INTERNATIONAL STANDARD

ISO 13374-1

First edition
2003-03-15

Condition monitoring and diagnostics of machines — Data processing, communication and presentation —

Part 1: General guidelines

Surveillance et diagnostic d'état des machines — Traitement, échange et présentation des données —

Partie 1: Lignes directrices générales

Reference number
ISO 13374-1:2003(E)

ISO copyright office
Case postale 56 • CH-1211 Geneva 20
Tel. + 41 22 749 01 11
Fax + 41 22 749 09 47
E-mail copyright@iso.org
Web www.iso.org

Published in Switzerland

Contents

Page

Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 13374-1 was prepared by Technical Committee ISO/TC 108, *Mechanical vibration and shock*, Subcommittee SC 5, *Condition monitoring and diagnostics of machines*.

ISO 13374 consists of the following parts, under the general title *Condition monitoring and diagnostics of machines — Data processing, communication and presentation*:

— *Part 1: General guidelines*

— *Part 2: Data-processing requirements*

— *Part 3: Communication requirements*

— *Part 4: Presentation requirements*

Introduction

The various computer software programs written for condition monitoring and diagnostics of machines that are currently in use cannot easily exchange data or operate in a plug-and-play fashion without an extensive integration effort. This makes it difficult to integrate systems and provide a unified view of the condition of machinery to users. The intent of ISO 13374 is to provide the basic requirements for open software specifications which will allow machine condition monitoring data and information to be processed, communicated and displayed by various software packages without platform-specific or hardware-specific protocols.

Extensible Markup Language (XML) is a project of the World Wide Web Consortium (W3C), and the development of the specification is being supervised by their XML Working Group. XML is a public format written in the Standard Generalized Markup Language (SGML) (see ISO 8879[1] for details) for defining descriptions of the structures of different types of electronic documents. The version 1.0 specification was accepted by the W3C as a Recommendation in 1998. A W3C Recommendation indicates that a specification is stable, contributes to Web interoperability, and has been reviewed by the W3C membership, who are in favour of supporting its adoption by academic, industry and research communities. It is designed to improve the functionality of the Web by providing more flexible and adaptable information identification.

Condition monitoring and diagnostics of machines — Data processing, communication and presentation —

Part 1: General guidelines

1 Scope

This part of ISO 13374 establishes general guidelines for software specifications related to data processing, communication, and presentation of machine condition monitoring and diagnostic information.

NOTE Later parts of ISO 13374 (under preparation) will address specific software specification requirements for data processing, communication and presentation.

2 Data processing

2.1 Overview

Relevant data processing and analysis procedures are required to interpret the data received from condition monitoring activities. A synergistic combination of technologies should establish the cause and severity of possible faults and provide the justification for operations and maintenance actions in a pro-active manner.

A data processing and information flow of the type shown in Figure 1 is recommended either on a manual or automatic basis, in order to implement condition monitoring successfully. The data flow begins at the top, where monitoring configuration data are specified for the various sensors monitoring the equipment, and finally results in actions to be taken by maintenance and operations personnel. As the information flow progresses from data acquisition to advisory generation, data from the earlier processing blocks need to be transferred to the next processing block and additional information acquired from or sent to external systems. Similarly, as the data evolve into information, both standard technical displays and simpler graphical presentation formats are needed. The flow progresses from data acquisition to complex prognostic tasks, ending in the issuance of advisories and recommended actions (one of which may be a modification of the monitoring process itself).

2.2 Data-processing blocks

2.2.1 Machine condition assessment processing blocks

Machine condition assessment can be broken into six distinct, layered processing blocks. The first three blocks are technology-specific, requiring signal processing and data analysis functions targeted to a particular technology. The following are some of the most commonly used technologies in condition monitoring and diagnostics of machines:

— shaft displacement monitoring;

— bearing vibration monitoring;

— tribology-based monitoring;

— infrared thermographic monitoring;

— performance monitoring;

— acoustical monitoring;

— motor current monitoring.

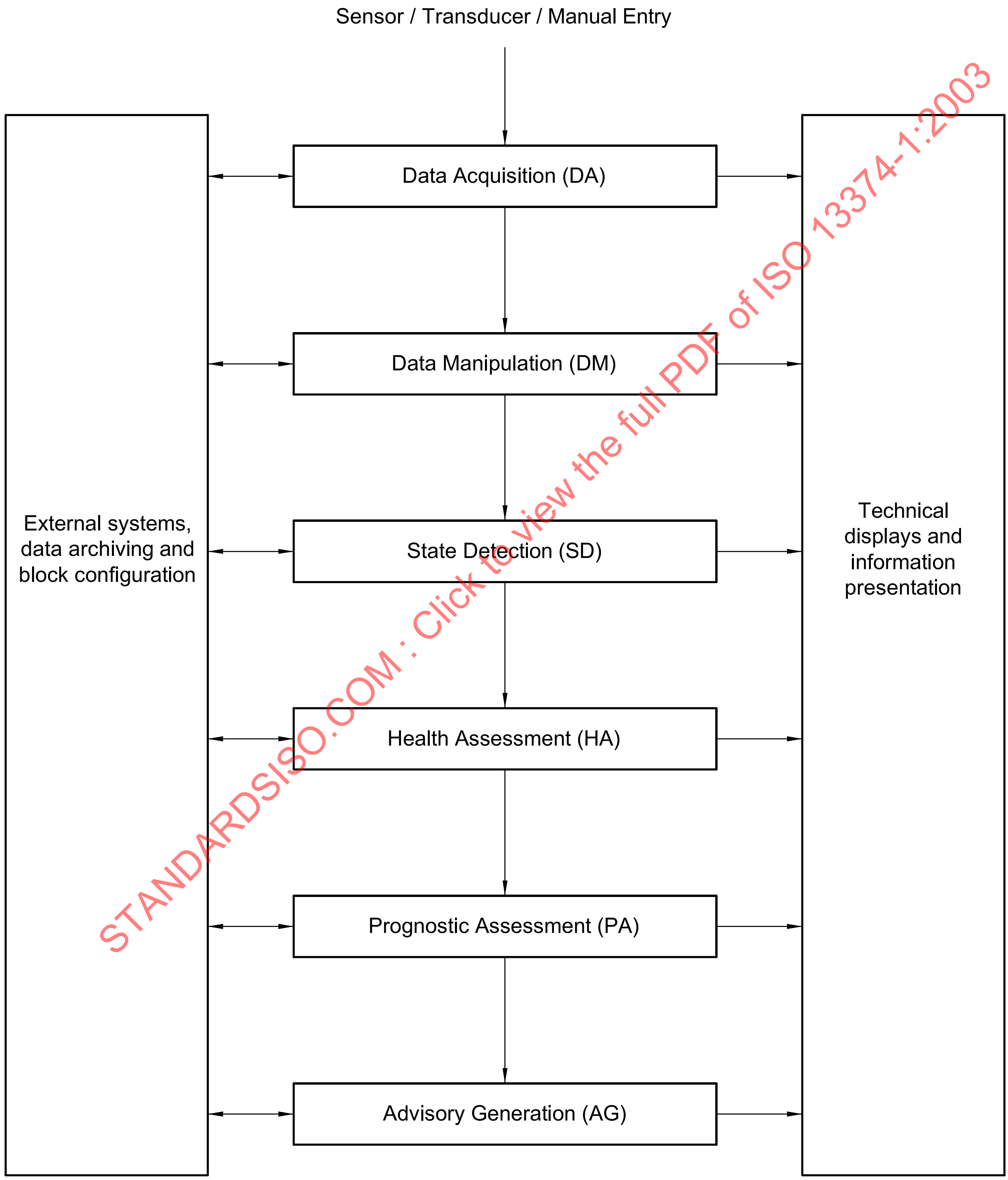


Figure 1 — Data-processing and information-flow blocks

The technology-specific blocks and the functions they should provide are as follows.

a) **Data Acquisition (DA) block**: converts an output from the transducer to a digital parameter representing a physical quantity and related information (such as the time, calibration, data quality, data collector utilized, sensor configuration).

b) **Data Manipulation (DM block)**: performs signal analysis, computes meaningful descriptors, and derives virtual sensor readings from the raw measurements.

c) **State Detection (SD block)**: facilitates the creation and maintenance of normal baseline "profiles", searches for abnormalities whenever new data are acquired, and determines in which abnormality zone, if any, the data belong (e.g. "alert" or "alarm").

The final three blocks normally attempt to combine monitoring technologies in order to assess the current health of the machine, predict future failures, and provide recommended action steps to operations and maintenance personnel. These three blocks and the functions they should support are as follows.

d) **Health Assessment (HA) block**: diagnoses any faults and rates the current health of the equipment or process, considering all state information.

e) **Prognostic Assessment (PA) block**: determines future health states and failure modes based on the current health assessment and projected usage loads on the equipment and/or process, as well as remaining useful life predictions.

f) **Advisory Generation (AG) block**: provides actionable information regarding maintenance or operational changes required to optimize the life of the process and/or equipment.

2.2.2 Technical displays

To facilitate analysis by qualified personnel, relevant technical displays showing data such as trends as well as associated abnormality zones are necessary. These displays should provide the analyst with the data required to identify, confirm or understand an abnormal state.

2.2.3 Information presentation

It is important that the data be converted to a form that clearly represents the information necessary to make corrective-action decisions. This may be done in a written format, numerically in order to demonstrate magnitudes, graphically in order to show trends, or a combination of all three.

The information should include pertinent data describing the equipment or its components, the failure type or fault, an estimate of the severity, a projection of condition and, finally, recommended action. Cost and risk factors may also be displayed.

2.2.4 External systems

Retrieval of previous work histories from the maintenance system and previous operational data (starts/stops/loads) from a process-data historian is important in the assessment of machinery health. After a health assessment is made, the maintenance action to be taken may range from increasing the frequency of inspection to repair or replacement of the damaged machinery or component. The effect on operations may be an adjustment of operating procedures or a request to shutdown the equipment immediately. This need for rapid communication to the maintenance and operational system requires software interfaces to maintenance management systems and operational control systems. These interfaces are useful in order to communicate recommended actions in the form of maintenance work requests and operational change requests.

2.2.5 Data archiving

Data archiving is an important feature during all blocks of a machine condition monitoring program. Previous data trends can be analysed for statistical relevance. Previous health assessments should be audited for accuracy, and root cause information added upon its discovery.

2.2.6 Block configuration

Each data-processing block requires configuration information, some of which may be static information and other data may be dynamically changed by the system during operation. For example, the configuration of the Data Acquisition block may include identification of measurement monitoring locations, orientation and relative transducer position, monitoring polling rates, sensor set-up data and calibration parameters.

2.3 Conceptual information schema guidelines

2.3.1 Overview

The conceptual information schema is a single integrated definition of the relative machinery and condition monitoring information, which is unbiased toward any single application of data and is independent of how the data are physically stored or accessed. The primary objective of the conceptual schema is to provide a consistent definition of the meanings and interrelationship of data, which can be used to integrate, share and manage the integrity of data. This information schema is a blueprint of the location of various data elements. There are various forms of information schema.

The file description schema format has been used for years in the scientific programming community. It maps the format for ASCII or binary data files, which can be exported from a computer system or imported into a computer system. A complete record format description is published which specifies the data fields contained in the file, their exact location in relation to the other data fields, whether the fields are in ASCII or binary format, and the exact data format (scientific floating point, integer, character, varying character string) of each field.

The relational information schema format is the definition language for relational database management systems. The relational method is analogous to a blue-print drawing which defines the following:

- various “room names” (or tables) where data will be stored;
- the data “contents” (or columns) in the rooms;
- each data column's exact data format (scientific floating point, integer, varying character string, etc.);
- whether or not a data column can be empty or not (not null);
- each data row's unique “key” (primary key) which uniquely identifies it.

A table can be related to another table by including a “reference” (foreign key) to it.

Extensible Markup Language (XML) is a project of the World Wide Web Consortium (W3C) and the development of the specification is being supervised by their XML Working Group. XML is a public format written in the Standard Generalized Markup Language (SGML) (see ISO 8879[1] for details) for defining descriptions of the structures of different types of electronic documents. It is called extensible because it is not a fixed format like Hypertext Markup Language (HTML), which is a single, predefined markup language. Instead, XML is actually a “meta-language” (a language for describing other languages) which allows one to design customized markup languages for limitless different types of documents. XML uses the internationally standardized 31-bit character repertoire specified in ISO 10646[2], which covers most human (and some non-human) languages. This is currently congruent with Unicode and is planned to be superset of Unicode. XML is intended to make it easy and straightforward to use SGML on the Web: easy to define document types, easy to author and manage SGML-defined documents, and easy to transmit and share them across the Web. It defines an extremely simple dialect of SGML, which is completely described in the XML Specification. The goal is to enable generic SGML to be served, received and processed on the Web in the way that is now possible with HTML. For this reason, XML has been designed for ease of implementation, and for interoperability with both SGML and HTML.

In 2001, the W3C issued XML Schema as a W3C Recommendation. XML Schemas define shared markup vocabularies, the structure of XML documents, which use those vocabularies, and provide hooks to associate semantics with them. By bringing datatypes to XML, XML Schemas increase XML's utility to the developers of data interchange systems. XML Schemas allow the author to determine which parts of a document may be validated, or identify parts of a document where a schema may apply. Furthermore, as XML Schemas are XML documents themselves, they may be managed by XML authoring tools.

A software object information schema is now becoming widely used in the computer industry. Software "objects" are defined using an object definition language, including their external characteristics and operations, unique keys, data attributes available, data types, relationships, etc. The Unified Modelling Language (UML) has emerged as the software industry's dominant modelling language. The Object Management Group (OMG) adopted UML as its standard modelling language.

NOTE The OMG has submitted the UML specification to ISO as a Publicly Available Specification (PAS).

2.3.2 Information schema requirements

Regardless of which information schema format is chosen, the schema will define a minimum set of data elements that should be included in the schema for compliance. In addition, a list of optional elements will be included.

To support data communication between multiple condition monitoring modules supplied by various vendors, a vendor-independent, open machine condition monitoring information schema architecture is required as an underlying framework. This framework can be utilized in various communication implementations.

Vendor independence is vital. Many vendors and users have implemented various methods of machine condition monitoring data storage. An open information schema allows for the integration of many sources of machinery information, supports peer-to-peer databases, allows user-defined lookup entries, and utilizes standardized timestamps and engineering units. The schema should support unique site identifiers and site database or data source identifiers to differentiate data taken at different physical locations. The schema should also support unique, system-wide identifiers for plant segments containing machinery (service segment locations) in a parent-child hierarchy. Also the schema should support a unique asset-specific identifier to allow individual component monitoring and tracking in a parts hierarchy. The basic framework of storing sites, site databases, process or machine segment information, asset nameplate data, model or part information, measurement locations, data measurement sources, transducers, ordered lists, and alarms should be specified in the schema. At a data level, the schema should support formats for communicating historical single-valued numeric data, Fast-Fourier Transform (FFT) spectra data, constant percentage band (CPB) spectra, time waveforms, sample-based test data, thermographic images, and binary large objects. The schema should support a date/time notation that references back to a specific instance in time, using the Gregorian (Common Era or CE) calendar, with a lexical representation based upon ISO 8601[3].

In order to communicate common machinery equipment types, measurement location types, orientations, etc., a standard set of reference entries should contain a set of common codes and associated text in various languages as required. The architecture should allow for each database to create and maintain additional reference table entries to allow maximum flexibility. An example of a publicly available XML Schema that supports this architecture is given in Annex A.

3 Data communication formats and methods for exchanging information

3.1 Communication methodologies

3.1.1 General

Various communication methods can be utilized to distribute data that has been formatted according to the information schema discussed above. The methodology utilized should be appropriate to the requirement of the application.

3.1.2 Data file export/import processors

A data file export processor method of data communication requires the data provider to generate data files of a specific information schema format using a set of user-defined filters and options. If a file description information schema format is used, no additional file syntax specification may be needed. If a relational or object information schema is used, then an export data file syntax should be specified. A data file import processor is then required to import the data into another target system.

3.1.3 Remote Database Access client/server

Remote Database Access (RDA) is a communication protocol (see ISO/IEC 9579[4] for details) for accessing a remote relational database or one that can be made to look like a relational database. RDA is used for accessing data distributed over a number of heterogeneous platforms throughout a network. RDA employs a client/server model in which the client monitors or controls the server, utilizing a published RDA language.

3.1.4 Structured Query Language client/server

Structured Query Language (SQL) is a relational database access language (see ISO/IEC 9075[5] for details). SQL structures a database as a set of tables. A table is a collection of data organized into a fixed number of columns and a variable number of rows. The SQL standard defines a syntax for embedding SQL statements in several computer programming languages. A data source can build an SQL server in which a client application is able to query a server using the SQL language.

3.1.5 Manufacturing Message Specification client/server

Manufacturing Message Specification (MMS) (see ISO/IEC 9506[6] for details) provides a large number of services for real-time monitoring and control in a distributed system. It defines coding rules, grammar and syntax for transmitting process data on a near-real-time basis from one computer to another. MMS employs a client/server model in which the client monitors or controls the server. The server's behaviour is modelled by the Virtual Manufacturing Device (VMD) abstraction. Since this standard is concerned with data access, reference is made to MMS's variable access services and the data model underlying those services.

3.1.6 Extensible Markup Language client/server

Extensible Markup Language (XML) is a subset of ISO's Standard Generalized Markup Language (SGML) and is now widely utilized on the internet. XML provides a standard by which the content structure of a wide variety of information, from simple to complex, can be marked up for easy transfer over internet/intranet network for use on a variety of computing platforms.

XML documents based on the same XML schema can be sent from one application to another, even across different operating systems and machines. An XML client application, running on one machine, can send an XML query to an XML information server running on a different computer on the network, and receive the information it needs in a computer-readable format.

Legacy data encoded in XML can be delivered over a local area network or the internet without having to be changed. Once on the client computer, it can be edited, manipulated and presented in various views without return trips to the server computer.

XML is enabling open exchange of business information over the internet. It can also be used in the exchange of maintenance and reliability information over computer networks as vendor-independent XML schema and protocols in accordance with ISO 13374 gain acceptance. An example of a publicly available set of XML client/server specifications for condition monitoring and diagnostics is found in Annex A.

3.1.7 Common Object Request Broker Architecture and Interface Definition Language

The Common Object Request Broker Architecture (CORBA) interoperability platform is an internationally accepted standard (see ISO/IEC 19500-2[7] for details) for software object-to-object communication which includes an Object Request Broker (ORB). This specification conforms to ISO/IEC 10746[8] on Open Distributed Processing.

CORBA communication specifications are written in Interface Definition Language (IDL), as specified in ISO/IEC 14750[9], which allows interfaces to be written independent of any programming language. Components specified in IDL publish the services they provide, the methods they support, the relevant parameters, attributes, error handlers and inheritance relationships with other components.

3.2 Selection guidelines for communication methodologies

3.2.1 Methods of data access

A data file method of data communication requires the file server and client to manipulate physical data files of a specific information schema format using a set of user-defined filters and options. This method is appropriate when a large volume of information needs to be transferred from one system to another, or if the target system is not on-line.

A relational query client/server method of data communication, such as RDA and SQL, requires that the data provider support a call level interface with some minimum level support for a user-defined “SELECT” construct of Structured Query Language (SQL). This data communication method is directly supported by the relational schema. The file description schema format requires a remapping effort to describe the file data as a relational schema in order to support this relational query method. An object information schema would also need to be converted into a relational schema to allow for this relational query language to be supported.

A memory-resident communication server method of data communication, such as MMS, requires that the data provider create a communication server that understands a defined protocol for acknowledging requests for data and sending the resulting data packets to the requester. In a file description schema format, each data atom to be transferred should be assigned a data atom identifier, and a data filter method should be agreed upon. In a relational schema, the requested table name and column names should be communicated along with row filter information. In an object schema format, the requested object class and object attributes are communicated, along with object class and attribute filter information.

An XML-based client/server data communication method requires the creation of XML schema or document type definitions (DTDs) which provide support for message transactions between a client and a server based upon a standard vocabulary derived from the conceptual information schema. The file description, relational schema and object schema all require a remapping effort to describe their contents in terms of an XML element in order to support this method.

Finally, a software object client/server method of data communication requires that a data provider create software objects which respond to a remote object call level interface with some minimum level support for a predefined object query language. Both the file description and relational schema require a remapping effort to describe their contents in terms of an object model in order to support this object query server method. This data communication method is directly supported by the software object schema format.

3.2.2 Additional issues

In the selection of the data communication and data access guidelines, several other issues also need to be considered, as follows:

— network communication requirements for error detection and recovery, inactivity timers, re-transmissions, checksums, re-sequencing and operation deadlines;

— reporting of errors to higher communication blocks;

— condition monitoring data source scanning rates and time resolution required to generate the analysis;

— operating system environment and network platforms.

4 Formats for presenting and displaying data

4.1 General

The user interface needs to provide an intuitive, intelligent and adaptive way to access the equipment condition monitoring data from distributed data sources. Analysts require user interfaces that will support their diagnostic analysis capabilities, assist them in determining the future health of the equipment, and assist them in generating and transmitting recommended actions. Operators and managers require information displays which assist them in making optimized decisions on the next operational or maintenance activity to take.

4.2 Determination of work flow procedures

In order to determine the formats for presenting and displaying data to an end-user, a determination of the work flow and information requirements of each phase of condition monitoring is required.

Machinery condition monitoring is the collection of data consisting of the levels of vibration, temperature, pressure, electrical characteristics, acoustic emissions, and any other parameter reflecting the operating conditions of the machine. These levels are recorded and compared with previously recorded "baseline" data, preset alarms or trip levels. Any changes to the levels are carefully observed, as they are usually an indication that some anomaly is developing that is having an adverse effect on the health of the machine. Also, the rate of change of parameters is an indication of the criticality of the machine's condition.

After it has been established that parametric levels are definitely changing, the next step is to determine the health of the machine, which includes the machine health index and the probable cause or causes of any problems.

Machinery health assessment involves more in-depth investigations of all the information at hand, and applying established techniques to determine why certain parameters are changing. Also of considerable importance are the inter-relationships of the various parameters. An abnormally hot bearing and an increase of wear particles in the lubrication oil are a perfect example of this inter-relationship. Normally, the analyst starts with a more complex but more complete analysis of the vibration signatures. This approach can provide a great deal of information regarding the machine’s behaviour. These analyses can include, but are not limited to, conducting a frequency analysis to determine the frequencies of the peak vibrations, establishing phase relationships, investigating shaft orbits and establishing cause and effect relationships. This information can often reveal the existence of rotor unbalance, misalignment, loose parts, bearing or gear wear, or resonant frequency conditions. A complete diagnostic analysis could also include process parameters such as load level, speed, fluid flow, cyclic fluctuations. It is essential that the diagnostic results be presented in a clear, informative manner. Diagnostic analyses include various tools (e.g. vibration analysis, thermography analysis, tribology-based analysis). Vibration analysis uses different methods, such as time waveform, constant percentage band (CPB) spectra, Fast Fourier Transform (FFT), orbits, coast-up/coast-down analysis, wavelet analysis, and transfer and coherence function analysis. Similarly, tribology-based analysis can include wear particle, spectrographic and ferrographic tests.

Once the diagnostic analyses propose the cause(s) of the problem, a prognostic evaluation can then be made to predict the expected life of the machine. Prognosis is the interpretation of data and diagnostic information related to the present condition of a machine in order to predict its probable future condition, behaviour and performance. The prognosis can be modified by process changes such as load level, operating temperatures, pressures, and other process parameters.

Prognosis involves design, reliability, availability and maintainability computations and thus demands the collection of relevant data. Also, unlike diagnoses of the causes of the faults, prognoses of future fault progressions require a foreknowledge of the probable future duties to which the machine will or might be subjected. This may demand the collection of previous duty and cumulative duty parameters, along with condition and performance parameters, prior to extrapolations and forecasts. Some examples of prognostic analyses are

— analysis of remaining life (L10) of bearing,

— boiler creep-fatigue damage prognosis, and

— dynamic stress-strength mean time to failure.

Finally, all of this information contributes to the recommended course(s) of action that can be made with a great deal more intelligence, as they are based on informative data.

4.3 General information display architecture

4.3.1 Overview

The implementation of a three-schema architecture is widely used to develop multiple-user presentations from multi-database applications. The objective of this architecture is to separate the definition of the logical relationships of data and other objects in the application from the way particular databases manage the data, and from the way applications interact with the user. The three schemas used in the architecture are internal, conceptual, and external as shown in Figure 2. Internal schemas correspond to the native formats of various data sources and external schemas correspond to users' views of the data. Multiple external schemas can be developed to overcome the mapping deficiencies of a two-schema approach. The conceptual schema, described in 2.3, is a single integrated definition of the data within an enterprise that is unbiased toward any single application and is independent of how the data are physically stored or accessed.

4.3.2 Display formats

Display formats should be customized for individual applications. For many users, the display may be separated into five distinct areas in order to provide the end-user with a quick summary of the situation. Subsequent screens may display additional data in more detail. Figure 3 is a sample of an aircraft engine display and Figure 4 represents a steam boiler display. The five areas are described briefly as follows.

a) State detection

This area of the display is reserved for the presentation of state information specific to the observed monitoring situation. Trend data (such as amplitude versus flight-hours, process performance versus time for an aircraft engine, or combined accumulated damage versus accumulated operating time for a boiler) can be shown together with corresponding abnormality zones. All of the information is displayed in such a manner that the observer is quickly appraised of the degree of abnormality in each case.

b) Health assessment

Based on the results of human or automated analyses, this area of the display summarizes the results of the machinery health state and diagnostics. A health index on a scale from 0 (complete failure) to 10 (as new) may be shown. For reciprocating or rotating machines, for example, phenomena such as misalignment, unbalance, bearing faults (e.g. spalling) can be evaluated and presented from vibration analysis. For pressure vessels, the percentage of creep-fatigue damage accumulation and its rate, in addition to sensor inaccuracies from boiler damage analysis, can be reviewed.

c) Prognosis

This area of the display contains prognosis-specific information. If equipment continues to be operated under existing conditions, it may fail when the projected number of operating hours is reached. However, if the equipment is operated differently, the proposed safe operating hours may be increased. With other equipment, several operating strategies can be provided (e.g. the ramping rate can be set at various percentages). Each rate has some merits and demerits. For example, a high ramping strategy may impose undesirable maximum stresses or calculated damage to the equipment and these considerations are guided by the organization's maintenance and operation strategies. Similarly, knowing the operating conditions, such as contact load angle, lubrication, revolutions per minute, load cycle, a statistical life analysis (L10) can be performed to estimate the remaining life of the shaft thrust bearing. As mentioned earlier, this can be improved by changing certain operating conditions, such as lubrication or a reduction of load level.

d) Recommended actions

The next area of the display lists the recommended actions to be taken. This advice is based on the criticality of the piece of equipment, operation costs, maintenance costs, availability of spares and other factors. The severity of the problem will also influence the actions requested. The recommendations can range from "reduce the power level" and "replace or repair components", to "change the oil" or "reduce the load."

e) Identification

This area of the display describes the identification of the equipment by the equipment number, component number, assessment date, etc., for historical recording, which is valuable for future reference.

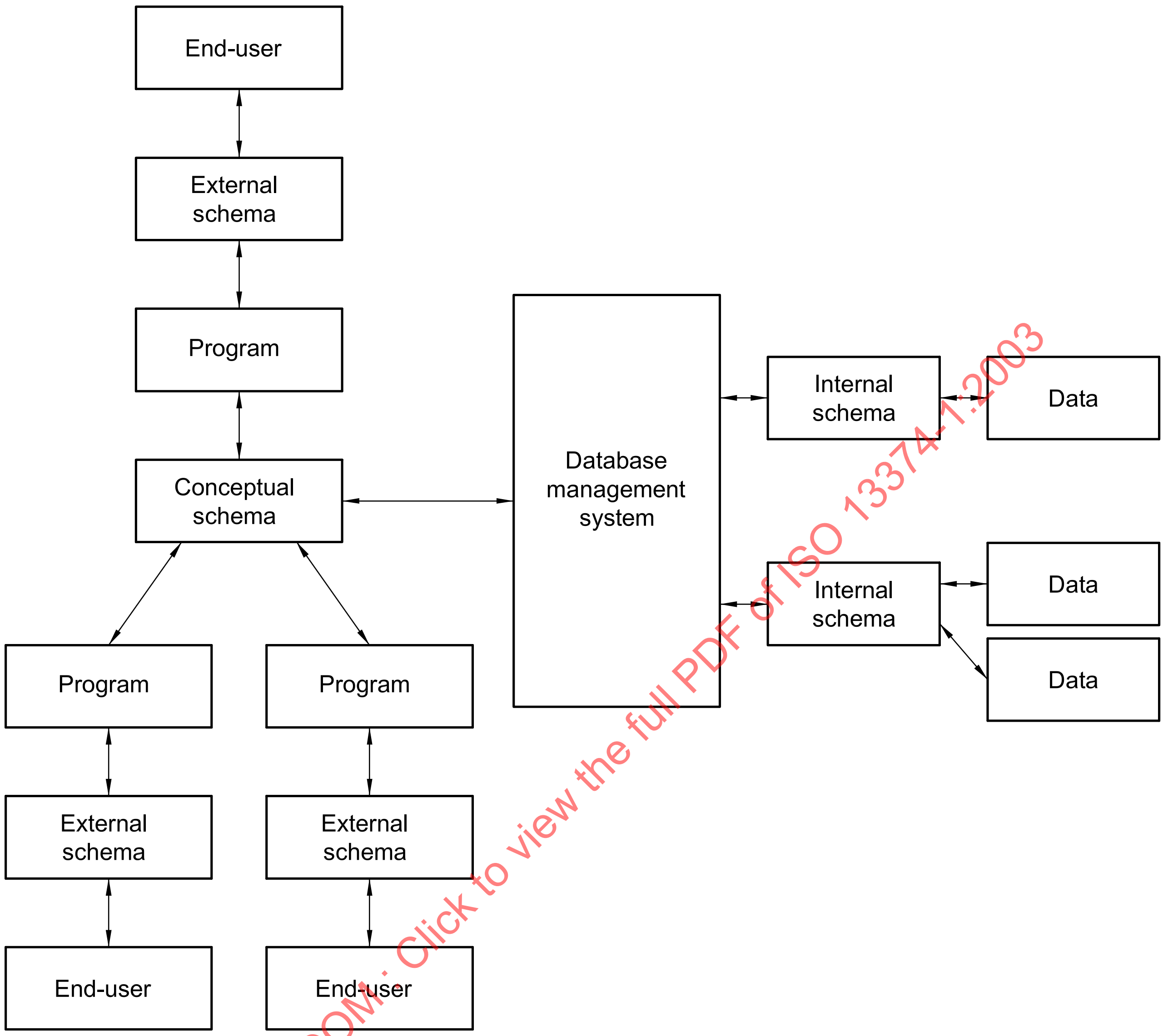


Figure 2 — Three-schema architecture

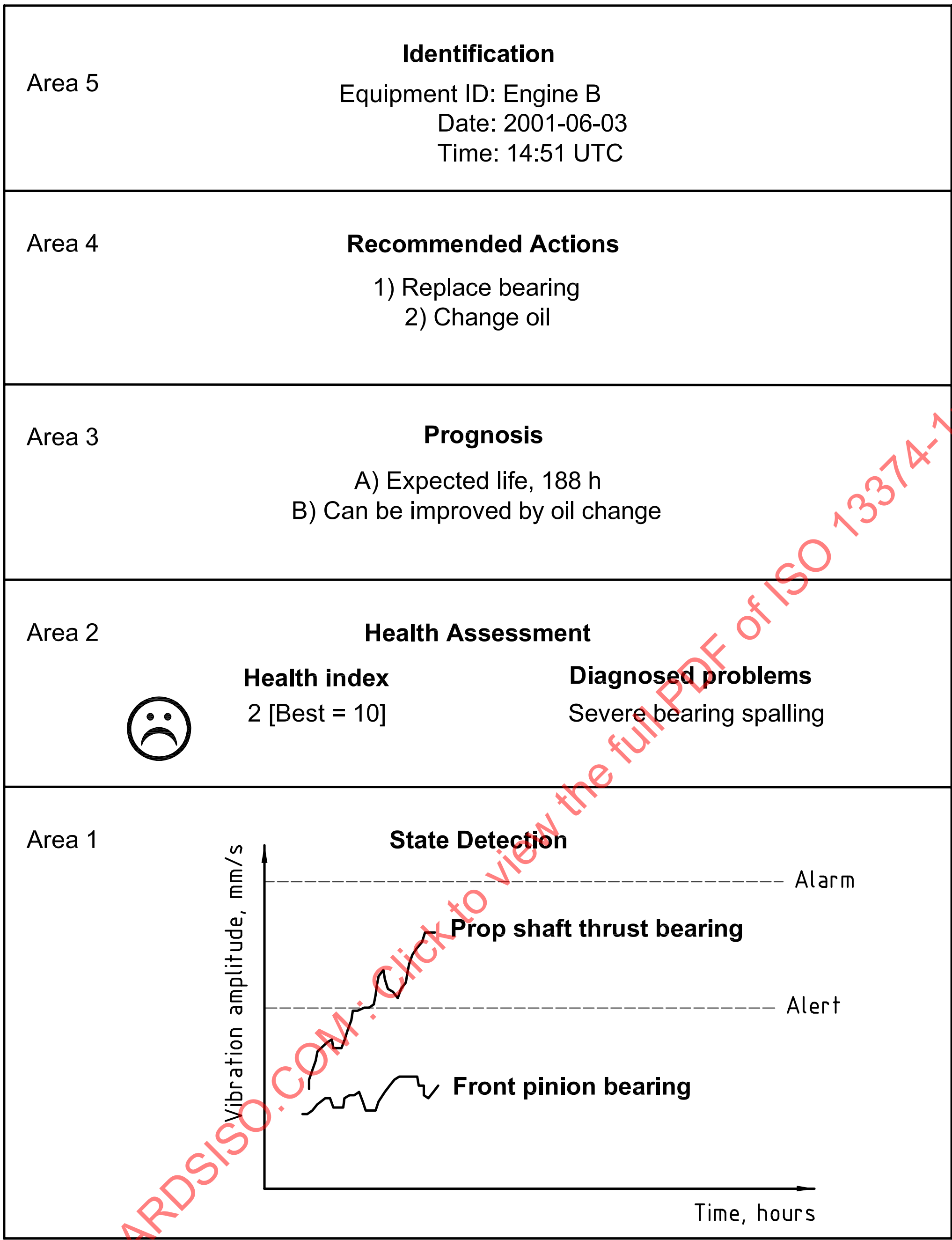


Figure 3 — Example of an aircraft engine display

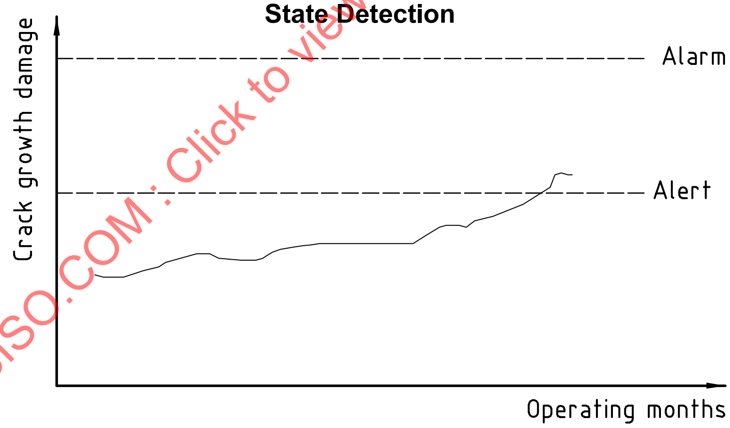
Area 5	**Identification** Equipment ID: Steam boiler B Date: 2001-06-02 Time: 08:41 UTC
Area 4	**Recommended Actions** 1) Select operation strategy C 2) Perform maintenance job plan A234 on boiler
Area 3	**Prognosis** A) 5 % per min ramping; increase damage 0,08 % B) 15 % per min ramping; increase damage 2 % C) 25 % per min ramping; increase damage 5 %
Area 2	**Health Assessment**  **Health index** 3 [Best = 10] **Diagnosed problems** 1) Creep-fatigue crack damage (80 % likely) 2) Possible sensor inaccuracy (1 % likely)
Area 1	**State Detection** 

Figure 4 — Example of a steam boiler display