INTRODUCTION

In recent years great pressure has been placed on manufacturing organisations to be more competitive in the worldwide market. The modernisation and automation that have taken place in almost all industries, combined with new and more demanding production philosophies (e.g., ‘Just-in-time’), have forced managers and engineers to optimise all the systems within their organisations[1]. As one of these systems, maintenance is under pressure to reduce downtime. Downtime affects a company’s productivity by reducing output and increasing operating costs, as well as interfering with customer service[2]. As a result, many new maintenance techniques and philosophies aimed at downtime reduction have been developed, many of them emphasising failure prevention but incapable of preventing all failures[3], and so...
unexpected failures do occur, which leads to corrective maintenance and in some cases to high levels of downtime. Thus downtime can be reduced by preventing failures and by repairing them as quickly as possible when they do occur, ie both failure frequency and severity need to be reduced.

This paper focuses on the reduction of failure severity. A study of the relevant literature has led us to propose an approach for reducing troubleshooting time which is based on the analysis of maintenance support documentation, particularly of failure records. It is suggested that future repair actions will be performed more effectively and efficiently if maintenance technicians are provided with easy access to technical documentation and to information on how previous failures were diagnosed and repaired. The approach also reviews failure information management, particularly addressing how current maintenance information systems, failure records and technical documents are coping with assisting troubleshooting.

Part II of this paper will present the results of an exploratory case study that mainly aims to assess whether support documentation systems can be derived, confirms literature results regarding failure information management, characterises the current situation of failure records utilisation, and reviews problems and suggestions regarding maintenance documentation that have been identified by practitioners.

BACKGROUND

Increased integration between manufacturing systems means that equipment failures tend to lead to more immediate and costly consequences. Machine breakdowns that occur during operation disrupt production and lead to additional costs due to downtime, production loss, and a decrease in quality. Minimising downtime is one of the most significant contributions that the maintenance function can offer to an organisation. Downtime reduction can be achieved by reducing both the frequency of failures (their number) and their severity (their duration).

Traditionally, maintenance strategies that focus on failure prevention, such as preventive and predictive maintenance, have been applied to reduce failure frequency. These strategies have made a significant contribution to downtime reduction and have brought many benefits to maintenance, examples of which include improved planning, reduced probability of equipment breakdowns, reduced maintenance costs, and less overtime. As such, these strategies have attracted more attention in both industry and research. However, failures in actual operations are almost inevitable, and so it is impossible to predict with certainty when failures will occur. According to Petrovic et al even the most reliable equipment will fail. Surveys show that most companies are convinced of the need for preventive activities, yet, in practice, the level of corrective activities in organisations is still high; in some cases higher than the levels of preventive work. For example, a study conducted in 1997 by Moore found that the average level of corrective activities in US manufacturers was approximately 49% (and hence little different from a 1992 level of 50%), indicating that, despite all the
The potential benefits of preventive programmes, corrective work represents in practice almost half of all maintenance activity\(^{13}\). Dhillon supports this argument, stating that

Both Dekker and Mather state that unplanned and reactive events dominate the state of affairs in a maintenance organisation\(^{14,15}\). Therefore, corrective activities cannot be entirely eliminated, and will be always be part of the responsibilities of maintenance management\(^{4}\). This paper focuses on the improvement of corrective activities, particularly on an approach to reducing the failure troubleshooting time.

**The reduction of troubleshooting time**

- involves minimising both diagnosis time and repair time (see Figure 1). Generally, the former is reduced by making the process of identifying the failures quicker, and by ensuring that the correct failure is addressed. Repair time can be minimised by speeding up the time to rectify the failure, and by ensuring that the correct repair procedures are followed. The reduction of both diagnosis and repair time traditionally relies on the knowledge (or skill) of the maintenance technicians\(^{16}\), which is typically achieved through experience and
An empirical study of the utilisation, in troubleshooting, of failure records

training. However, training and experience generally take a long time to acquire, are expensive, and become obsolete at the same time as the equipment.[17]

Maintenance technicians might also refer to support documentation to assist both diagnosis and repair; in particular, to knowledge regarding past failure experiences.[16, 18]. In support of this argument Kelly points out that referring to failure records can significantly support the difficult task of diagnosing the causes of failure and prescribing the corrective action.[19]. Ruszkiewica suggests that corrective activities can be assisted by a database consisting of equipment descriptions, failure diagnoses, repair descriptions, and records of resources used.[20]. Durham et al. demonstrated that both downtime and the labour needed for troubleshooting are reduced by the employment of failure data collection systems.[21]. They also stated that the ability to efficiently retrieve and review failure information is an effective tool for troubleshooting. According to Gandhi et al. the traditional troubleshooting strategy used by experts is to first attempt to apply the available tacit knowledge (personnel knowledge) to find a quick solution to the given problem.[22]. If this knowledge fails to provide an acceptable solution, then explicit knowledge (e.g. technical documents) is used to ensure that a correct solution is found. As such, it may be concluded that support documentation has a major role to play in the troubleshooting process.

In summary, this section has shown that preventive and corrective maintenance are the two main strategies used to achieve downtime reduction. It has demonstrated that, despite the popularity of preventive activities, the level of corrective activities is still high. Moreover, due to the lack of supporting tools to assist corrective activities, it proposes an approach to reduce troubleshooting time, an approach which focuses on support documentation. The following proposition is therefore put forward –

‘A support documentation system, based on failure records, can be developed to assist maintenance technicians during troubleshooting’.

The following section reviews failure information management, addressing in particular the methods used to manage maintenance documentation and the main documents that can be used to support failure troubleshooting, ie failure records and technical documents.

THE MANAGEMENT OF FAILURE INFORMATION

Maintenance information systems. The methods used to manage maintenance documents can be divided into two main categories, viz paper-based systems and computerised systems. The former are becoming less used because they require the expenditure of considerable time and effort for those functions involving data storage, retrieval, analysis and communication.[23, 19]. Conversely, among computer-based systems, computerised maintenance management systems (CMMS’s) are most widely used for managing maintenance documents.[24, 6]. CMMS’s, however, have usually been poorly utilised[19], and many companies have been disappointed with their results[25].
Cato and Mobley suggest that there is only a 9% overall utilisation of CMMS\cite{26}, while the complexity of most systems and the difficulties of retrieving information are often reported as main causes for the low CMMS utilisation rate\cite{27, 28, 29}. Consequently, unless sufficient training is provided\cite{29}, data are rarely effectively used for maintenance activities\cite{8}.

It appears that providing direct support to maintenance technicians during troubleshooting is not a main feature of current CMMS's. According to Cato and Mobley data fields describing what was found and what was done are not among the main fields customarily included in every CMMS\cite{26}, although it is recognised that every maintenance information system should include such information\cite{18}. Moreover, rather than using it to assist during failure troubleshooting, the information contained in CMMS's is used primarily to evaluate failure trends, to produce information to prevent future breakdowns, and to evaluate costs\cite{28}. Wireman points out that reducing equipment downtime by scheduling preventive maintenance is one of the main aims of the CMMS\cite{23}. In his survey, O’Hanlon found that only 20% of maintainers track 100% of maintenance and repair work in their CMMS\cite{25}. These arguments suggest that CMMS’s are generally designed to provide more support to preventive rather than to corrective activities, a tendency confirmed in the low rate of utilisation, by maintenance technicians, of CMMS’s\cite{6}.

**Technical documents.** Maintenance technicians might refer to technical documents to assist troubleshooting. Such documents are traditionally provided by equipment suppliers, and typically include: drawings; diagrams; manuals for operation, maintenance and design. Although the maintenance manuals do contain useful information for assisting troubleshooting, the recommendations provided are generally limited in their application. The data contained is not extensive\cite{18}; the manuals fail to take into account the context in which equipment is operating\cite{23}, address only the standard failure modes, and are often regarded as verbose and confusing\cite{22}. Since many of these documents are paper-based, they also present accessibility, portability and storage problems\cite{31}.

According to Bohn, maintenance technicians have relied extensively in the past on external knowledge, eg that of equipment suppliers\cite{34}. However, suppliers’ recommendations tend to be increasingly questioned, and are being replaced by the company’s past experiences obtained from its own failure records\cite{35}. A study undertaken by Cooke demonstrated that the skill requirements for maintenance work are much wider than is covered by the scope of the information provided in existing technical documents\cite{36}. The extensive amount of information that usually exists for equipment is a further problem with technical documentation. When people receive so much information they begin to ignore it\cite{37}, and so it is important for troubleshooting to derive a system that is able to filter relevant information.

Considering the above problems, and the fact that maintenance technicians prefer to use their experience (their tacit knowledge) to solve problems, failure records are probably a better source for troubleshooting information.
**Failure records** – are documents that store different types of failure information. Only troubleshooting failure information is considered in this paper. Recording past failure experiences into failure reports is a method of collecting part of the tacit knowledge of maintenance technicians and transforming it into explicit knowledge. Individual knowledge can therefore be transformed into group knowledge, a process that is particularly important for inexperienced and untrained maintenance technicians who might make decisions by guessing and who need to refer to documentation to support their decisions. It also means that part of the expert’s knowledge will be always be available.

Writing up failure records is one of the main problems. Maintenance technicians will not be motivated to complete failure reports if they will not directly benefit from them and do not know what are they are for. A study conducted by Hipkin showed that several managers reported that explaining to maintenance technicians why data collection is necessary improved the quality of information recorded. The usual work pressures on maintenance technicians, combined with the highly detailed nature of the typical data collection form, means that only rarely does a company undertake systematic failure recording. There is also a fear that such records will be used to replace people, and so records are not kept and much equipment history is retained only inside people’s heads; where it is not available for others to use. Despite stressing that these reports might contain information for assisting troubleshooting, maintenance technicians often do not refer to them because it is difficult to access the information and it is often not relevant.

Ventura supports the accessibility argument, pointing out that 20-30% of repair time is spent searching for information in documents. We therefore conclude that, since assisting corrective work is not a main function of most maintenance information systems, it is unlikely that failure reports are designed to assist maintenance technicians.

From an analysis of the relevant literature it has been demonstrated, in this first part of our paper, that current maintenance information systems are not, in general, fully coping with maintenance requirements (something which is shown in part by the low utilisation rates of such systems). It has also been argued that these systems are failing to adequately address the task of providing assistance to maintenance technicians during troubleshooting. Also stressed has been the importance of failure records and technical manuals for assisting troubleshooting, and some of the problems involved have been identified. Our second proposition is therefore that –

An empirical study of the utilisation, in troubleshooting, of failure records

Part II of the paper will present the results of an empirical study of failure records utilisation, a study which has aimed to complement and confirm the findings of our literature review, to assess the validity of our propositions, and to guide later research towards the development of a support system based on failure documentation that will seek to assist maintenance technicians during troubleshooting.
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