
- operators
- supervisors
- managers
- process/production engineers.

WHAT YOU WILL NEED

- notebook and pencil
- access to at least one colleague.

HOW MUCH TIME?

- You will need to allow between 20 and 30 minutes to work throughout his section.

AIM OF THIS SECTION

The aim of this section is to enable you to recognise stages of development in the design of a record system.

OBJECTIVES OF THIS SECTION

At the end of this section you should be able to:

- identify essential items of information in your own situation
- choose an appropriate method of recording
- choose an appropriate method of fault record presentation.

KEEPING YOUR DESIGN SIMPLE

The overall aim is to keep record system design as simple as possible.

There have to be at least six items of information in an effective fault diagnosis record system:

1. symptom
2. fault
3. cause
4. action
5. spare parts used
6. total time taken to diagnose and repair.

Each item of information beyond this basic minimum adds to complexity, and increases the possibility of the system being rejected by users. **Therefore, the use of every additional item of information must be justified.**

Examples

- As number 2 on the above list, the medical practitioner would add signs which indicate, more precisely than the symptom, where the problem (fault) may lie.
- The engineer in a hazardous environment would add essential information about health and safety checks.
- The manager of a high capital, new technology-intensive process would require a more detailed itemising of downtime, such as time to diagnose, time to repair, and elapsed time since last recording of that symptom, fault and cause.

Exercise 11

Consider what additional information is needed in your situation, and give a clear justification for its inclusion.

ITEM OF ADDITIONAL INFORMATION	REASON FOR INCLUSION

Next, in the design of a record system we need to be aware of two distinct parts to effective record keeping.

PART ONE	PART TWO
The day-to-day recording of fault event information.	The maintenance of machine and/or system histories.

The relationship between these two parts and fault diagnosis is shown in FIGURE 7.

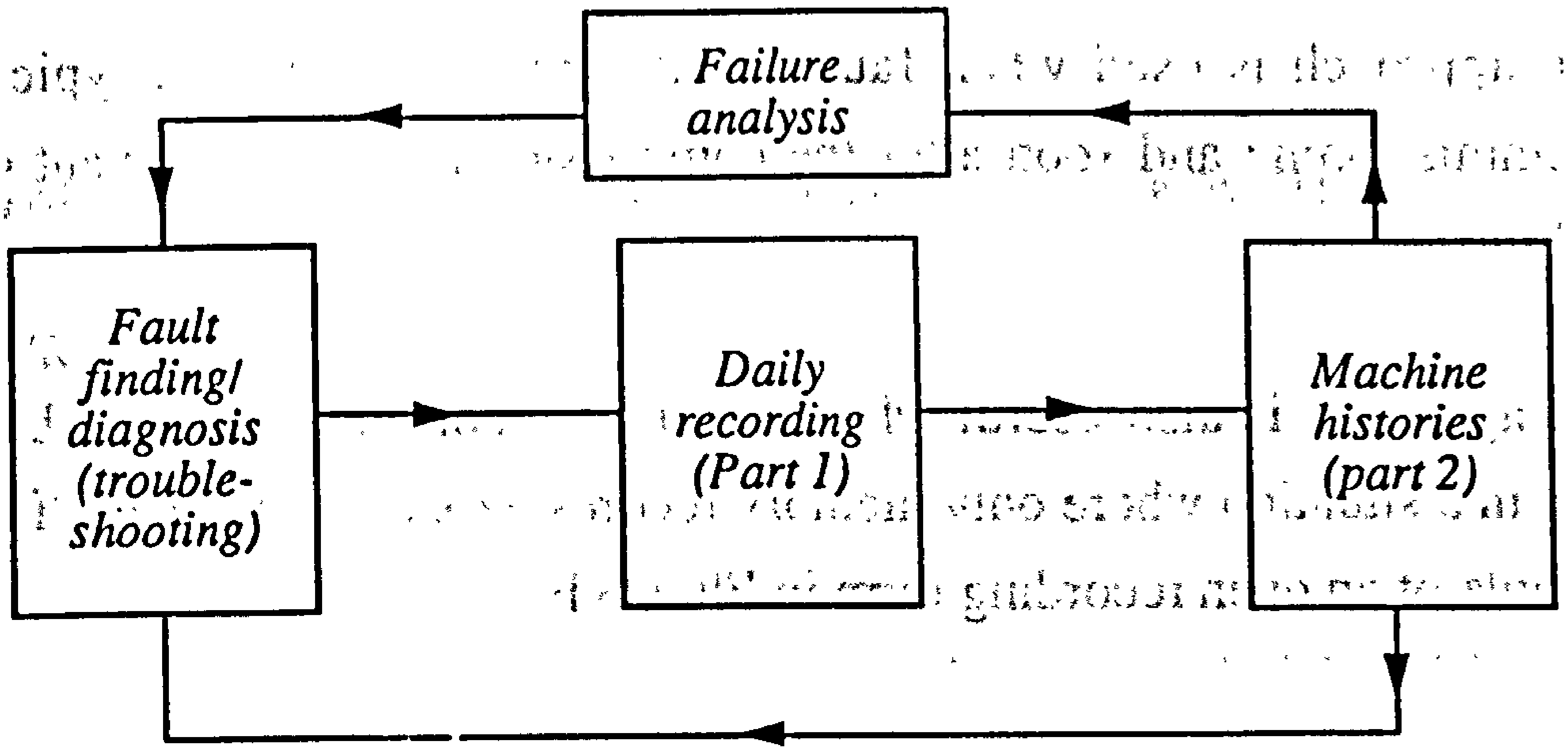


FIG. 7

The histories provide fault diagnosis aids for use when diagnosing, and provide analysts with valuable data for failure analysis.

DESIGN OF RECORDING SYSTEM FOR PART ONE: DAY-TO-DAY RECORDING OF FAULT EVENT INFORMATION

There are two broad approaches to recording day-to-day fault events:

1 open approach

2 closed approach

The Open Approach to Recording

The open approach is used when fault events are unpredictable, typically during commissioning and soon after the commissioning of a new plant or a new machine.

The open approach is also useful when a formal recording system is being developed in a situation where only memory records existed previously. There is an example of an open recording form in FIGURE 8.

DATE ....

SYMPTOM

FAULT

CAUSE

ACTION

JOB STARTED .... JOB FINISHED.................. DOWNTIME ....

LABOUR USED ....

SPARES USED ....

....

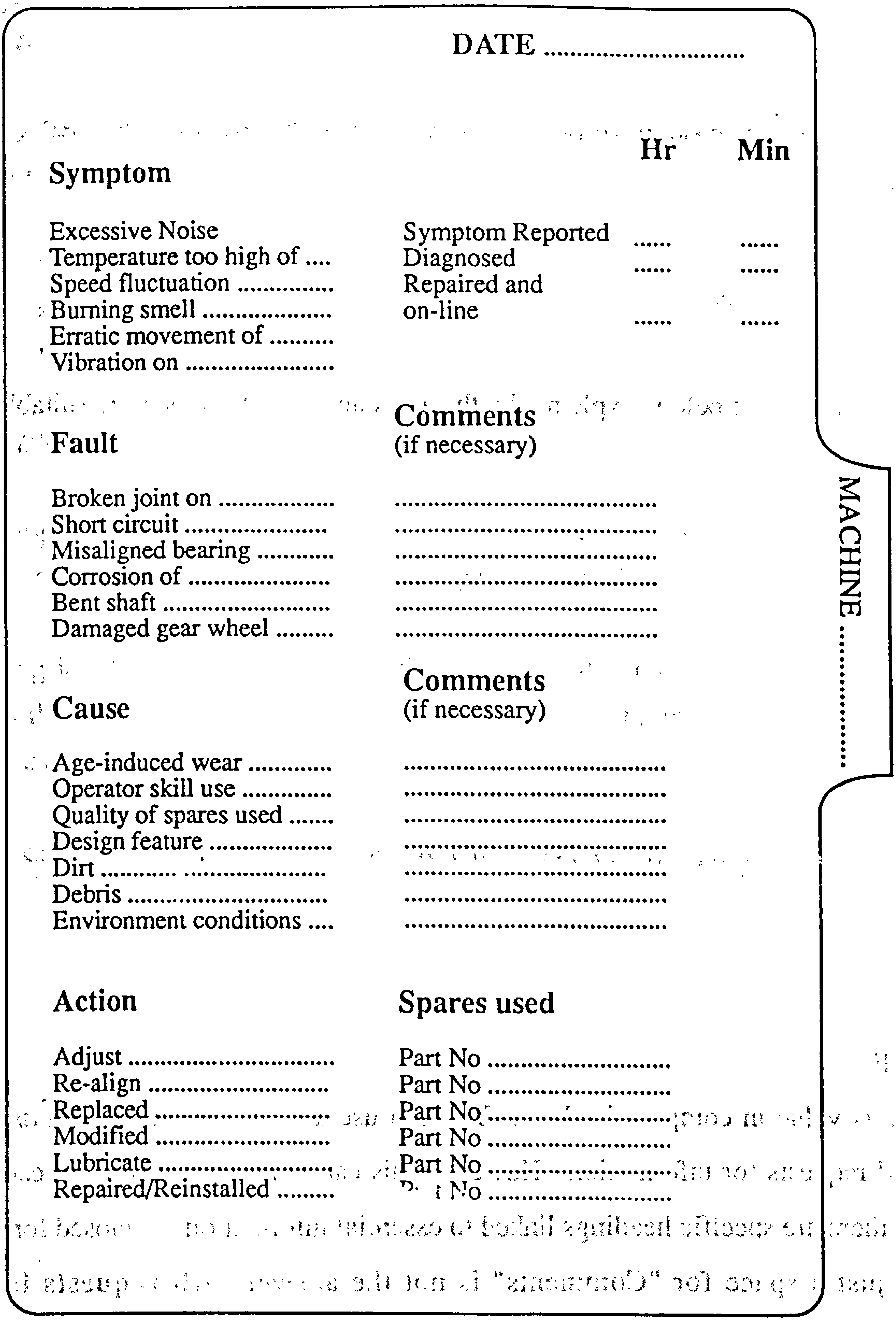
WHO NEEDS TO KNOW ....

FIG. 8

THE CLOSED APPROACH TO RECORDING

The closed approach can be used in situations where most symptoms, faults and causes are known to the practitioners. This approach is generally more acceptable to those who must do the recording, and is easier to analyse using a standard statistical package.

An example of a closed form is shown in FIGURE 9.



DATE ....

	Hr	Min
Symptom Reported	......	......
Diagnosed	......	......
Repaired and on-line	......	......

Symptom

Excessive Noise
Temperature too high of ....
Speed fluctuation ....
Burning smell ....
Erratic movement of ....
Vibration on ....

Fault

Broken joint on ....
Short circuit ....
Misaligned bearing ....
Corrosion of ....
Bent shaft ....
Damaged gear wheel ....

Comments
(if necessary)

....
....
....
....
....
....

Cause

Age-induced wear ....
Operator skill use ....
Quality of spares used ....
Design feature ....
Dirt ....
Debris ....
Environment conditions ....

Comments
(if necessary)

....
....
....
....
....
....
....

Action

Adjust ....
Re-align ....
Replaced ....
Modified ....
Lubricate ....
Repaired/Reinstalled ....

Spares used

Part No ....
Part No ....
Part No ....
Part No ....
Part No ....
Part No ....

MACHINE ....

FIG. 9

Exercise 12

In your work situation, is an open or closed approach most suitable? (tick one answer)

Open

Closed

Now, in the space below, explain why the approach you chose is more suitable.

NOTE

There is value in compromise here. You can use a combination of open *and* closed requests for information. However, this can only work well if, in each case, there are specific headings linked to essential information. A closed form with just a space for "Comments" is not the answer. **All requests for information on a fault diagnosis recording form must be precise and essential.**

DESIGN OF RECORDING SYSTEM FOR PART TWO: MAINTENANCE OF MACHINE AND/OR SYSTEM HISTORIES

There are three broad approaches to the presentation of information in machine and/or system histories.

1 listing
2 algorithms
3 fault trees

LISTING

Listing is simple, and is therefore to be encouraged. However, in complex situations there can be more value to be gained from algorithms or fault trees.

Listing involves the collecting together of day-to-day fault event records and, from these, producing an almost definitive list of symptoms, related faults and their causes.

An example of a listing is shown in FIGURE 10 on the next page.

1 SYMPTOM

Loss of pump pressure

2 POSSIBLE FAULTS

*	**	
E	1	Suction line joint leak
F	5	Valve leak
A	4	Blocked filter box
B	2	Drive clutch slipping
D	3	Loss of motor power
C	6	Pump seals failure
G	7	Impeller damage

*	Marked alphabetically in order of probability
**	Marked numerically in order of easiest to check

3 POSSIBLE CAUSES

*	
B	Dirt
D	Debris
C	Oil contamination
A	Preventative maintenance (level of)
F	Past repair-related fault
E	Plant operator-induced fault.

FIG. 10

[Note: This is for example purposes only, and is not related to any particular situation.]

ALGORITHMS

We will use the simplest symbols for applying algorithms, that is, rectangles for description of process and diamonds for decisions. FIGURE 11 is an example of an algorithm.

An algorithm of this kind can be used to provide a clear step-by-step route from symptom to cause, and is capable of including actions taken. In very complex situations, however, it can become too long to be of real practical value.

In such cases, algorithms need to be used in conjunction with the functional block technique. (See Module**2**). Dividing up a complex system into functional blocks makes the use of algorithms for each block a practical option.

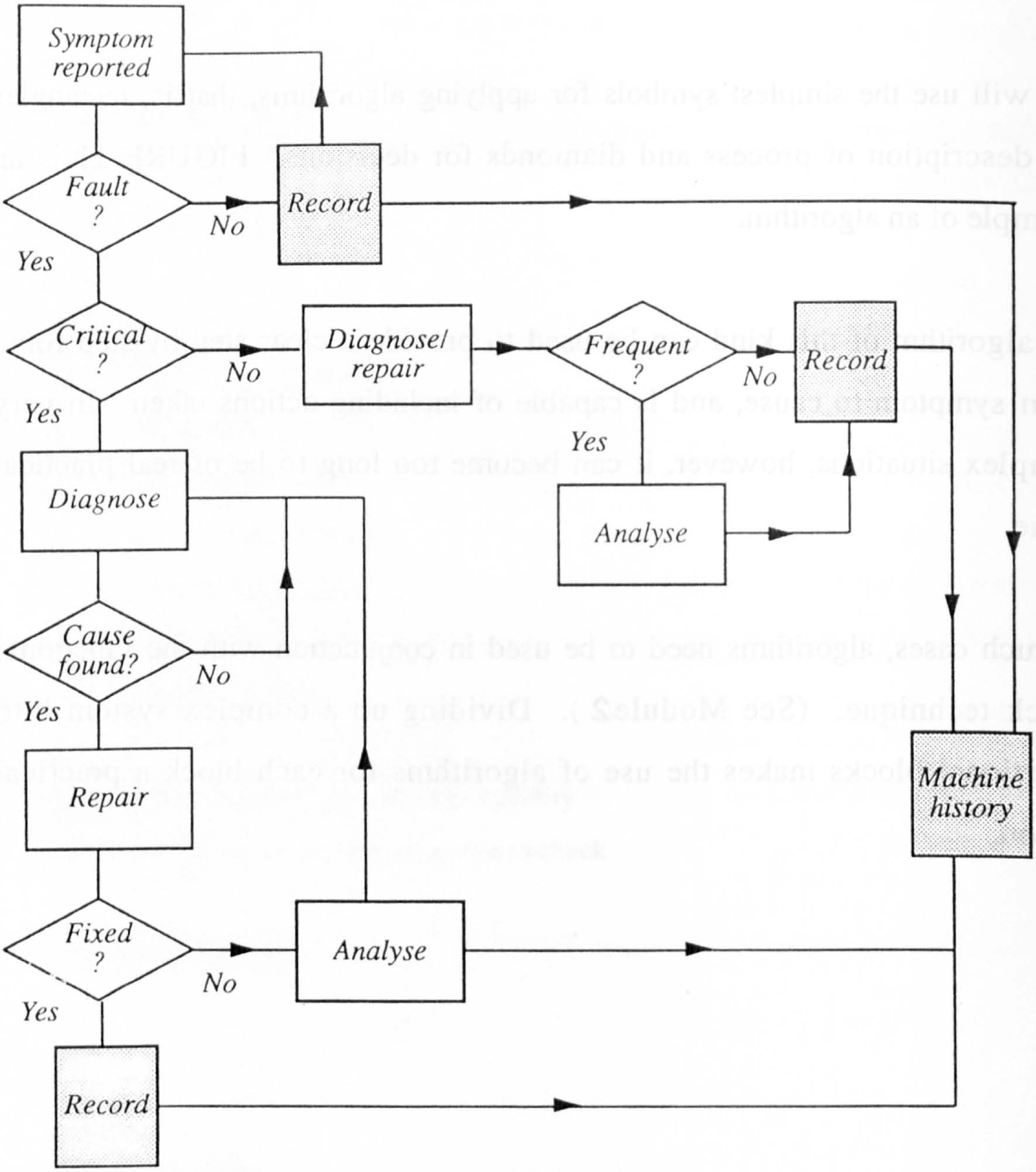
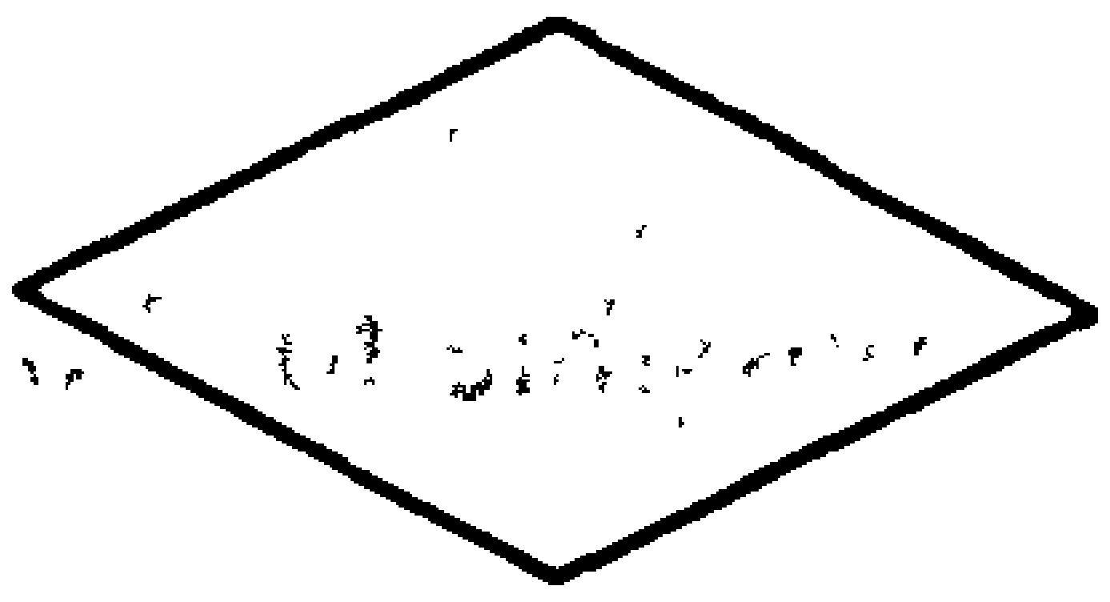

Symptom reported
Fault ?
No
Yes
Record
Critical ?
No
Yes
Diagnose/ repair
Frequent ?
No
Yes
Record
Analyse
Diagnose
Cause found?
No
Yes
Repair
Fixed ?
No
Yes
Analyse
Machine history
Record

FIG. 11

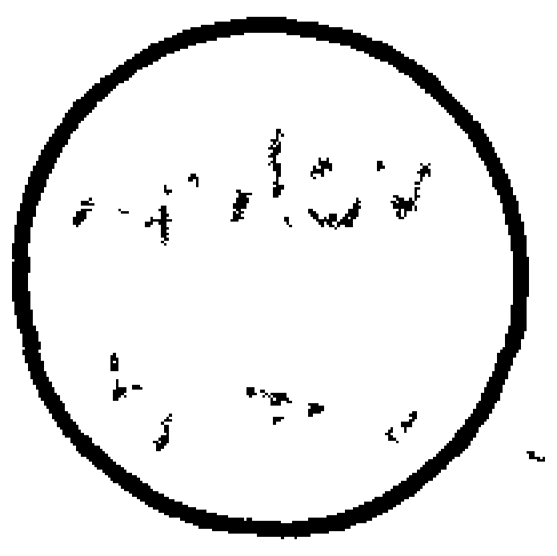
FAULT TREE

There are a few standard symbols to be used in the design of a fault tree.

An assumed possible fault.

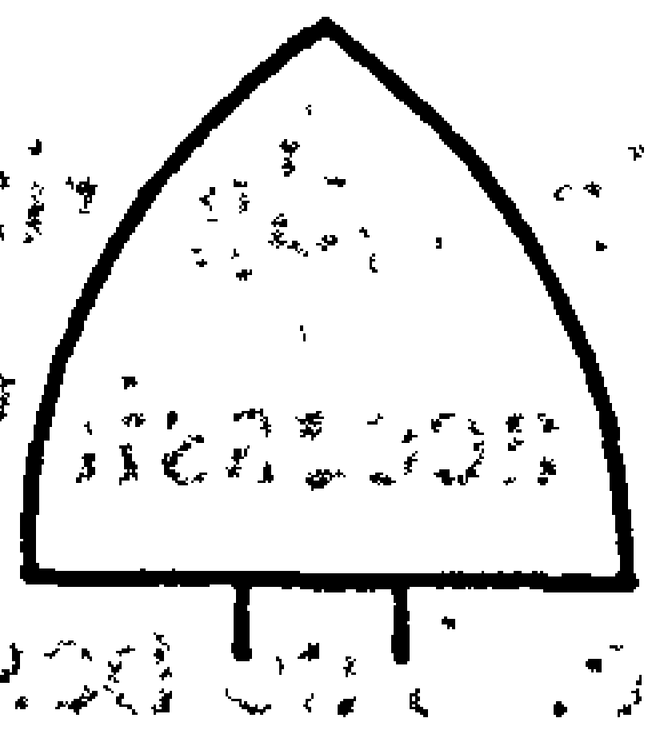


An independent fault, not part of the normal sequence of possible faults.

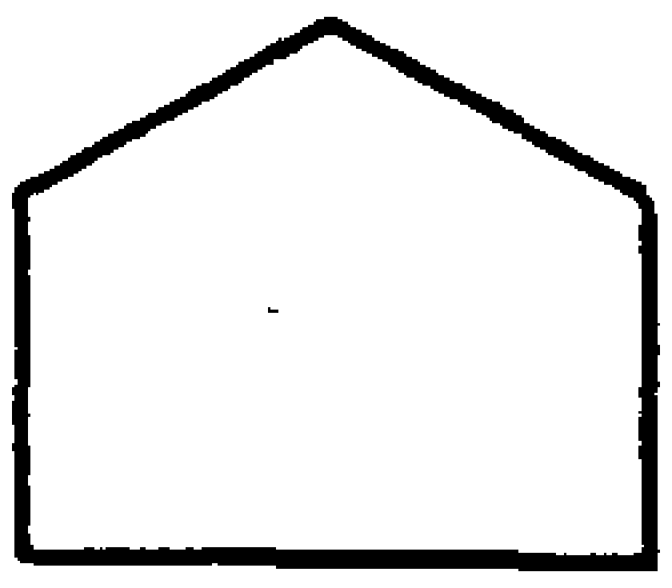


AND gate, which means that both input conditions must apply if described output is to apply.

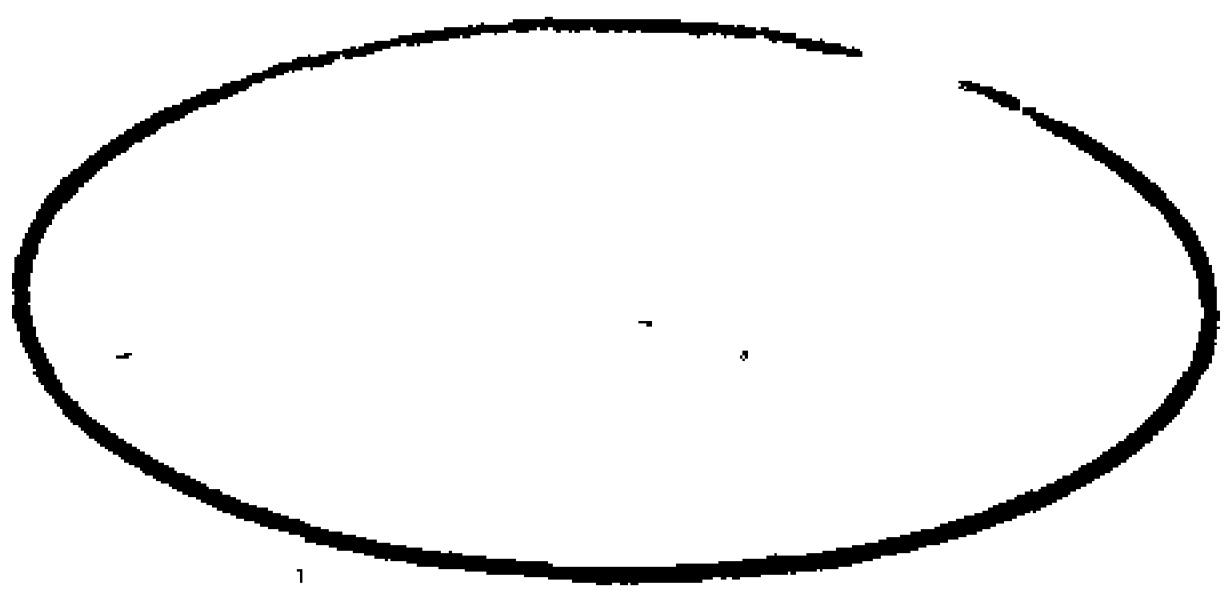
OR gate, which means that either input is sufficient for the output to apply



Normal event, not a fault.



INHIBIT, which puts certain conditions on the gate inputs.



In the example of a fault tree shown in FIGURE 12, there is a 'top event' which, in effect, is a symptom, in this case 'hospital blackout'. For this fault event to happen, two main failures must occur together, hence the AND gate.

Below this step it is possible to show more specific faults which could account for the two failures.

Further steps can be developed in this way to a point where all, or almost all, fault possibilities are covered.

The value of this approach, apart from its comprehensiveness, is that most probable faults and their causes can be highlighted and seen on one diagram.

This approach also encourages troubleshooters and operators to recognise a logical reasoning to fault identification. That is by saying:

"If this and this, then ..."
"If this or this, then ..."

Whether you use listing, algorithms or fault trees, the most important point is that they are readily accessible to users. The best place is on-site, at the machine or on the line. The best means of presentation is on wipe-clean cards, indexed by symptoms in a box or ring binder.

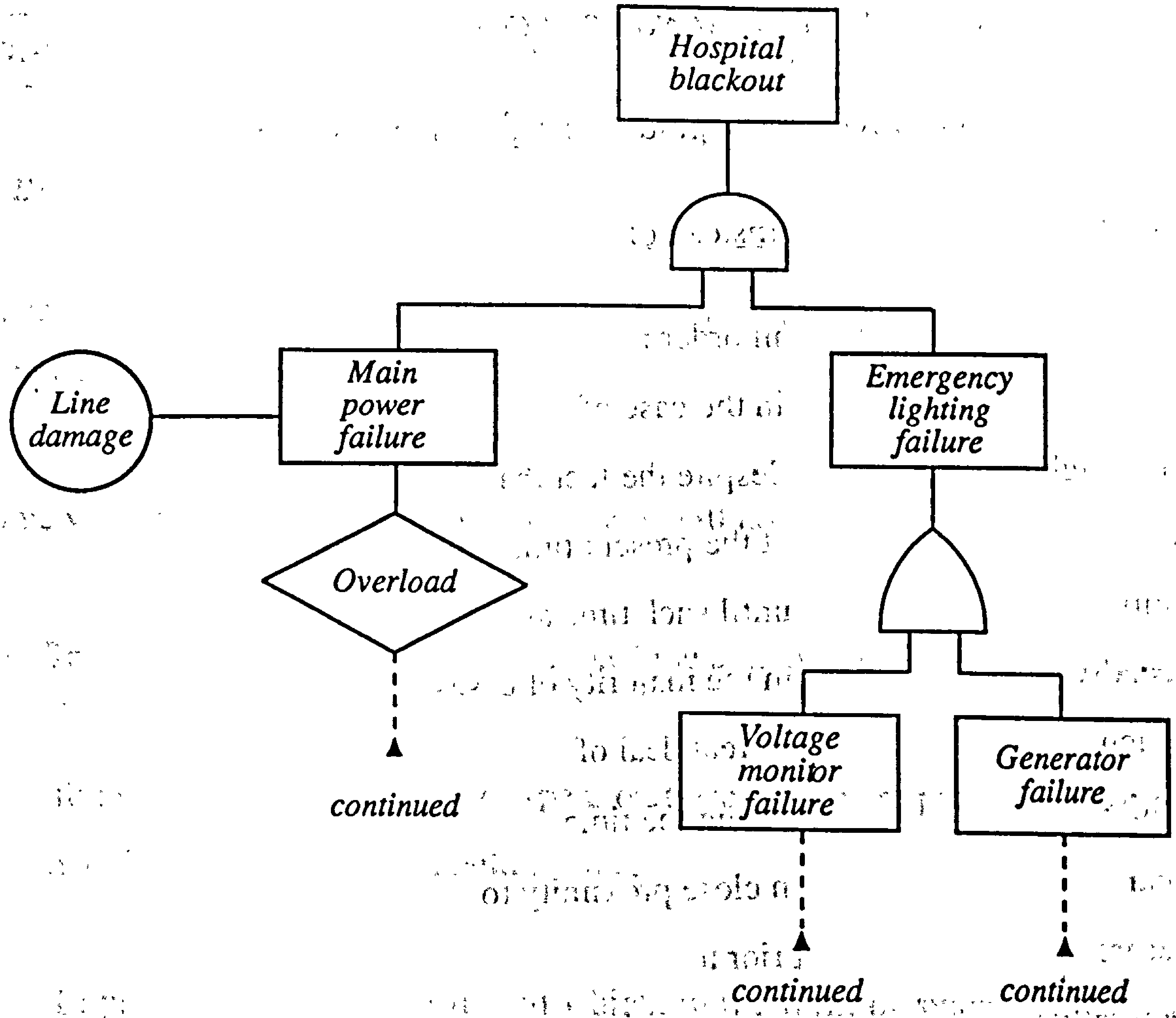

Hospital blackout
Line damage
Main power failure
Emergency lighting failure
Overload
continued
Voltage monitor failure
Generator failure
continued
continued

FIG. 12

USE OF TERMS IN FAULT DIAGNOSIS RECORDING

These notes are provided as a guide to keeping records simple.

Write:	Instead of:
to	in order to
if	in the case of
although	despite the fact that
now	at the present time
until	until such time as
usually	in the majority of cases
much	a great deal of
while	during the time
near	in close proximity to
before	prior to
generally	as a general rule
history	past history
if possible	if at all possible
except	with the exception of
because	on grounds that
take action	take appropriate measures
for	with due regard for

Given these examples, you can check whether you are inclined towards over-writing when producing accounts of records (recording).

MODEL ANSWERS TO SELF-DIAGNOSTIC QUESTIONS

QUESTION ONE

There are a number of valid, and justified, reasons for keeping records of faults and their diagnosis.

Some will apply in your situation, and others will not.

(a) To provide data for assessment of machine and/or plant system reliability.

(b) To provide accurate control of spare part use, and spare part requisition to avoid excess capital stock held in store.

(c) To provide future diagnostic aid which, in the form of symptom cards or record sheets, helps reduce the time spent on diagnosis.

(d) To provide up-to-date feedback on types of faults and causes to people who can affect system reliability, e.g. designers, stores personnel, buyers and production maintenance management.

(e) To encourage closer communication between production and maintenance personnel.

QUESTION TWO

The most common methods in use are:

- (a) Long Term Memory (LTM)
- (b) Word of mouth
- (c) Fag packets
- (d) Book of record chits
- (e) Workshop logbook

Less common methods in use are:

- (f) Symptom cards
- (g) Traffic light sheets
- (h) Computer software
- (i) Closed response record sheet
- (j) Open response record sheet.

QUESTION 3

There are six basic headings which provide essential fault diagnosis information in *all* situations. This is information which can be generalised.

1 Symptom
2 Fault
3 Cause
4 Action taken
5 Spare parts used
6 Time taken to diagnose and repair.

Additional information to be added depending upon the situation:

7 Time to respond to symptom report
8 Checking out time
9 Who needs to know about fault and cause
10 Who was involved
11 Time since last report of that symptom
12 Time since last fault of any kind
13 Time to get required spare parts
14 Suitability of spares
15 Design-induced fault
16 Operator-induced fault
17 Maintenance-induced fault
18 Need for preventive maintenance
19 Alternative cover used during diagnosis and repair
20 Effect on the system
21 How fault can be avoided
22 Incorrect reporting of symptom.

SELF-DIAGNOSTIC QUESTION 4

Apart from the obvious people such as troubleshooters (electrical, mechanical, process), and operators or users of machines and equipment, consideration needs to be given to other possible recorders.

Other recorders can be drawn from technicians, clerical and data processing personnel. This provides a back-up to the brief records produced by troubleshooters and operators.

QUESTION 5

FIMS }
FSD } See page 9.

MTTF = Mean time to failure
MTTR = Mean time to repair
FMECA = Failure Modes Effects Analysis
A bottom-up approach
This form has the heading of:
Item ....
Failure modes ....
Cause of Failure ....
Possible Effects ....
Probability of Occurrence .....
How critical .....
FTA = Fault Tree Analysis
Top-down approach. See pages 74 – 75.

LCC = Life Cycle Costs. See module 5.

DOM = Designed-out maintenance, which has the aim of reducing the need for maintenance and fault diagnosis through more effective design.

MTBMA = Mean Time before Maintenance Action

MDT = Mean downtime

USEFUL REFERENCES

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Training
in
Fault Diagnosis

A Systems Approach

Module 5

Costing

Malcolm Craig.
1991.

CONTENTS

INTRODUCTION

Please read this introduction carefully. It is an important part of the module.

In this module we describe the costs and means of measurement involved quite specifically in the process of fault finding and diagnosis. This is not normal practice. Such costs are swallowed up in the overall cost of maintenance.

On-going changes in technology have shifted the emphasis increasingly towards fault diagnosis tasks and the effect this type of work has on industry, both in the manufacturing and service sectors.

Maintenance is playing an increasingly vital role, and within maintenance the time, resources and cost of fault diagnosis increases in proportion to other activities, to the extent that it can be as high as 70% of maintenance activity.

As maintenance, and in particular fault diagnosis, becomes more complex, it also becomes more costly. The maintenance cost in manufacturing a product can be up to 25% of the added value (i.e. the sale price less the cost of energy and materials.)

These costs arise mainly from breakdown time, which is part of downtime. The downtime cost varies between industries, from around £2000 per minute in automobile manufacture to £25 a minute in food production.

Therefore, attempting to identify the true coast of fault diagnosis activities is a worthwhile task. By 'true cost' we mean not only the cost of fixing a fault, but also the influence that effective and ineffective fault diagnosis practices have on the organisation in terms of cost.

The relationship between fault diagnosis cost and other costs, as presented in this module, is shown in FIGURE 1.

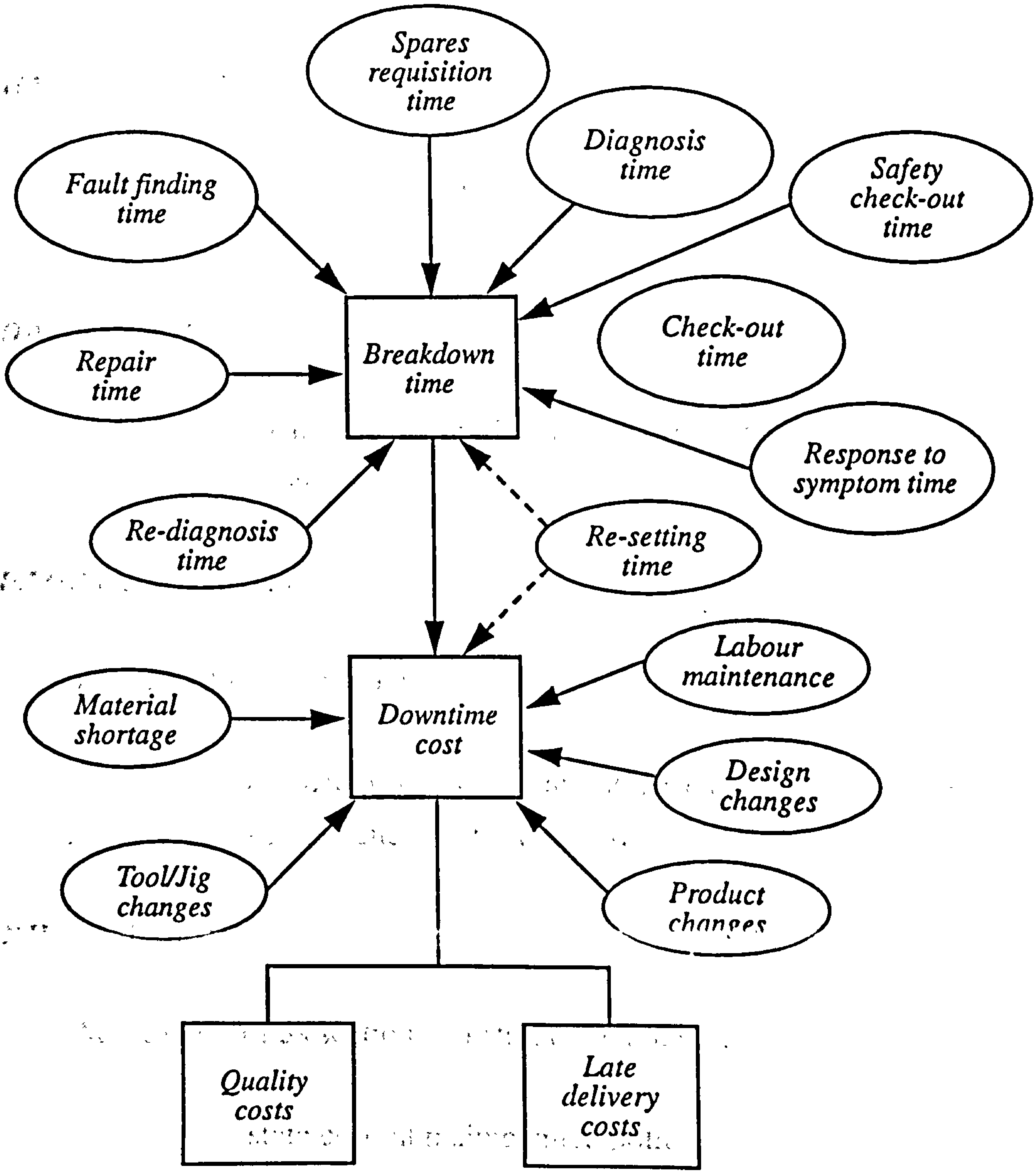

FIG. 1

We begin our examination of these costs by considering overall maintenance cost issues. (For more detailed information on these issues, see the section entitled 'Useful References'). Then, the costs of fault diagnosis are considered in detail. Following this section the description opens out again to finish with broader issues.

SECTION A: SELF-DIAGNOSTIC QUESTIONS

WHO SHOULD WORK THROUGH THIS SECTION?

- production/service managers
- production/service/maintenance supervisors
- troubleshooters

WHAT YOU WILL NEED

- access to company cost statements, accounts and department policy.

HOW MUCH TIME?

- You will need to allow between 30 and 40 minutes to complete this section.

AIM OF THIS SECTION

The aim of this section is:

- to encourage debate about cost issues as they affect fault finding and diagnosis practices.

OBJECTIVE OF THIS SECTION

At the end of this section you should be able to:

- state current maintenance policy.

QUESTION 1

What is the average cost of downtime of machines and/or equipment in your organisation?

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QUESTION 2

List the various cost elements that add up to produce an overall average downtime cost.

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QUESTION 3

When a machine, a new piece of equipment or a new system is installed, what is the normal pay-back time?

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QUESTION 4

What proportion of pay-back time is attributable to maintenance?

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QUESTION 5

What is the maintenance policy of your organisation: Preventive Maintenance Policy (PMP); Breakdown Maintenance Policy (BMP); a fifty-fifty approach, or more emphasis on one than the other?

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QUESTION 6

By how much, in pounds sterling, is your policy better than other possible alternatives?

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QUESTION 7

How many cost areas can be affected by fault diagnosis performance in your organisation?

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QUESTION 8

Is maintenance in your organisation recognised as an indirect overhead cost, or is all or part of it attributed to direct cost?

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QUESTION 9

"How maintenance is costed makes a difference to the role of the department within the organisation". Do you agree or disagree with this statement?

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....

....

SECTION B: OVERALL COST ISSUES

WHO SHOULD WORK THROUGH THIS SECTION?

- production maintenance managers
- production/maintenance supervisors
- troubleshooters
- stores personnel

WHAT YOU WILL NEED

- access to maintenance cost information
- access to fault record information
- notebook and pencil

HOW MUCH TIME?

- You will need to allow between 60 and 70 minutes to complete this section.

AIMS OF THIS SECTION

The aims of this section are:

- to introduce you to fault diagnosis costing through a consideration of overall maintenance costs
- to raise your awareness about overall approaches to running cost-effective troubleshooting
- to emphasise, through costing issues, the increasing importance of the maintenance function, and in particular fault diagnosis.

OBJECTIVES OF THIS SECTION

At the end of this section you should be able to:

- state the three main elements in overall costing of maintenance
- itemise the various elements in costing of maintenance
- use basic models for illustrating relationships between types of costs.

COSTS: GENERAL

Overall costs are normally described under the headings shown in FIGURE 2.

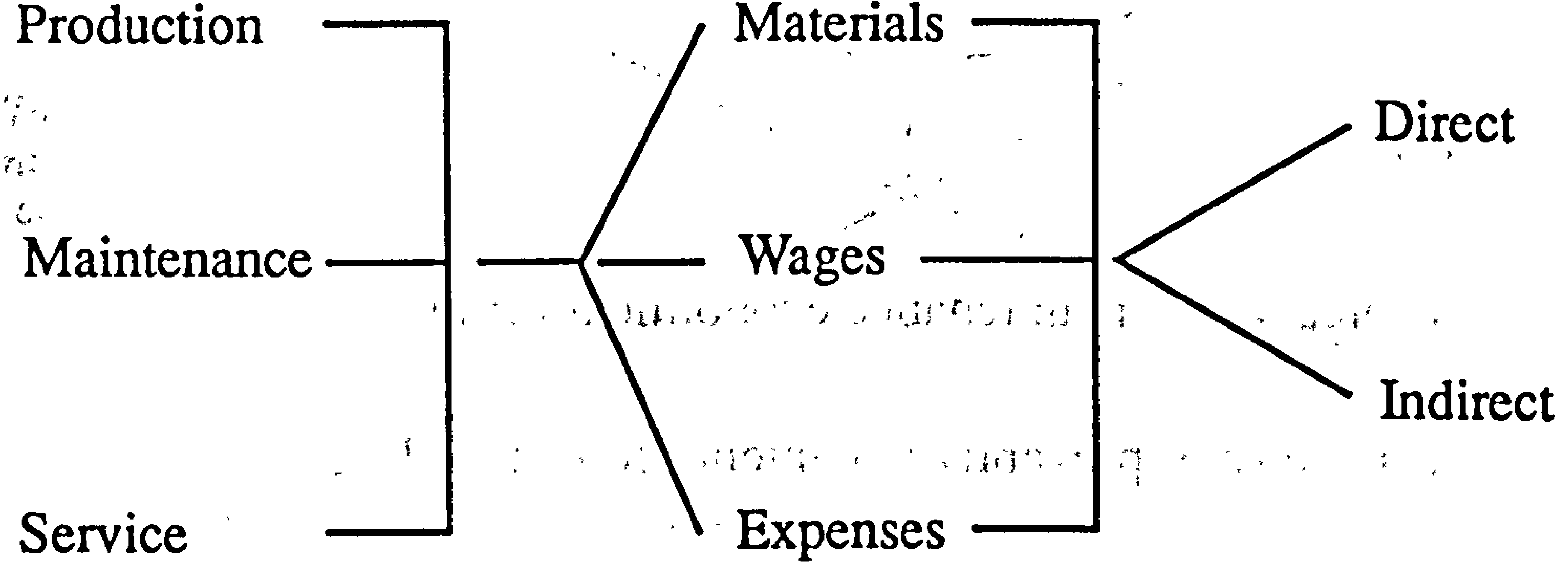

FIG. 2 : COSTS

It is common practice for any materials, wages and expenses which go into the actual product or services to be considered as **direct costs.** Maintenance activity, of which fault diagnosis is a part, tends to be seen as **indirect or overhead cost.** In the United States, overhead cost is named more descriptively as 'burden'.

Direct costs, sometimes known as 'prime costs', are variable. Indirect (or overhead) costs are fixed or semi-fixed. It can be argued that while some maintenance costs are fixed, the cost of fault diagnosis is variable and inseparable from production and quality costs.

OVERALL MAINTENANCE COST ISSUES

There are a number of clear cost issues which managers grapple with, and which should be clear to other personnel who are involved in the use of these costs, such as troubleshooters, technicians and operators.

Key cost issues

- Is breakdown maintenance economical for us?
- Is the cost of preventive maintenance justified?
- How far can operators go with maintenance work?
- What is the optimum number of troubleshooters?
- What is the effect of maintenance on quality cost?
- Are spare parts used most effectively?
- How far can more effective maintenance-production communication reduce costs?
- Does the present organisational structure help or hinder the effective use of maintenance costs?

These issues will be considered throughout the module.

Probably one of the most prominent overall cost issues is the balance to be achieved between a preventive maintenance policy (PMP), and a breakdown maintenance policy (BMP). There is a tendency for the calls in favour of preventive maintenance to take on a bandwagon effect. When all the issues are considered, the balance in favour of one or the other is seldom clear-cut.

The most simplistic view of this issue is shown in FIGURE 3.

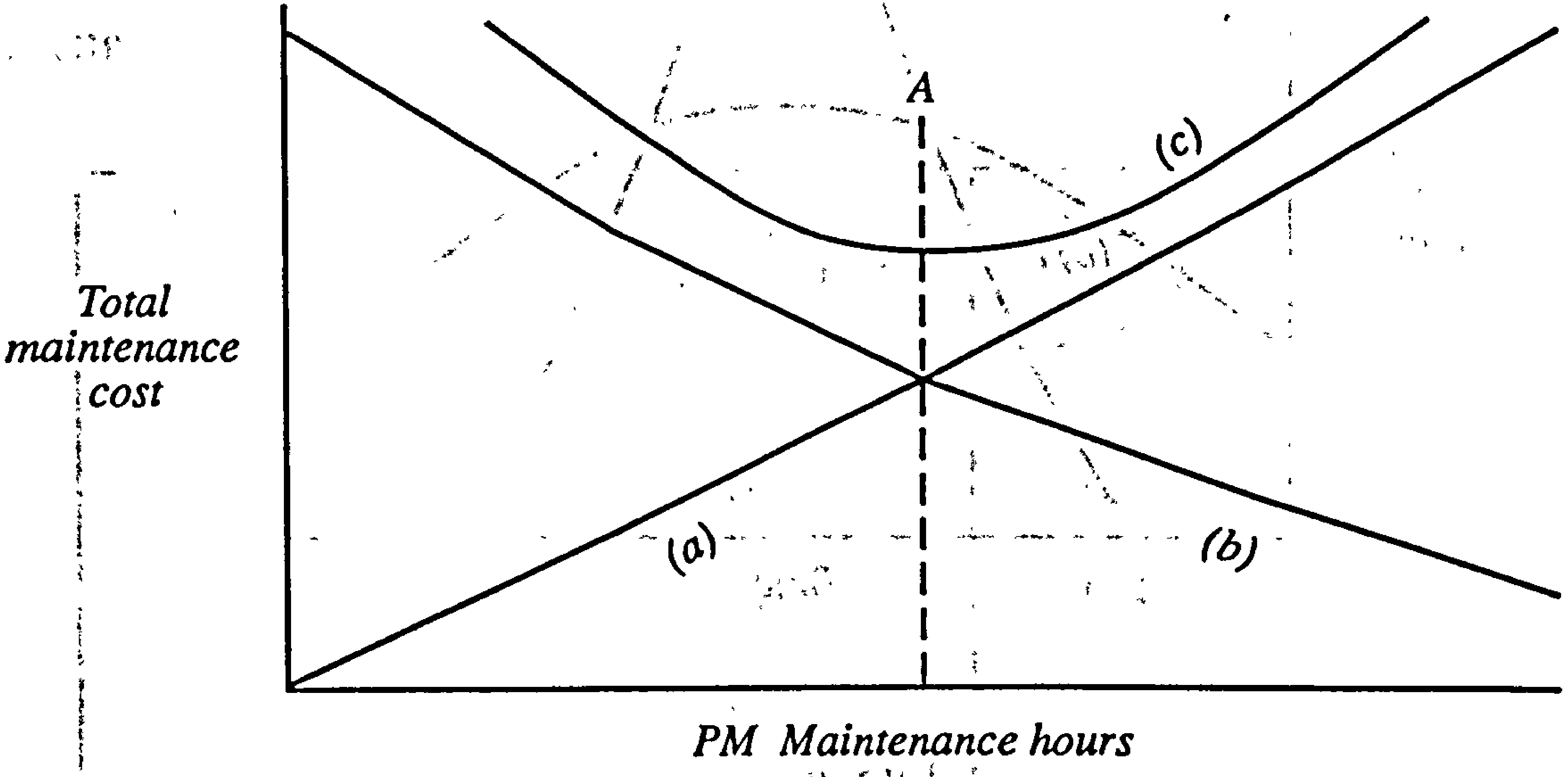

FIG. 3

Here the slope (a) increases to bring down the cost of breakdown maintenance (b), and, most importantly, to bring down overall cost (c).

There is usually an optimum level, at A, when lowest overall cost is achieved.

A balance is necessary because no matter how effective preventive maintenance is, there will always be breakdown maintenance.

When preventive maintenance is used there is a **PM cycle,** that is the number of weeks or months between preventive maintenance action.

There is also a **breakdown cycle.** Depending upon the industry this can be highly variable or of low variability. This is shown more clearly in FIGURE 4.

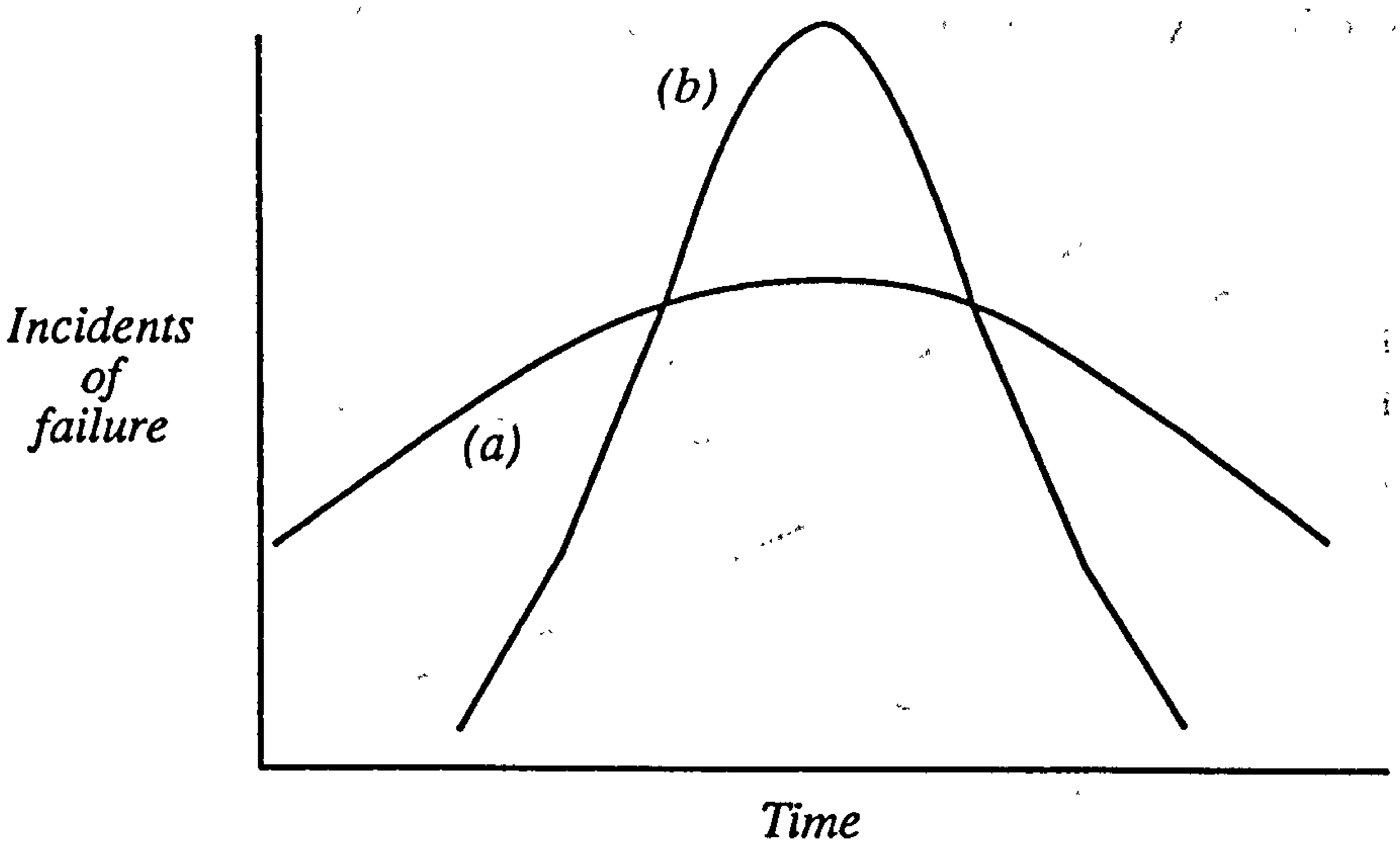

FIG. 4

Here, the slope (a) shows high variability, the faults occurring at random over time. The slope (b) shows a predictable peak of fault probability.

Generally, preventive maintenance is best when faults have low variability.

PROBABILITY

The probability of breakdown is a key measure to be taken into account when making a decision between preventive and breakdown maintenance.

For example, the probability of a booster engine failure was given by NASA as one in 500. An American Air Force study gave the figure of one in 35. When the space shuttle Challenger exploded in 1986, it was the twenty-fifth take off. (*Discover,* April 1986)

Using an example of one hundred coil winding or pharmaceutical tablet-making machines (TABLE 1), we can say that the probability of breakdowns among the machines is:

Month following Maintenance (*a*)	Probability of Breakdown (*b*)	Average Uptime ($a \times b$)
One	0.2	0.2
Two	0.2	0.4
Three	0.3	0.9
Four	0.3	1.2
		2.7 months/machine

TABLE 1

From this information we can state the average number of breakdowns per month: $\frac{100}{2.7}$ = 37 machines per month.

To compare the PMP with the BMP we need more information:

(a) BMP cost per breakdown (*Cb*) = £ ....

(b) PMP cost per breakdown (*Cp*) = £ ....

Exercise 1

You are asked to fill in the costs involved here for your own case.

It may be necessary to simply do an 'off-the-top-of-your-head' estimate. Please do this because the figures will be used in the next exercise. If you do no preventive maintenance, you will need to estimate a figure for Exercise 2.

To arrive at an overall cost for breakdowns, given that you operate a BMP, simply multiply the average number of breakdowns per month and the average cost per breakdown.

In our example this is 37 × the cost per month.

Note: You need not think only of machines or equipment. A process, such as a chemical plant, can be divided up into sub-systems which break down. It is only a question of where you draw the boundaries (see Module 3).

In the case of PMP, the calculation becomes a little more involved. Using the information in TABLE 1, we can say that the number of breakdowns expected in a month is:

$$Eb_1 = Np_1$$

Where Eb_1 = Expected breakdowns in month one
N = Number of machines
p_1 = Probability of breakdown in month one

$100 \times 0.2 = 20$ machines/month.
(See TABLE 1)

When the preventive cycle is two months, the expected breakdown is:

$N(p_1 + p_2)$ plus the number of machines fixed in the first month which broke down in the second month.

$$Eb_2 = N(p_1 + p_2) + Eb_1p_1$$

From Table 1 again

$$= 100(0.2 + 0.2) + (20 \times 0.2)$$

$$= 44 \text{ machines}$$

A three-month cycle produces these results.

$$Eb_2 = N(p_1 + p_2 + p_3) + Eb_1p_1 \; Eb_2p_2$$

$$= 100(0.2 + 0.2 + 0.3) + (20 \times 0.2) + (44 \times 0.2)$$

$$= 82.8 \text{ machines/month.}$$

A Cycle time months	B Expected breakdowns	C Average breakdowns/ month	D Monthly breakdown cost	E Monthly PM cost	F Monthly cycle cost
1	20	20	......	......	......
2	48.0	24	......	......	......
3	83.6	27.9	......	......	......
4	135.0	33.75	......	......	......
			Column C × your cost from Exercise 1.	Your cost from Exercise 1 × 100/ Column A.	Column D + Column E.

TABLE 2

Exercise 2

You are asked to enter your two costs from Exercise 1 into TABLE 2 to discover whether one PM cycle is more economical than others.

The actual results from such exercises are less important than the realisation that changing certain values can make significant changes to decisions about the balance between breakdown and preventive maintenance.

- For example, any change in practice which reduces the cost of each breakdown will affect this balance
- If the probability of breakdown changes, this too affects the balance
- If fault diagnosis becomes more effective, thereby reducing breakdown cost, this too changes the balance
- If quality costs[1] are saved despite the higher cost of preventive maintenance there may be additional, less measurable, factors to be considered (such as customer satisfaction) which will affect the balance.

---

[1] Discussed later in the module.

On the subject of balance between PMP and BMP, if there is no difference in cost between PMP and BMP, then breakdown maintenance must be favoured. Only the less measurable factors can swing the balance in favour of preventive maintenance.

It is worth noting at this point that methods of preventive maintenance are changing, which again affects the balance. Probably the most significant change is towards condition monitoring (CM). Here, the change is from periodic manual inspection, repair and/or replacement to automatic monitoring of equipment, systems or machines.

The cost of CM is largely in the capital cost of the monitoring equipment, such as devices to apply:

- thermography
- ultrasonic monitoring
- oil debris analysis etc.

In addition to this initial capital cost plus maintenance and depreciation cost of the equipment, there is the cost of a specialist analyst.

The capital investment in CM can be between 0.5% and 5% of the capital value of the plant, depending upon the degree of hazard to be avoided. However, this cost, like the PM cost referred to earlier, is clearly measurable and can be used in the calculations given in this module.

Exercise 3

What percentage of costs, within your overall maintenance costs, are allocated to the following?

(a) Troubleshooter/technical/craft labour cost

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(b) Overheads + expenses

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(c) Material/spares

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(d) Test equipment

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(e) Data recording

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(f) Training

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Various studies, although at times conflicting, point to a distribution something like:

(a) 45%
(b) 22%
(c) 23%
(d) 5.2%
(e) 4.6%
(f) 0.2%
———
100%

How does the distribution of your costs compare?

OVERALL COSTS AND PAY-BACK

When thinking about the overall cost of maintenance, it is worth considering pay-back on capital. This is highly significant and is one factor that provides, or should provide, a much higher profile for maintenance activities in your organisation.

Pay-back is the time required for a new machine piece of equipment or system to pay for itself. For example, in the case of a robot costing, say, £120 000, pay-back could be anything from 18 months to four years.

The key elements in pay-back calculations are shown in FIGURE 5.

Payback

$$P = \frac{I}{L - E}$$

I = Capital Investment

L = Labour Saving Costs

E = Maintenance Cost

One Shift Working

Two Shift Working

Three Shift Working

FIG. 5

One means of reducing pay-back time is to operate for three shifts around the clock, seven days per week. This increases the saving in labour costs by replacing more people over three shifts than could be done on one or two shifts. Inevitably, in this case, there are higher maintenance costs to be offset against other savings. Maintenance costs, and in particular fault diagnosis costs, represent the one variable factor that can influence pay-back time. The lower the maintenance cost, the lower the pay-back time.

OVERALL COSTS AND SPLIT BATCHES

The cost of having split batches occurs most often in schedule product-focused industries, such as in the use of Flexible Manufacturing Systems (FMS), or in the use of electronic assembly lines.

During periods of fault diagnosis and repair, there can be the cost of re-scheduling work, such as when supervisors take alternative action in order to utilise machine and operator time.

A crucial part of the fault diagnosis process is the maintaining of open and effective lines of communication between troubleshooters and production personnel (Module 1). In this way, the cost of taking alternative action can be greatly reduced by the supervisor having up-dating information from troubleshooters. For example: how much longer ....? what can be used ....? what alternatives are possible .....?, etc.

LATE DELIVERY COST

Here it is necessary for personnel in account departments to liaise with troubleshooters, and make known to them how specific penalty costs are incurred. With this information, together with fault diagnosis record information, it should be possible to state what proportion of late delivery costs is due to malfunction, and which faults and causes can account most for downtime, which in turn leads to late delivery.

OPERATOR IDLE TIME COST

In situations where effective fault finding and diagnosis is practised, there is little of this cost to be found. Operators and troubleshooters work together to reduce downtime.

At present, this tends to be a practice adopted more by Japanese companies, using Total Productive Maintenance (TPM), where a declared aim is to have zero downtime due to machine or equipment malfunction. Where frequent periods of downtime lead to 'Operator Idle', this becomes a significant cost incurred by fault diagnosis and repair activity.

The involvement of operators in fault diagnosis work can offset this cost substantially by reducing downtime.

SPECIALIST TROUBLESHOOTER COSTS

There can be a conscious decision by management to contract out specialist troubleshooting work. In such cases it is normal practice for the contractor, or consultant, to specify that breakdown will be limited to a stated minimum as part of the contract.

This approach by management, when used, reflects a rather narrow view of fault diagnosis, i.e. the view that tasks in this area are concerned only with the malfunctioning of machines or equipment.

Using outside agents limits the amount of organisational learning that needs to take place through the use of fault diagnosis feedback on a day-to-day basis.

However, even when contractors or consultants are not used in this way, there can still be occasions when their services are called upon. The most common example is the use of manufacturers' troubleshooters beyond the end of the commissioning date. Again it is normally quite difficult for in-house troubleshooters and operators to learn from this outside expertise. The transfer of learning is not generally well achieved in these circumstances.

The main lesson here is that before any contract is agreed with manufacturer or supplier, there needs to be assurance that the means exist for full transfer of learning between the source experts and the user. This is possibly the only way to reduce the need for this costly expert assistance.

SUMMARY OF OVERALL COST ISSUES

One of the main cost-saving decisions to be made is in making the choice between preventive and breakdown maintenance. If preventive maintenance is adopted, a further choice has to be made between manual inspection, repair and/or replacement at fixed periods (called 'preventive maintenance cycle'), and the use of condition monitoring. For a more detailed description of these options, you are referred to Monks (1987), Buffa (1987) and Mahadevan (1982). (See also useful references on page 55.)

Breakdown maintenance can be a viable policy in the right circumstances, and is made even more viable as fault diagnosis becomes more effective.

The costs to the organisation of machine, equipment or system downtime are higher than is generally recorded, for example by ignoring some of the major cost elements described here. You are asked to consider your situation and list what you recognise as costs which contribute to what can be called a true cost of downtime.

SECTION C: FAULT DIAGNOSIS COSTS

WHO SHOULD WORK THROUGH THIS SECTION?

- production/maintenance managers
- production/maintenance supervisors
- troubleshooters
- stores personnel
- operators.

WHAT YOU WILL NEED

- access to maintenance costs and fault records
- access to at least one colleague
- notebook and pencil.

HOW MUCH TIME?

- You will need to allow between 60 and 70 minutes to complete this section.

AIMS OF THIS SECTION

The aims of this section are:

- to focus your attention on specific fault diagnosis cost elements
- to raise your level of awareness about methods of itemising fault diagnosis costs.

OBJECTIVES OF THIS SECTION

At the end of this section you should be able to:

- relate different types of causes to cost
- name and describe specific cost elements in the process of fault diagnosis
- calculate labour costs from fault record information
- draw distribution curves for fault diagnosis time in your own situation
- calculate most effective spares holding
- relate reliability to cost.

This section, like the last, relies heavily upon fault diagnosis information being available. The importance of an effective record system in industry today cannot be stressed too strongly (see Module 4).

To begin looking at the costs of fault diagnosis more specifically, we will consider *causes* of faults.

We begin by examining your own work situations. To help you with this, complete Exercise 4 on the next page.

Exercise 4

(a) List six main causes of breakdown in your situation.

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(b) Which cause results in the highest breakdown costs?

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How critical causes are, in terms of cost, can be demonstrated by using frequency of causes over a set period, and by stating the percentage of breakdown cost for each cause.

Figures, like those shown in TABLE 3, can be provided by taking a 'snapshot' analysis of causes over a fixed period, e.g. one month.

Cause	Frequency	Cost (£)	%
Operator-induced	4	1200	8
Below-standard spares	8	3600	24
Failed circuit board	6	2200	14
Out of adjustment	10	1900	12
Age-related wear	2	4500	30
Machine design	3	1800	12
		15200	100

TABLE 3

Certain causes may inflict higher cost despite low frequency. In this example, one costly cause (age-related wear) may have longer diagnosis time, longer repair time or both.

Analysis of this kind can help you to recognise cost critical causes. This will repay action taken to achieve improvements in diagnosis, methods of rectification and provision of back-up support.

FAULT DIAGNOSIS COST ELEMENTS

In Exercise 4 you were asked to think of breakdown costs, other than those of production or service loss.

Now we focus in to consider specific cost elements related to fault finding and diagnosis.

Exercise 5

Think about the people who are involved, either directly or indirectly, in the task of fault finding and diagnosis. In how many ways are costs incurred?

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There are a number of what can be called 'cost elements' in any fault finding diagnosis task. A list of possibilities is printed below.

- troubleshooter labour costs to fault-find and diagnose
- troubleshooter response time labour costs
- troubleshooter safety check-out time cost
- troubleshooter completed work check-out time cost
- troubleshooter re-diagnose labour cost
- operator/user idle time cost
- spares procurement time cost
- production supervisor re-allocating work cost
- quality cost to production
- consultancy/expert guidance cost
- consultancy/expert contact/travel cost
- late delivery cost
- lost production cost
- fault/failure recording costs
- further communication: 'who needs to know' cost.

You may have these and others on your list from Exercise 5.

These costs can be incurred during the time it takes to go through a typical fault finding diagnosis sequence, such as:

(1) symptom reported and recorded
(2) response to symptom report
(3) safety check-out
(4) operator assists troubleshooter, is reallocated work or is idle
(5) fault finding and diagnosis, action
(6) procure spares
(7) repair*
(8) check-out and run
(9) re-diagnose (if necessary)
(10) record diagnostic action
(11) communicate to those who need to know.

- Repair stage is the only one which is not part of the fault finding and diagnosis process. This is the 'mechanic' part of repair or replace.

Linking the list of cost items on page 32 with the fault finding diagnosis sequence should enable you to see that scope can exist for minimising costs. This can only be done, however, if certain information is available.

The minimum information required is:

(a) knowledge of maintenance policy (see page 19)
(b) record of downtime and its analysis (see Module 4)
(c) breakdown of costs for the elements involved in your own case (see Exercise 5).

TROUBLESHOOTER COSTS

One of the most critical elements is labour cost. The proportion of troubleshooters/technicians to production personnel is increasing. Therefore the time utilised by fault finding diagnostic specialists is becoming more crucial. The relationship between downtime cost and labour cost is shown in FIGURE 6.

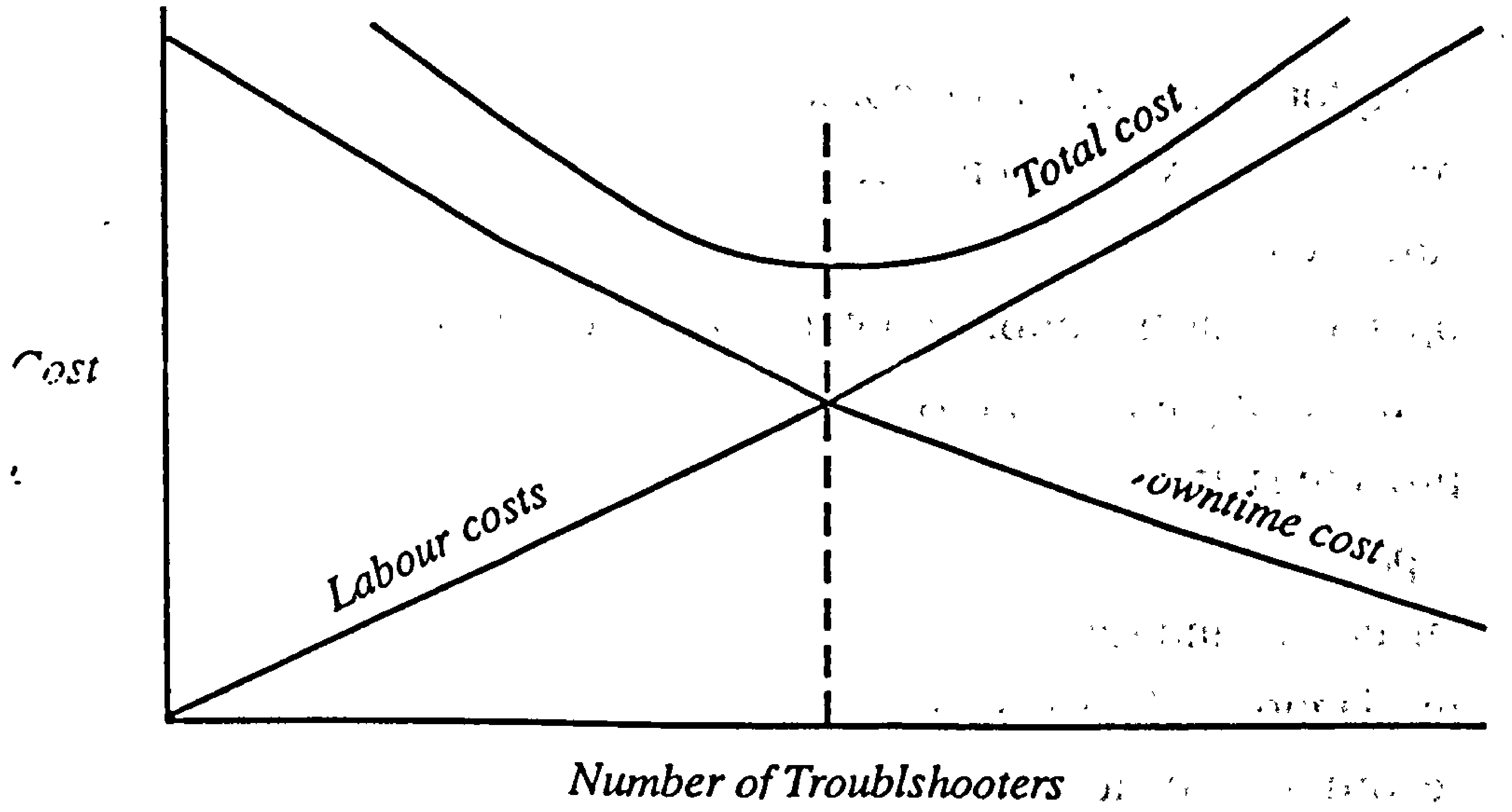

FIG. 6

A useful sum for any troubleshooter to do is the working out of the actual time available for fault finding diagnosis, and for the many other related and not-so-related activities. For example, given five troubleshooters:

5 × 40 hours × 52 weeks	=	10400	hours
less 7% absenteeism (UK average)		728	hours
less leave 5 × 40 hours × 4 weeks		800	hours
less statutory days 5 × 8 × 7		280	
Balance		8592	hours

(i.e. 1718 hours per troubleshooter)

Exercise 6

Using your own figure for person/hours per week, can you say how many of these hours are spent in fault finding and diagnosis?

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A more graphic display of time allocation is shown in FIGURE 7.

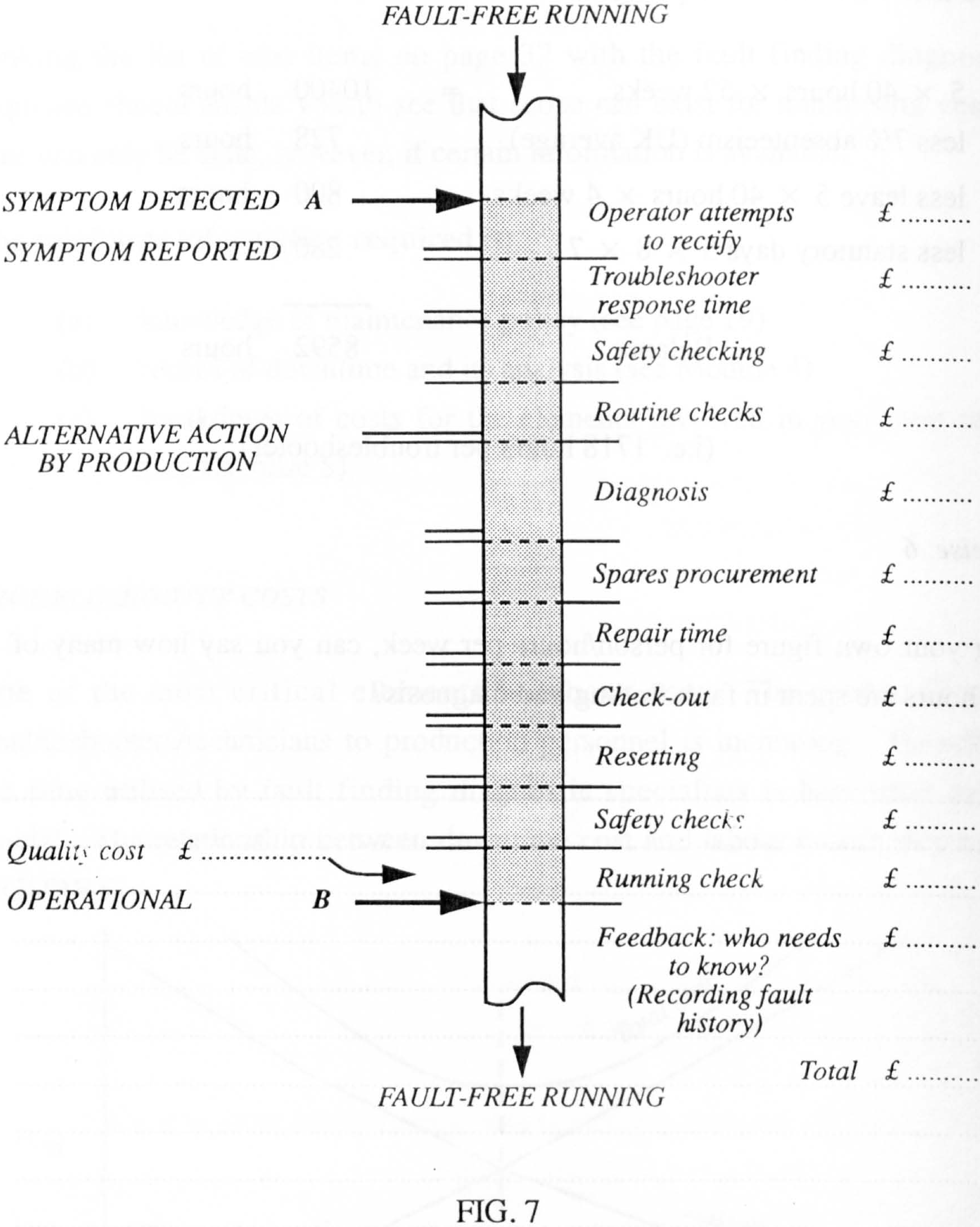

FIG. 7

Your first reaction when looking at the lapsed time between point A and point B may well be for you to say that it depends upon the kind of fault.

In most situations the time, and therefore a significant part of the cost, follows a normal distribution across the number of faults that occur.

A comparison between fault diagnosis times in three companies is shown in FIGURE 8.

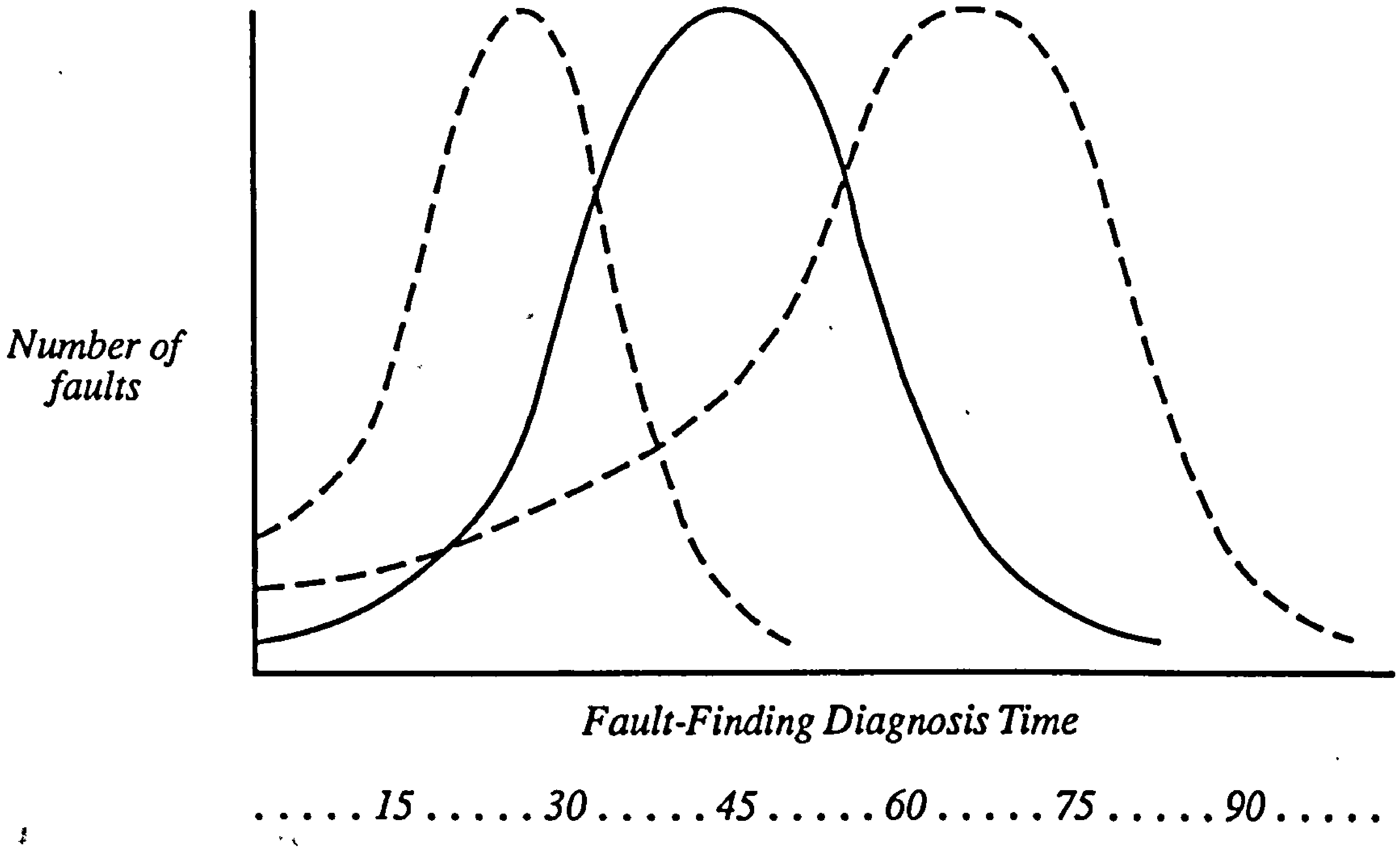

FIG. 8

Exercise 7

Now draw a distribution curve for fault finding and diagnosis times in your own situation. You may be able to do this with some accuracy, or you may need to estimate what the curve would look like using your own rule of thumb, or combined rules of thumb from your colleagues.

It is quite possible that you arrived at a curve something like one of the two shown in FIG. 9.

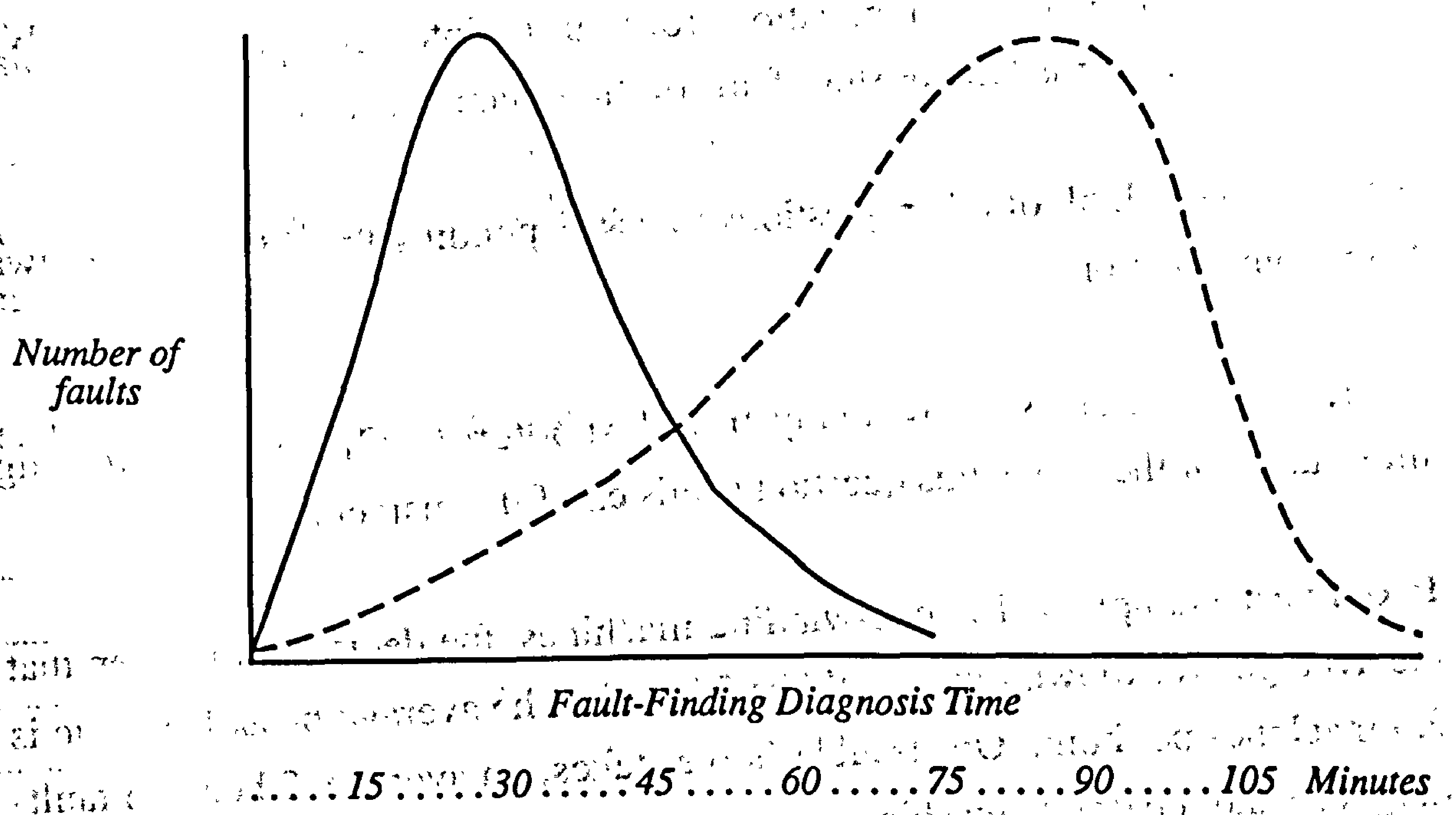

FIG. 9

These two curves are skewed about the mean. It is not uncommon for some companies to have numerous short, say less than 10 minutes, fault finding and diagnosis times, and only a few lengthy sessions of, say, at least 5 hours.

Given that you have arrived at a 'picture' of your fault finding diagnosis time like this, you will find that you can ask a number of interesting questions about how this picture emerges. Answers to these questions can, in turn, lead to means of reducing this costly time. Here are some typical questions which you could ask.

(a) How many of the short duration times are recurring identical faults, indicating ineffective diagnosis?

(b) How far are the short time spans due to rapid response time bought at the cost of readily available labour on site?

(c) Of the longer times, especially if your curve shows these to be in the majority, what proportion is response time?

(d) Where is most time spent during the longer sessions?

(e) What are the implications for your maintenance policy of any bias towards long or short fault finding diagnosis times?

You may well think of other questions to ask depending upon the curve drawn from your situation.

A critical question is: 'How many troubleshooters?' Given the increasing importance of their role, this question needs careful consideration.

In our past example of 100 coil-winding machines, the decision was taken that the average breakdown time should be 2 hours. The average breakdown rate is 2.5 machines per hour. One troubleshooter takes, on average, 2 hours to fault-diagnose and repair one machine.

With this information we can calculate the number of troubleshooters required.

First we need to know the average repair rate (μ) per hour.

$$\mu = \lambda + t\,r$$

where λ = breakdown rate.

$t\,r$ = average time allowed to repair.

$$\mu = 2.5 + 0.5 = 3 \text{ machines per hour.}$$

Given that the average repair rate is 3 machines per hour, and that one troubleshooter can repair 0.5 machine per hour, we have:

$$3 \div 0.5 = 6 \text{ troubleshooters.}$$

Exercise 8

Now take one area in your own situation and apply your own figure to this example calculation.

A key factor here is the time taken to fault-diagnose and repair, the highest proportion of which, apart from heavy mechanical plants, is the fault diagnosis time.

Use the space below for your answer.

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An alternative method is to use fault record information on mean time to repair (MTTR) and mean time before failure (MTBF).

Other information needed here is the number of operating hours per year (h) and the number of machines or sub-machines in use (n).

The number of maintenance person hours (MPH) can then be given as:

$$\text{MPH} \quad = \quad \frac{n\ h}{\text{MTBF}} \times \text{MTTR}$$

Divide this figure by person hours per year* to arrive at the number of troubleshooters.

*See page 34.

For example:

> Ten machines are operated over two eight-hour shifts for fifty weeks per year, and a five-day week is worked.

n = 10
h = 4000 hrs
MTBF = 5 hrs
MTTR = 0.6 hr

MPH = 4800

One troubleshooter person hours per year = 1718 (page 34).

Number of troubleshooters = 3

FAULT DIAGNOSIS

Use of Spares

The decisions taken by buyers in a purchasing department have a critical effect on fault diagnosis performance. Quite often, when organisations analyse their fault records, a cause of recurring faults can be the use of below-standard spares, whether they be electronic components, motors, pumps, pump seals or nuts and bolts.

There are various means whereby buyers aim to get 'the best deal', such as trade discounts, quantity discounts, seasonal discounts, and cash discounts.

The main aim of the spares purchase should be to buy **quality**, and the best measure here is not necessarily price but reliability.

There needs to be open communication between troubleshooters and those who bring spare parts into the organisation.

One way of emphasising the importance of spare part reliability is to think of a machine or a system that contains 100 spare parts. Compared with current technology, this is not a particularly complex machine or system. Given that all parts had a reliability of 0.999 (nothing is 100%), the reliability of this machine or system would be 0.906.

Some figures for comparison are show in TABLE 4.

One part	0.999	=	0.999	reliable
Two parts	0.999	=	0.998	reliable
One hundred parts	0.999	=	0.906	reliable
Four hundred parts	0.999	=	0.673	reliable
Seven hundred parts	0.999	=	0.500	reliable

TABLE 4

The ideal machine, something like a bicycle, should contain as few parts as possible, and each part should be as reliable as possible.

Another critical factor in spares use and fault diagnosis is the relationship between the fault diagnosis technique and the cost of spares holding.

In Module 2, on Strategies, there is a description of replacement technique. This is the practice of replacing parts or units as a means of overcoming a breakdown quickly. This practice can be effective in terms of time, but overall is excessively costly. Often parts which have not failed are replaced, and are not used again. There is also the question of capital cost tied up in large holdings of spares. In some cases this can amount to thousands of pounds on one unit, such as a spare robot arm. There has to be careful inventory management, and this can only be done well when the fault diagnosis technique includes fault recording and feedback to stores personnel (see Module 4).

The optimum holding of stores is normally given by:

$$E(F) = \sum Pn\,(n-s)\,c$$

Where $E(F)$ = expected failure

Pn = probability of n parts out of order

s = number of spares available and used as replacements

c = cost of non-availability of machine or system.

Σ = sigma (add up, sum of)

For example, in a situation where the following information is available (see TABLE 5), we can compare different amounts of spares holding. These are examples of spare part stock holding for a given situation.

% of time failed	Number of times that part failed
40%	0
30%	1
20%	2
10%	3

TABLE 5

So, reading down TABLE 5, for 40% of the time no parts fail, one part fails in 70% of the time and three parts fail in 90% of the time. In total, size parts fail over the period recorded.

The following calculations are for stock holding of zero, one, two and three parts respectively. As you will see, no holding is most costly, three holdings is next most costly, and there is a balance between one and two holding of spares.

With no spare held in stock

0.4 (0) + 0.3 (1) (£100) + 0.2 (2) (£100) + 0.1 (3) (£100)

= 100

+ cost of spare 00

£100

With 1 spare held

4 (0) + 0.3 (1–1) (£100) + 0.2 (2–1) (£100) + 0.1 (3–1) (£100)

= £40

+ cost of spare £30

£70

With 2 spares held

4 (0) + 0.3 (1–1) (£100) + 0.2 (2–2) (£100) + 0.1 (3–2) (£100)

= £10

+ cost of spare £60

£70

With 3 spares held

4 (0) + 0.3 (1–1) (£100) + 0.2 (2–2) (£100) + 0.1 (3–3) (£100)

= 0

+ cost of spare £90

£90

Exercise 9

Consider how relevant such calculation of spares-holding cost is to your circumstances.

Think of a part replaced on a frequent basis and apply this calculation.

One other aspect of spares control and handling is critical in terms of fault diagnosis and costs. This is the quality checking of spares. Faulty or below-standard spares can be detected at stages along the maintenance process.

The respective costs at each of these stages can typically be:

At inward goods inspection	25p
In the unit or on circuit board	£2.50
In machine during check-out	£25.00
In production at breakdown	£250.00

The early checking of spares is vital.

Other means of saving on spares control can be achieved when troubleshooters and stores personnel work together. A good example of this is when combinations of spares can be made up ready for use and held in the store as made-up units. This can reduce downtime by removing the need to combine spares at the actual time of failure.

SUMMARY

The use and control of spare parts must be seen as part of fault diagnosis activity. The methods of fault diagnosis used have a direct effect on spare part holding.

The troubleshooter has a key part to play in the optimum economical control of spares. This can be achieved when effective fault records are maintained, to allow accurate analysis of spare part utilisation.

RELIABILITY COSTS

Throughout this module there has been reference to breakdown costs and downtime costs.

From a maintenance point of view, the key measure of effectiveness is breakdown cost, rather than downtime cost.

The main objective of maintenance is to ensure that machines, equipment and systems are available.

Availability is:

$$\frac{\text{Mean Time Before Failure (MTBF)}}{\text{Mean Time Before Failure (MTBF)} + \text{Mean Time To Repair (MTTR)*}}$$

$$\frac{\text{MTBF}}{\text{MTBF} + \text{MTTR}}$$

*Includes fault diagnosis time

The Mean Time Before Failure is largely determined by the effectiveness of diagnosis, and by the quality of the repair plus reliability of any parts used.

Note

Mean Time Before Failure is sometimes referred to as Meant Time to Failure (MTTF). However, this second term applies more appropriately to absolute failure, such as an unmanned space vehicle failing totally in time.

The overall objective is that availability is as high as possible.

Downtime, on the other hand, can have many components:

- non-availability of labour
- material shortage
- power failure
- design changes
- product change
- etc.

It is important that improvements achieved in fault diagnosis and repair can be measured through reduction in **breakdown costs,** and increased **availability.**

Improvement initiatives can be introduced, such as:

- training
- more effective record system
- more effective communications
- more effective stores control.

These, too, have a cost, but analysis of the 'no initiative' costs should demonstrate the pay-off to be achieved.

MODEL ANSWERS TO SELF-DIAGNOSTIC QUESTIONS

1. The answer to this question, though a very important one, is seldom easy to provide or particularly accurate when stated.

   The cost of downtime is the one most often quoted. But it is the cost of breakdown time which is most relevant to fault diagnosis, and this may not be the same as downtime.

   Downtime has many possible causes apart from machine or equipment malfunction.

   If you can provide a ready answer to this question, it is possibly one measure of production lost, or may include other elements too, hence the next question.

2. Many possible elements are listed in this module. Off the top of your head, or from formal records, you may have mentioned:

   - spares requisition costs
   - operator idle time cost
   - lost production cost
   - late delivery of order cost
   - expert help cost.

3. This again is often a standard amount of time. For example, two years for a robot, ten years for a large printing press, eighteen months for a small plastic extrusion machine.

4. This varies from industry to industry, and between types of machine or pieces of equipment.

   By reducing the amount of breakdown time, or downtime due to machine malfunction, it is possible to reduce the time of payback by months. It is through this measure that improved performance in fault finding and diagnosis can be demonstrated in financial terms.

5. A straightforward question here. The important word is 'policy'; it is worth considering to what extent your method of working can be called a positive policy of the company.

6. This may be a difficult question to answer. However, if your method does amount to a company policy there should be a measure, in cost terms, to show that this policy is better value than that offered by alternative methods.

7. This question is asking you to take a systems view of fault diagnosis. Possible cost areas which can be affected are:

   - quality cost
   - marketing cost
   - stores handling cost
   - operator cost
   - alternative back up cost, etc.

8. The most likely answer is that maintenance is seen as a service activity. Therefore, it is an indirect cost to production.

A total production approach merges the engineering services with manufacturing or service activity, as the case may be. In these circumstances it seems appropriate to recognise the direct input of engineering as a direct cost. Also, in such circumstances, certain plant maintenance may still be regarded an an overhead indirect cost and kept separate.

There is an argument for saying that cost treatment does influence how activities are viewed in an organisation.

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APPENDIX D

*** PLEASE NOTE: IN THIS APPENDIX TWO LOGIC EXERCISES ONLY ARE PRESENTED FOR THE PURPOSE OF ILLUSTRATING THE PRINCIPLE IDEA.**

FAULT FINDING AND DIAGNOSIS

LOGIC REASONING EXERCISES

INTRODUCTION

There are four exercises, increasing in level of difficulty from exercise one to exercise four.

The aim of these exercises is to provide a self assessment of how well you can handle reasoning tasks of this kind, and to indicate how trainable you would be in skills which require this type of reasoning.

The objective is to locate faults on digital circuits after you have been given the information that is needed to do each exercise.

WHAT YOU WILL NEED

Four exercises, one sheet for each exercise showing the circuit diagram and test points (silver discs).

Four instruction sheets, one for each exercise.

A pen and coin or other hard object to remove silver coating from the test points.

HOW RESULTS ARE MEASURED

For exercises one, two and three the objective is to locate the faults:

a) With as few tests as possible.

b) Without using redundant tests, that is tests which give you no more information than you already have.

c) As quickly as possible.

CONTINUED OVER....

Therefore, the most successful outcome for these three exercises is one where minimum tests are used in the shortest possible time, and where the correct solution is found.

The objective of exercise four is to achieve correct working of all outputs from the circuit by changing the state of inputs (switches).

Therefore, the successful outcome of this exercise is to have the switches changed correctly, in as short a time as possible.

Malcolm Craig

LOGIC REASONING EXERCISES

INSTRUCTION SHEET FOR EXERCISE ONE

HAVE THE SHEET MARKET EXERCISE 1 IN FRONT OF YOU.

WHAT YOU NEED TO KNOW

INPUTS: There are five inputs marked S1 to S5. The lines coming from these inputs are marked A to E and each line is at either 1 (one) or 0 (zero). For example, if you want to know whether line B is at 1 (one) or 0 (zero) you would rub test point B, and this will show 1 (one) or 0 (zero). This is how you test the lines on the circuit.

Note:- All other lines through to line M are also at 1 (one) or 0 (zero).

LOGIC GATES: There are two logic gates in this circuit. OR gate marked G1, G2, G3. The second type of gate here is the AND gate, marked G4, G5.

HOW THE GATES WORK

The OR gate will give a 1 (one) on the right hand side (output) if at least one line on the left hand side (input) is at 1 (one). If both lines are at 1 (one) the output will still be at 1 (one). If both inputs are at 0 (zero) then the output will be 0 (zero).

The AND gate will give a 1 (one) on the right hand side (output) only when both inputs are a 1 (one). If one or both inputs are at 0 (zero) then the output will be at 0 (zero).

THE OR GATE

INPUT		OUTPUT
1	0	1
1	1	1
0	0	0

THE AND GATE

INPUT		OUTPUT
1	0	0
1	1	1
0	0	0

THESE CONDITIONS FOR THE TWO DIFFERENT GATES ARE SUMMARISED IN TABLE ONE.

TABLE 1

CONTINUED OVER.....

THE PROBLEM

There are three outputs, marked X Y Z. Outputs Y and Z are off, line L and line M are at 0 (zero) and they should be at 1 (one).

There are faults on the circuit at two of the eight terminals marked T1 to T8. By testing lines on the circuit (rubbing test points) you must decide which faulted terminal is the cause of outputs Y and Z being off.

Note:- Although there are two faults, only one is the cause of the problem.

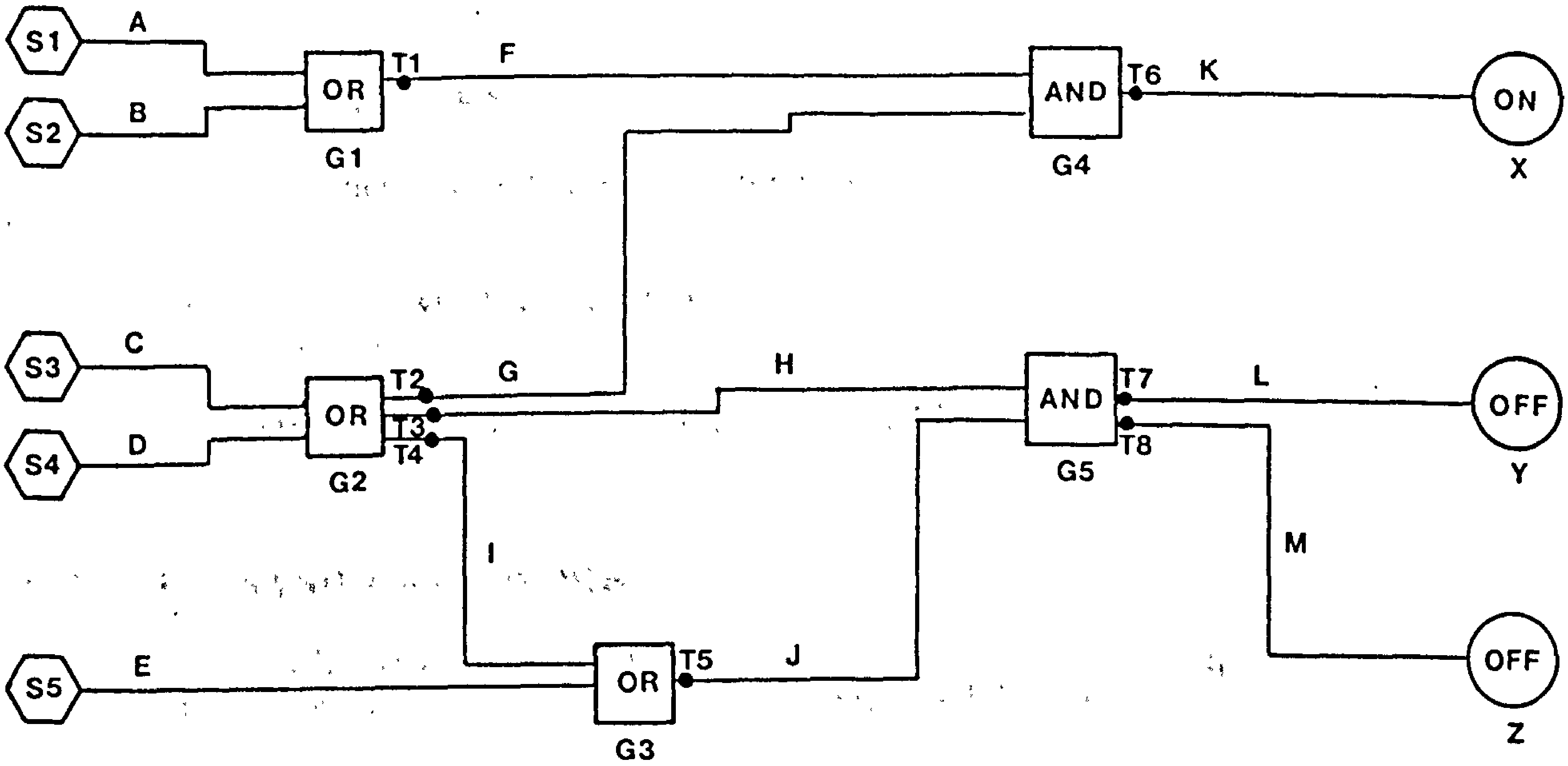
EXAMPLE

This description of reasoning is for example purposes only. The fact that line L is at 0 (zero) making output Y off, does not necessarily mean that there is a fault at T7. To confirm this you need to know the state of line H and line J. If you tested these by rubbing test points H and J, and found that they were both at 1 (one) then you could say that the fault and the cause was at T7. Remember, for the purpose of this exercise only, the faults are said to be at the terminals. Otherwise gate G5 could be equally at fault. This is an example of what you have to do.

As you test a line, write the letter marking the line in the test space provided: TEST1.... TEST2..... etc until you are in a position to decide which terminal is at fault and causing the problem. When you have decided, write the result in the decision box on the sheet.

The objective is to find this fault in as few tests as possible, and as quickly as possible, without testing for redundant information.

*** NOTE: THE SILVER COVERING IS REMOVED BELOW TO SHOW THE STATE OF THE RESPECTIVE LINES A TO M**



EXERCISE 1

A	B	C	D	E
1	0	1	0	1
F	**G**	**H**	**I**	**J**
1	1	1	0	0
K	**L**	**M**		
0	0	0		

DECISIONS:

THERE ARE TWO FAULTY TERMINALS.

ONLY ONE IS THE CAUSE OF Y BEING OFF.

THE FAULTY TERMINAL THAT IS THE CAUSE IS T.......(Write in terminal number)

Immediately you have done each test, write the letter of the test point in the space below.
For Example: If you made the first test at K, write K in the space for TEST 1. Then write the letter of the next test in the space for TEST 2... and so on,until you can make a decision about the cause of the fault.

TEST 1..... TEST 2...... TEST 3..... TEST 4..... TEST 5..... TEST 6..... TEST 7.....

LOGIC REASONING EXERCISES

INSTRUCTION SHEET FOR EXERCISE THREE

HAVE THE SHEET MARKED EXERCISE THREE IN FRONT OF YOU

WHAT YOU NEED TO KNOW:

INPUTS. This time there are eight inputs, marked S1 to S8, and three outputs marked X, Y and Z.

There are two logic gates which are new to you from the last exercise, these are the NAND gate and the NOT gate.

(If you need to refresh your memory about OR gates and AND gates look back at Table 1.)

HOW THE NAND GATE WORKS.

The NAND gate will give a 1 (one) at the output side (right) if one or both inputs are at 0 (zero) If both inputs are at 1 (one) then the output will be at 0 (zero)

HOW THE NOT GATE WORKS.

The NOT gate will give a 1(one) at the output side, if the input is at 0 (zero). If the input is at 1 (one) the output will be at 0 (zero).

The only time these conditions do not apply is if the gates are not working properly (at fault).

WHAT YOU HAVE TO DO.

This time you must decide which two logic gates are at fault (there are no terminals to consider this time)

THE NAND GATE

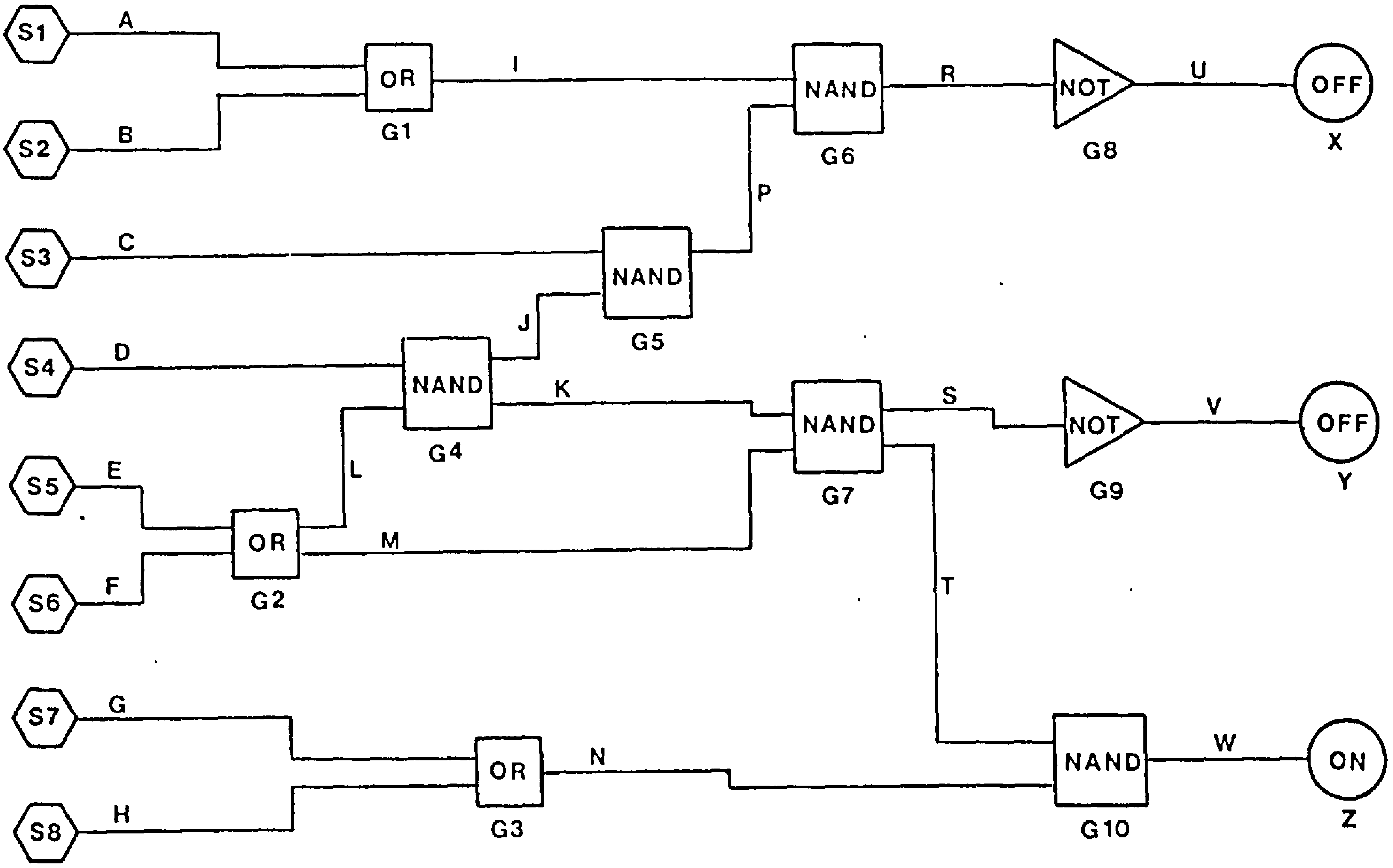
INPUT.		OUTPUT
1	0	1
1	1	0
1	0	1

THE NOT GATE

INPUT	OUTPUT
1	O
0	1

TABLE 2

* NOTE: THE SILVER COVERING IS REMOVED BELOW TO SHOW THE
STATE OF THE RESPECTIVE LINES A TO W



EXERCISE 3

A	B	C	D	E	F	G	H
1	1	0	0	1	0	0	0

I	J	K	L	M	N	P	R
1	0	0	1	1	0	1	0

S	T	U	V	W
1	1	0	0	1

DECISIONS:

THERE ARE TWO FAULTS.

GATE G..... IS FAULTY

GATE G..... IS FAULTY

(Write in the number of the gate in each case)

Immediately you have done each test write in the letter of each test point in a space below. For Example: If you make a test at K, write K in the space for TEST 1. Then write the letter of the next test point in the space for TEST 2, and so on, until you can make a decision about the fault

TEST 1..... TEST 2..... TEST 3..... TEST 4..... TEST 5..... TEST 6..... TEST 7.....

TEST 8..... TEST 9..... TEST10..... TEST11..... TEST12..... TEST13..... TEST14.....