

Analyser systems — Guidance for maintenance management

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National foreword

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Analyser systems – Guidance for maintenance management



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CONTENTS

1	Scope and object.....	5
1.1	Purpose of this technical report	5
1.2	Safety and environment.....	5
2	Normative references	7
3	Terms and definitions	7
4	Classifying analysers using a risk-based approach	11
4.1	Introduction	11
4.2	Safety protection	13
4.3	Environmental protection	13
4.4	Asset protection	15
4.5	Profit maximization.....	16
4.6	Performance target.....	16
4.7	Maintenance priority.....	17
4.8	Support priority.....	17
5	Maintenance strategies	17
5.1	Introduction	17
5.2	Reliability centred maintenance (RCM).....	18
5.3	Management systems/organization.....	21
5.4	Training/competency	22
5.5	Optimal resourcing	25
5.6	Best-practice benchmarking	27
5.7	Annual analyser key performance indicator (KPI) review	28
6	Analyser performance monitoring	28
6.1	Introduction	28
6.2	Recording failures – Reason/history codes	29
6.3	SPC/proof-checking.....	31
6.4	Analyser performance indicators	34
6.5	Analyser performance reporting.....	44
	Appendix 1 Step 1 – Equivalent analyser per technician (eqat) – Calculation methodology	46
	Appendix 2 Step 2 – Equivalent analyser per technician (EQAT) – Calculation methodology ..	47
	Appendix 3 SPC techniques applied to analysers – Interpreting control-chart readings	54
	Appendix 4 Adopting a strategy	58
	Appendix 5 Analyser benchmark by key success factor analysis	59
	Appendix 6 Analyser maintenance cost against benefit example	64
	Appendix 7 Analyser performance typical results	68

0 Introduction

In connection with the publication of EEMUA 187, the following text is related to the legal aspects of its publication in the U.K.

0.1 Legal aspects

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0.2 Overview

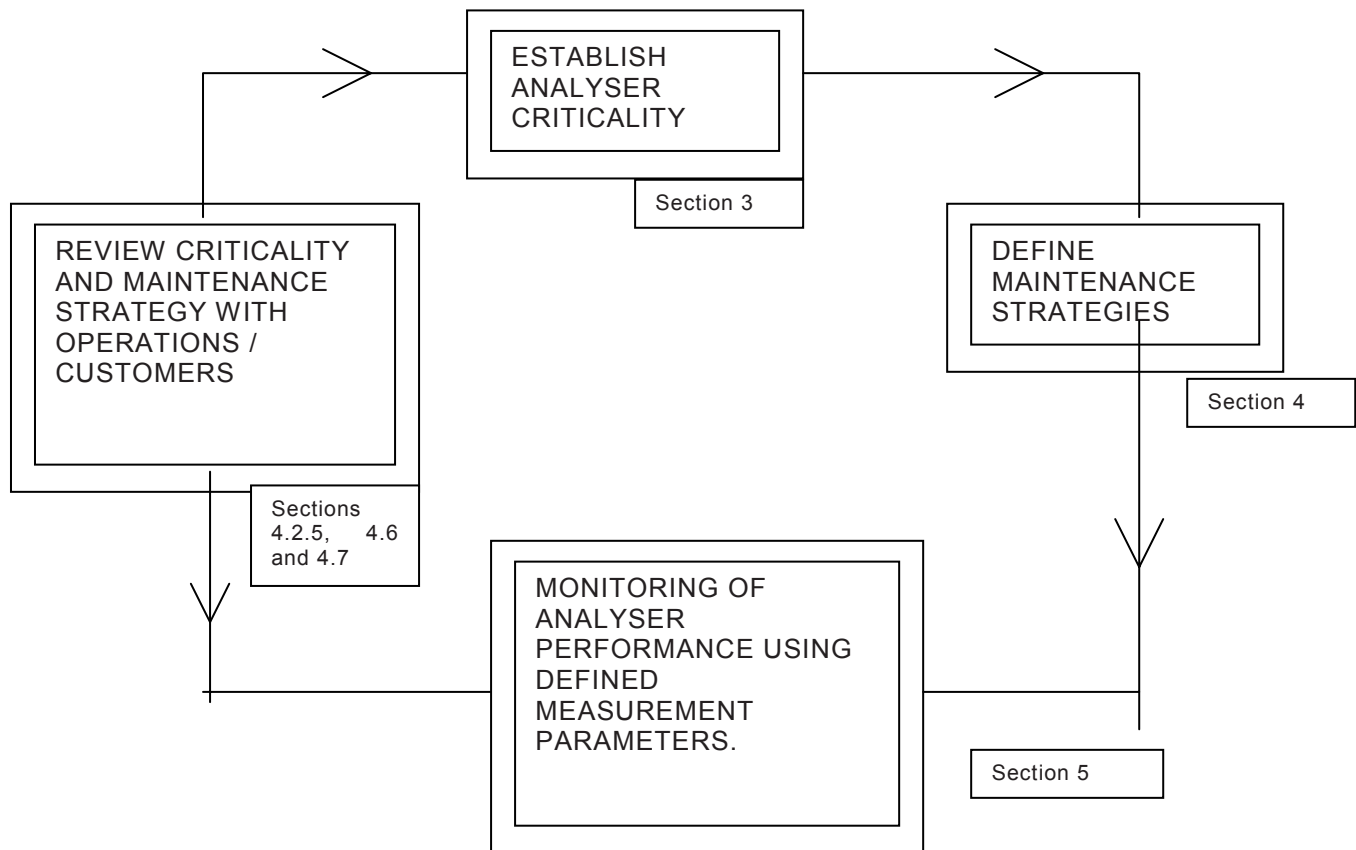
This guidance defines the best practices in the maintenance of on-line analysers. Analysers are used in industry to measure variables which significantly contribute to safety, environmental, asset protection and profit maximization.

Maintenance organization, prioritizing of maintenance effort, maintenance methods, correct resourcing, performance monitoring and reporting all play an important role in successful application of on-line analysers.

The ultimate effectiveness of the contribution of on-line analysers is measured by the ability to perform their functional requirements upon demand. This technical report gives guidance on performance target-setting, strategies to improve reliability, methods to measure effective performance, and the organizations, resource and systems that need to be in place to allow this to occur.

The various subjects covered in this document are discrete items and can appear unrelated in the overall scheme of analyser maintenance procedures and strategies. The following flow path ties the sections together in a logical sequence of approach.

0.3 Flowpath detailing inter-relationships of document subject-matter



IEC 1684/05

Figure 1 – Flowpath

This technical report provides a mechanism by which the criticality of an analyser can be determined by means of a risk assessment, the risk assessment being based upon consideration of the consequence of the loss of the analysis to the operation of a process unit, or group of process units, personnel/plant safety and the environment.

Determination of a criticality rating for the analyser allows target values for reliability to be set for each criticality classification and prioritization for maintenance and support. Such approaches are covered in Clause 4.

A number of strategies designed to allow the target reliabilities calculated by the risk assessments to be met are defined in Clause 5.

Finally, mechanisms for tracking analyser performance and quantifying the performance as meaningful measures are presented in Clause 6.

ANALYSER SYSTEMS – GUIDANCE FOR MAINTENANCE MANAGEMENT

1 Scope and object

This technical report applies to analyser systems.

1.1 Purpose of this technical report

This technical report is written with the intention of providing an understanding of analyser maintenance to individuals from a non-engineering background. It is also designed as a reference source to individuals more closely involved with maintenance of analytical instrumentation, and provides guidance on performance target-setting, strategies to improve reliability, methods to measure effective performance, and the organizations, resources and systems that need to be in place to allow this to occur.

Effective management of on-line analysers is only possible when key criteria have been identified, and tools for measuring these criteria established.

On-line analysers are used in industry for one of the following reasons.

1.2 Safety and environment

One category of analysers are those used to control and monitor safety and environmental systems. The key measured parameter for this category of analyser is on-line time. This is essentially simpler to measure than an analyser's contribution to profits but, as with process analysers applied for profit maximization, the contribution will be dependent upon the ability to perform its functional requirements upon demand.

1.2.1 Asset protection and profit maximization

On-line analysers falling into this category are normally those impacting directly on process control. They may impact directly on protection of assets (for example, corrosion, catalyst contamination) or product quality, or may be used to optimize the operation of the process (for example, energy efficiency).

For this category of analysers, the key measured parameter is either the cost of damage to plant or the direct effect on overall profit of the process unit. Justification as to whether an analyser should be installed on the process may be sought by quantifying the payback time of the analyser, the pass/fail target typically being 18 months, although it should be noted that the contribution of the analyser to reduction in the extent of damage to, or the profit of, the process unit is difficult to measure. However, this contribution will be dependent upon the analyser's ability to perform its functional requirements upon demand.

This technical report focuses on the cost/benefits associated with traditional analyser maintenance organizations. In a modern set-up, the complexity of analysers demands on occasion data from chemotricians and scientists who may be owned by other parts of the organization, and, as such, care must be exercised to include their costs.

1.2.2 Questions that need to be addressed

When considering on-line analyser systems and their maintenance, the following list of key points is useful in helping decide where gaps exist in the maintenance strategy. Additionally, a structured mechanism by which the "health" of an analyser organization can be appraised is provided in Appendix 5.

1. What is the UPTIME of each critical analyser? (Do you measure UPTIME and maintain records? Do you know the value provided by each analyser and therefore which ones are critical? Do you meet regularly with operations ("the customer") to review priorities?)
2. What is the VALUE delivered by each analyser in terms of process performance improvement (i.e. improved yield figures, improved quality, improved manufacturing cycle time and/or process cycle time, process safety (for example, interlocks), environmental importance)? (Is this information readily available and agreed to in meetings with operations? Is the value updated periodically?)
3. What is the "utilization" of each critical analyser – that is, if the analyser is used in a control loop, what percentage of the time is the loop on manual due to questions about the analyser data? (Do you keep records on the amount of time that analyser loops are in automatic? Do you meet regularly with operations to review the operators feelings about the "believability" of the analyser data?)
4. Do you have a regular preventive maintenance programme set up for each analyser which includes regular calibrations? (Does the calibration/validation procedure include statistical process control concepts – upper/lower limits and measurement of analyser variability (or noise)? Is the procedure well documented? Do you conduct it regularly? Even when things are running well?)
5. Do you have trained personnel (capable of performing all required procedures and troubleshooting the majority of analyser problems) who are assigned responsibility for the analysers? (Do the trained personnel understand the process? Do they understand any laboratory measurements which relate to the analyser results?)
6. Do the trained maintenance personnel have access to higher level technical support as necessary for difficult analyser and/or process problems? (Do they have ready access to the individual who developed the application? Do they have ready access to the vendor? Can higher level support personnel connect remotely to the analyser to observe and troubleshoot?)
7. Do you have a maintenance record keeping systems which documents all activity involving the analysers, including all calibration/validation records, all repairs and/or adjustments? (Do you use the record-keeping system to identify repetitive failure modes and to determine the root cause of failures? Do you track the average time-to-repair analyser problems? Do you track average time-between-failures for each analyser?)
8. Do you periodically review the analysers with higher level technical resources to identify opportunities to significantly improve performance by upgrading the analyser system with improved technology or a simpler/more reliable approach?
9. Do you meet regularly with operations to review analyser performance, update priorities, and understand production goals?
10. Do you have management who understand the value of the analysers and are committed to, and supportive of, reliable analysers?
11. Do you know how much the maintenance programme costs each year and is there solid justification for it?

Consideration of the above questions will help to identify opportunities for continuously improving the reliability of installed process analysers. Once the opportunities are identified, the following sections are intended to give guidance in achieving the solutions with the aim of

maximising performance and benefit of installed analysers;

achieving full operator confidence in the use of on-line analysers;

analyser output data becoming reliable enough to be used by operators, control systems, and other users to improve plant operation versus world-class manufacturing metrics and become best-of-the-best.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 61508 (all parts), *Functional safety of electrical/electronic/programmable electronic safety-related systems*

IEC 61508-5, *Functional safety of electrical/electronic/programmable electronic safety-related systems – Part 5: Examples of methods for the determination of safety integrity levels*

IEC 61649, *Goodness-of-fit tests, confidence intervals and lower confidence limits for Weibull distributed data*

IEC 61710, *Power law model – Goodness-of-fit tests and estimation methods*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

3.1

availability

ability of an item to be in a state to perform a required function under given conditions at a given instant of time or over a given time interval, assuming that the required external resources are provided

[IEV 191-02-05]¹

3.2

catastrophic failure

failure of a component, equipment or system in which its particular performance characteristic moves completely to one or the other of the extreme limits outside the normal specification range

3.3

consequence

measure of the expected effects of an incident outcome case

3.4

control system

system which responds to input signals from the process and/or from an operator and generates signals causing the EUC to operate in the desired manner

3.5

diversity

performance of the same overall function by a number of independent and different means

3.6

error/fault/failure/mistake

fault: state of an item characterized by inability to perform a required function, excluding the inability during preventive maintenance or other planned actions, or due to lack of external resources [IEV 191-05-01]

¹ IEC 60050-191, *International Electrotechnical Vocabulary (IEV) – Chapter 191: Dependability and quality of service.*

undetected fault: fault which is not detected by a diagnostic check

design fault: fault in the design caused by a mistake in the design phase of a system. A design fault causes an error, remaining undetected in a part of the system until specific conditions affecting that part of the system are such that the produced result does not conform to the intended function. This results in a failure of that part of the system. If the conditions appear again, the same results will be produced

error: discrepancy between a computed, observed or measured value or condition and the true, specified or theoretically correct value or condition [IEV 191-05-24]

failure: termination of an item to perform a required function [IEV 191-04-01]

mistake/human error: human action that produces an unintended result [IEV 191-05-25]

failed state: condition of a component, equipment or system during the time when it is subject to a failure

3.7

fault tree analysis

analysis to determine which fault modes of the subitems or external events, or combinations thereof, may result in a stated fault mode of the item, presented in the form of a fault tree

[IEV 191-16-05]

3.8

functional safety

ability of a safety-related system to carry out the actions necessary to achieve a safe state for the EUC or to maintain the safe state for the EUC

3.9

hazard

physical situation with a potential for human injury

3.10

level of safety

level of how far safety is to be pursued in a given context, assessed with reference to an acceptable risk, based on the current values of society

3.11

maintainability

ability of an item, under given conditions of use, to be retained in, or restored to, a state in which it can perform a required function, when maintenance is performed under given conditions and using stated procedures and resources

[IEV 191-02-07]

3.12

mean time between failures

MTBF

expectation of the operating time between failures

[IEV 191-12-09]

3.13

mean time to failure

MTTF

expectation of the time to failure

[IEV 191-12-07]

3.14

mean time to repair

MTTR

expectation of the time to restoration

[IEV 191-13-08]

3.15

proof-testing

method of ensuring that a component, equipment or system possesses all the required performance characteristics and is capable of responding in the manner desired

3.16

random hardware failure

failure occurring at a random time, which results from one or more of the possible degradation mechanism in the hardware

NOTE 1 There are many degradation mechanisms occurring at different rates in different components, and, since manufacturing tolerances cause components to fail due to these mechanisms after different times in operation, failures of equipment comprising many components occur at predictable rates but unpredictable (i.e. random) times.

NOTE 2 A major distinguishing feature between random hardware failures and systematic failures is that system failure rates (or other appropriate measures) arising from random hardware failures can be predicted with reasonable accuracy but systematic failures, by their very nature, cannot be predicted. That is, system failure arising from random hardware failure rates can be quantified with reasonable accuracy, but those arising from systematic failure cannot be accurately quantified because events leading to them cannot easily be predicted.

3.17

redundancy

in an item, the existence of more than one means of performing a required function

[IEV 191-15-01]

3.18

reliability

probability that an item will perform a required function under given conditions for a given time interval ($t_1.t_2$)

[IEV 191-12-01]

3.19

risk

probable rate of occurrence of a hazard causing harm and the degree of severity of harm. The concept of risk always has two elements; the frequency or probability at which a hazard occurs and the consequences of the hazard event

3.20

safety

freedom from unacceptable risk of harm

3.21

safety integrity

SI

probability of a safety-related system satisfactorily performing the required safety functions under all the stated conditions within a stated period of time

3.22

safety integrity level

SIL

one of four possible discrete levels for specifying the safety-integrity requirements of the safety functions to be allocated to the safety-related systems, SIL4 having the highest level of safety integrity, SIL1 the lowest

3.23**safety-related system****SRL**

system that

implements the required safety functions to achieve a safe state for the EUC or to maintain a safe state for the EUC; and

is intended to achieve, on its own, or with other safety-related systems, the necessary level of integrity for the implementation of the required safety functions

3.24**safety-related control system****SRCL**

system which carries out active control of the EUC and which has the potential, if not in accordance with its design intent, to enter an unsafe state

3.25**safety-related protection systems****SRPS**

designed to respond to conditions on the EUC, which may be hazardous in themselves, or if no action were taken, could give rise to hazardous events, and to generate the correct outputs to mitigate the hazardous consequences or prevent the hazardous events

3.26**safety requirements specification**

specification that contains all the requirements of the safety functions that have to be performed by the safety-related systems divided into

safety-functions requirement specification;

safety-integrity requirement specification

3.27**software**

intellectual creation comprising the programs, procedures, rules and any associated documentation pertaining to the operation of a data processing system

3.28**system**

set of components which interact according to a design. A component may be another system (a subsystem). Such components (subsystems) may be, depending on the level:

a controlling or controller system; and

hard, software, human interaction

3.29**systematic failure**

failure related in a deterministic way to a certain cause, which can only be eliminated by a modification of the design or of the manufacturing process, operational procedures, documentation or other relevant factors

[IEV 191-04-19]

3.30**system life cycle**

activities occurring during a period of time that starts when a system is conceived and ends when the system is no longer available

3.31

systematic safety integrity

IS

that part of the safety integrity of safety relating to systematic failures in a dangerous mode of failure

3.32

top event

unwanted event or incident at the “top” of a fault tree that is traced downward to more basic failures using logic gates to determine its causes and likelihood

3.33

validation

confirmation by examination and provision of objective evidence that the particular requirements for a specific intended use are fulfilled

3.34

verification

confirmation by examination and provision of objective evidence that the specified requirements have been fulfilled

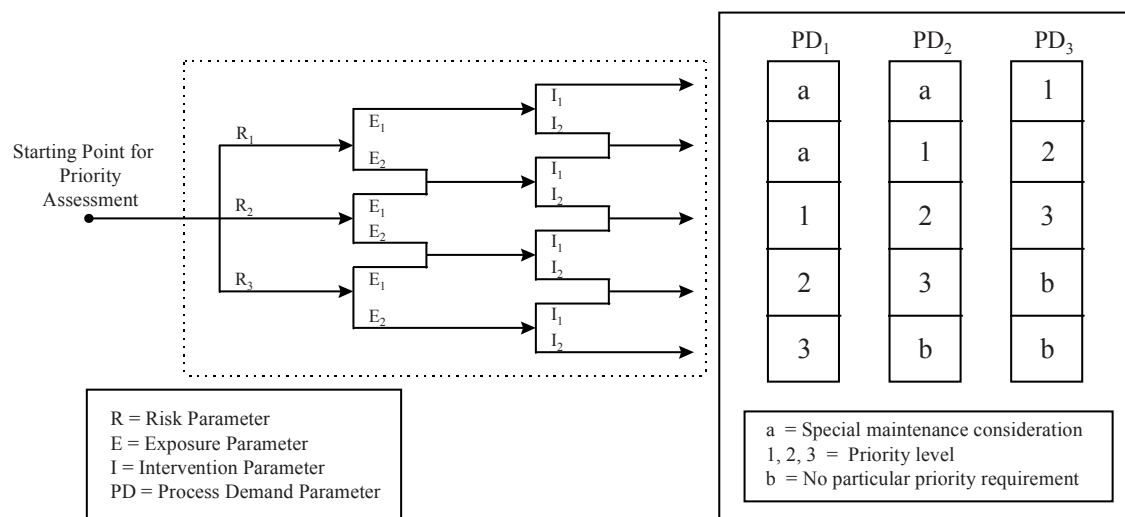
4 Classifying analysers using a risk-based approach

4.1 Introduction

Definition of on-line analysers as being related to the functional categories of safety, environmental, asset protection or profit maximization necessitates that the capability exists to determine the required priority for performance target-setting and maintenance direction of each instrument by designed functional category. This can be achieved using a risk graph, whereby the target category rating of an analyser is calculated on the basis of the required risk factor. The hazard rate of the event the analyser is designed to protect against (the so-called top event) and the consequence of the top event must be known.

The method takes the principle and general format of the risk graph approach for IEC 61508-5. However, as this technical report is aimed at analyser maintenance priorities, it must be noted that

- a) where analysers are part of a safety system, it is not an alternative approach to determining safety integrity levels (SILs) and where SILs demand certain proof-checking periods, duplication of analysers etc., these will take precedence;
- b) the ranking system adopted is in line with accepted analyser maintenance practice, i.e. the highest priority is 1 and the lowest priority is 3.



IEC 1685/05

Figure 2 – Risk graph

Using the generalized risk graph shown in Figure 2, each design functional category is considered in turn. The risk graph for each analyser function should be "calibrated". This is best achieved by defining the consequences for failures, then evaluating a number of scenarios. The exercise will establish if the outcome in terms of risk reduction is appropriate to the applications.

At the starting point of working through the risk graph towards priority setting, it is necessary to establish the initial element which is the risk parameter (R), i.e. the main area of impact associated with analyser failure, for example, plant damage, loss of profit, environmental damage, serious injury/loss of life. The second element is applied on judgements of importance of the analyser in keeping the plant running and is termed the exposure parameter (E), i.e. high risk of immediate/short-term damage, plant control scheme ability to function, environmental consent limitations or area sensitivity, frequency of exposure of personnel to hazard. The third element is the intervention parameter (I) which is an assessment of whether operator intervention can mitigate the impact of the failure or not. The graph then leads to the prioritization box which gives priority choice based on the process demand parameter (PD), i.e. the likelihood of the process requiring the measurement when a failure occurs

Table 1 summarizes a typical application of the elements in the risk graph, and explanatory notes are given in 4.1, 4.2, 4.3 and 4.4.

Table 1 – Application of the elements in the risk graph

	Safety	Environmental	Asset protection	Profit maximization
R1	Multiple fatalities on or off site	Release causing permanent damage or major clean-up costs	Damage with major replacement costs	Production profit margins high
R2	Fatality on or off site, injury (resulting in hospitalization to a member of public or staff)	Release causing temporary damage requiring significant clean-up	Damage with moderate replacement costs	Production profit margins medium
R3	Minor injury with lost time impact	Release with minor damage which should be recorded, or failure to record critical data	Damage with minor replacement costs or no damage	Production profit margins low

Table 1 (continued)

	Safety	Environmental	Asset protection	Profit maximization
E1	Frequency of exposure to the hazard is: more frequent to permanent	Consent restrictions and/or sensitive area	High risk of immediate/short-term damage	Control scheme cannot function
E2	Frequency of exposure to hazard is: rare to more often	No consent restrictions and/or non-sensitive area	Low risk of immediate/short-term damage	Control scheme can function in short term
I1	Unlikely that operator action will prevent or mitigate circumstances			
I2	Possible for operator to take action to prevent incident or to significantly reduce consequences where there is sufficient time and suitable facilities available			
PD1	Demand is frequent			
PD2	Demand occurs on an average basis			
PD3	Demand occurs very rarely			

4.2 Safety protection

IEC 61508 defines the requirements for E/E/PES devices in all safety related systems. This technical report does not seek to add to or modify the requirements of that standard in relation to a method for determining analyser priority on safety issues and takes the principle and general format of the risk-graph approach for IEC 61508-5. However, as this technical report is aimed at analyser maintenance priorities, it must be re-emphasized that the ranking system adopted is in line with accepted analyser maintenance practice, i.e. the highest priority is 1 and the lowest priority is 3

The following should be noted when considering the use of analytical instrumentation as measuring elements for safety-related systems.

The mean time between failure of analytical instrumentation is lower than standard instrumentation used in safety-related systems (pressure, temperature and flow measurements). This is especially true of complex analysers such as spectrometers and gas chromatographs.

Should analytical instrumentation be utilized in safety-related systems, duplex and triplex sensors, and frequent proof-checking would routinely be required to achieve the necessary on-line times. These should be determined in accordance with the procedures and rules laid down in IEC 61508 – the above risk-graph usage in this technical report is intended as a guide only to setting maintenance priority and is not intended as an alternative route to defining safety-integrity levels (SIL).

4.3 Environmental protection

Measurement of variables which impact directly on the environment are an increasingly important function of on-line analytical instrumentation. Data produced by environmental analysers may require submission to governmental bodies concerned with legal and procedural aspects of environmental monitoring.

There is significant diversity in the nature of the techniques. Traditional applications and methods are continuous air monitoring (CAM) and vent-emission monitoring by gas chromatography or electrochemical sensors, organics in aqueous effluent by total carbon (TC) and total oxygen demand (TOD), and acidity/basicity of aqueous effluent by electrochemical pH sensor. These are supplemented by more modern techniques such as air-quality monitoring by open-path spectrometry and elemental analysis by X-ray fluorescence.

Failure of the analyser to perform its specified function may lead to consequences R1, R2, or R3 depicted in Table 1. It should be noted that environmental analysers are often used to record data, but examples whereby analyser failure leads direct to consequential damage are far fewer.

An R1 consequence would be illustrated by the failure of a CAM system interlocked to process valves, the overall function of which would be to detect emission of chemicals and actuate the valves in order to contain the bulk of the process inventory.

An instance of an R2 consequence would typically be the result of a failure of an organics in aqueous effluent monitor to detect a high level, thus neglecting to divert the out-of-specification effluent for further treatment before release to the surrounding environment.

Typically, an R3 consequence would be an oxygen-analyser failure on a burner, leading to emission of partly combusted fuel; or the failure of a vent-gas composition analyser, with failure to record environmentally critical data.

The second element of the graph requires a determination to be made on the environmental status of the affected area.

Classification of an area as E2 would require the probability of causing harm to the populations in the affected area to be low. The potential to cause political as well as physical damage should be assessed. Should it be considered that the consequence of analyser failure has the potential to significantly affect populations in the affected area, that area should be classed as E1. Alternatively, if environmental consent limits are imposed by the authorities, this will determine whether route E1 or E2 should prevail.

The third element requests a determination as to the likelihood of an operator mitigating the consequences of analyser failure. The probability of operator intervention depends on the nature of the operator's intervention with the process. Where the operator is required to directly carry out actions as a consequence of the analyser's results, there will be a high probability of positive intervention. Automated systems, whereby the operator has no direct involvement in implementing process adjustment due to the measured variable, are more prone to unrevealed failure. Analyser failure diagnostics, and the facility given to the operator to mitigate the consequences of the failure by manual intervention (for example, grab sampling and laboratory analysis) should be considered when selecting I1 or I2.

The final element of the risk graph is a determination of how often a demand is placed by the process upon the analyser.

Process demands on the analyser are broadly classed as infrequent, average and frequent. Categorization of process demand is primarily the responsibility of the process engineer and not the analyser/instrument engineer.

Some examples of process demand, and frequency categorization are detailed as follows.

- PD1** A frequent demand – can typically be considered to be one significantly exceeding the single annual demand defined in PD2. The demand on either of the examples cited in R3 are almost perpetual (the need to record environmentally critical data is considered to place a continuous demand on the process).
- PD2** An average demand – can typically be considered to be a single demand placed upon a system on an annual basis. An example would be a high organic content in aqueous effluent occurring on an annual basis (see consequence R2, failure of an organics in aqueous effluent monitor to detect a high level, thus neglecting to divert the out-of-specification effluent for further treatment before release to the surrounding environment).

PD3 An infrequent event – can typically be illustrated by the demand rate placed upon a CAM system such as the one described in R1 (a CAM system interlocked to process valves, the overall function of which would be to detect emission of chemicals and actuate the valves in order to contain the bulk of the process inventory). Such systems are designed to detect emission of a large mass of airborne process material, an event, which, good process design should ensure, is infrequent.

4.4 Asset protection

Protection of assets is a need which can be provided in many instances by use of on-line analysers. Examples include oxygen analysers for the monitoring of inerting systems, conductivity analysers for monitoring the mineral content of condensed steam for turbine safety and moisture analysers for monitoring water level in feed stocks or pH measurement for corrosion reduction.

The initial element of the graph requires an estimate of the impact of the failure of the analyser.

The consequences of the loss of integrity of the asset protection analyser are generally of a more catastrophic nature and may have safety and environmental implications as well.

For example, failure of an oxygen analyser on an inerting system may cause an explosion leading to widespread damage to a process plant (as well as causing injury to personnel and the public, and loss of containment).

The second element of the graph requires a judgement on the likelihood of tolerance of the plant to the onset of the damage mechanism if analyser failure occurs.

Determination of damage risk should be determined by process dynamics or plant design (for example, corrosion allowances). In the example of an oxygen analyser monitoring an inerting system, any oxygen ingress may be potentially rapid risking an immediate danger (high-risk route on the graph) whilst on the other hand the space monitored may be under pressure and unlikely to allow oxygen ingress unless this pressure falls at the same time as the analyser failure. This case would allow other short-term monitoring to be put in place (low-risk route on the graph).

The third element requests a determination as to the likelihood of an operator mitigating the consequences of analyser failure. The possibility of this happening is strongly dependent on whether the operator normally represents a human element in a system.

In the example of a failure of an oxygen analyser monitoring an inerting system to send its signal to an emergency shutdown system (assuming that the failure of the analyser is unrevealed), the operator is unlikely to detect the analyser failure and thus action any corrective measures.

The final element of the risk graph is a determination of how often a demand is placed by the process upon the analyser.

Again referring to the example of the oxygen analyser, assuming that the analyser is monitoring an inerting system (and is not directly used in controlling the level of inert gas), the demand on the analyser (as a sub-component of an emergency shutdown system) would be expected to be low. This assumption can be justified by the fact that, under normal conditions, the control of the flow of inert gas into the process is controlled by simple devices, with low failure rates.

4.5 Profit maximization

Utilisation of analysers for maximization of profits is extremely common, applications being numerous and varied, for example, measurement of the concentration of the product of a reactor using infra-red spectrometry, with subsequent feedback control of reactor feeds to maintain a constant concentration in the product; or control of the take-off at the top of a distillation column with the aim of maintaining a constant concentration at a point within the column.

The initial element of the graph requires an estimate as to the likely impact of analyser failure.

The consequences of the loss of integrity of an analyser associated with profit maximization will depend on the size of margins being derived by the extra quality control given over simple process control of temperatures, pressures, levels and flows.

The importance of production losses should be determined by company policy, i.e. the graph should be calibrated on a process-by-process basis.

The second element of the graph requires a judgement on the ability of a control scheme to tolerate analyser failure. Analysers normally trim control set points or optimization models. More complex dynamic matrix control schemes may be unable to function at all without all inputs. Analyser failure can lead to loss of the whole automatic control scheme.

The third element requests a determination as to the likelihood of an operator mitigating the consequences of analyser failure. The possibility of this happening is strongly dependent on whether the operator normally represents a human element in a system.

Consider an analyser on a distillation column, the results of which are used for automatic control of the take-off at the top of a distillation column. By controlling the take-off rate, a constant concentration of the analyte of interest can be maintained at the sample point on the column. Should the operator be alerted to the failure of the analyser, for example, by a grab sample analysed in the QA laboratory, a regime of grab samples can be instigated, the results of which can be used for process control. The scenario is especially true of systems where equilibria change very slowly.

The final element of the risk graph is a determination of how often a demand is placed by the process upon the analyser.

The distillation analyser example can be considered as a case where the process places a constant (i.e. frequent) demand upon the analyser. An oxygen analyser used only during a process regeneration cycle carried out only a few times a year could be placed in the “demand occurs on an average basis” bracket.

4.6 Performance target

The risk graph analysis provides a method to classify analysers into category levels based on their application and importance to the application. Category levels enable the setting of realistic targets for process on-line analysers (availability and utilization) and also provide a basis upon which to prioritize support effort for routine maintenance and breakdown repair. This effectively helps to maximize analyser added value against support effort available.

Depending on the requirements within each functional category of the analysers, availability targets can be set against the categorization numbers derived by the method outlined in 4.1. Typically, based on industry-wide experience, these could be as shown in Table 2.

Table 2 – Performance

Category rating	Availability target %			
	Safety	Environmental	Asset	Profit
1	98	97	96	97
2	96	95	92	92
3	92	92	90	85
NOTE The availability targets are not calculated directly from the risk analysis but are quoted on what is considered to be best industry practice.				

4.7 Maintenance priority

For maintenance purposes, it is necessary to set proof-check frequencies which allow the performance targets in 4.2 to be met. This is achieved by considering the mean time to failure and mean time between failure of the analyser. For an analytical instrument with known MTTF and MTBF, the proof-check frequencies will need to be more frequent to achieve the higher reliabilities quoted for Category 1 analysers. When considering proof-check frequencies, the fault diagnostic tools available on the analyser should also be taken into account. These can be used to warn the user of analyser failure or, ideally, to alert the owner of impending failure. This can be taken into account when calculating the downtime of the analyser.

4.8 Support priority

For support purposes it is necessary to differentiate between the analyser categories to avoid conflict of priority; for example, which should be given priority: asset protection, profit maximization, environmental or safety and, if breakdowns occur in the same category, which takes precedence? Calculation of a category rating via a risk-based approach allows maintenance priorities to be set in a straightforward manner using the following rules.

Highest maintenance priority is given to the highest category analysers; for example, Category 1 will have priority over category 2.

Where two Category 1 analysers require maintenance support, the order of importance shall be determined in the functional category order: 1. safety, 2. environmental, 3. asset protection, 4. profit maximization

NOTE If a priority rating greater than 1, i.e. an 'a' on the risk graph in Clause 4, is found then the risk is too high for a solution with a single analyser and redundancy techniques are required. However, these analysers would, for maintenance purposes, be category 1 priority.

5 Maintenance strategies

5.1 Introduction

A key aim for any analyser maintenance function is to improve analyser system reliability and try to avert failure and, if failure does occur, minimize the impact of any failure. The mechanism involved to meet these aims is a combination of many facets and functions within an analyser support organization.

Management systems and organization, maintenance programmes, technician training and competency, optimization of resources through matching technician numbers to analyser work load and/or use of in-house against contracted-out maintenance, analyser monitoring using statistical control tools, optimizing maintenance strategy, and key performance indicator setting and review are all important parameters in achieving these aims.

Knowing where a maintenance organization stands in comparison to other sites is also a useful incentive for improvement. Benchmarking of best practices is another useful tool that can be applied.

5.2 Reliability centred maintenance (RCM)

RCM is an on-going process which determines the optimum mix of reactive, preventive, condition-based and proactive maintenance practices in order to provide the required reliability at the minimum cost, as shown below. The principal features of each strategy are shown below in their block. These maintenance strategies, rather than being applied independently, are integrated to take advantage of their respective strengths in order to optimize analyser efficiency within given constraints.

5.2.1 Reactive maintenance

Also referred to as breakdown maintenance, repair, fix when fail or run to failure.

Maintenance, equipment repair, or replacement occur only when the deterioration in the condition of an analyser causes a functional failure.

Assumes that failure is equally likely to occur in any part, component, or system.

The assumption precludes identifying a specific group of repair parts as being more necessary or desirable than others.

If the item fails and repair parts are not available, delays ensue while parts are obtained.

If certain parts are urgently needed to restore a critical analyser to operation, a premium for expedited delivery must be paid.

There is no ability to influence when the failures occur because no action is taken to control or prevent them.

When this is the sole type of maintenance practice, there is a high percentage of unplanned maintenance activities; high replacement part inventories and inefficient use of maintenance effort typify this strategy

A purely reactive maintenance programme ignores the many opportunities to influence analyser reliability.

5.2.2 Preventative or planned maintenance

Consists of regularly scheduled inspection, adjustments, cleaning, lubrication, parts replacement, calibration, and repair of components and equipment.

Referred to as time-driven or interval-based maintenance.

It is performed without regard to equipment condition.

Schedules periodic inspection and maintenance at pre-determined intervals (time, operating hours, or cycles) in an attempt to reduce analyser failures.

Depending on the intervals set, PM can result in a significant increase in inspections and routine maintenance.

It should also reduce the frequency and seriousness of unplanned analyser failures for components with defined, age-related wear-out patterns; however, replacement components can introduce an additional risk of failure during the initial life of the component (bath-tub curve effect on failure rates).

Traditional PM is keyed to failure rates and times between failures.

It assumes that these variables can be determined statistically, and therefore one can replace a part due for failure before it fails.

Statistical failure information leads to fixed schedules for the overhaul of analysers or the replacements of parts subject to wear.

Failure rate or its reciprocal, mean time between failures (MTBF), is often used as a guide to establishing the interval at which the maintenance task should be performed.

Weakness in using these measurements to establish task frequency is that failure rate data determines only the average failure rate.

The reality is that failures are equally likely to occur at random times and with a frequency unrelated to the average failure rate.

Thus, selecting a specific time to conduct periodic maintenance for a component with a random failure is difficult at best.

PM is not for random-failure analyser components

5.2.3 Condition-based strategy

Also known as predictive maintenance, uses primarily SPC calibration/validation techniques, visual inspection, and data comparison, trend data to assess analyser condition.

Replaces arbitrarily timed maintenance tasks with maintenance that is scheduled only when warranted by the condition of the analyser.

Continuing analysis of analyser condition-monitoring data allows planning and scheduling of maintenance or repairs in advance of breakdown.

Condition-based data collected is used in one of the following ways to determine the condition of the analyser and identify the precursors of failure. The methods include

- a) tests against limits and ranges (SQC);
- b) data comparison;
- c) trend analysis;
- d) correlation of multiple technologies (expert system).

5.2.4 Proactive maintenance

This employs the following basic techniques to extend analyser life:

- specifications for new analyser sampling system (FEL);
- precision rebuild and installation;
- analyser systems require proper installation to control life-cycle costs and maximize reliability;
- failed-part analysis;
- root-cause failure analysis;
- reliability engineering (design changes);
- age exploration;
- failure mode and effects (FMEA).

5.2.4.1 Proactive maintenance

Proactive maintenance has the following characteristics.

Using feedback and communications to ensure that changes in design or procedures are rapidly made available to analyser technicians.

Employing a life-cycle view of maintenance and supporting functions.

Employing a continuous process of improvement.

Optimizing and tailoring maintenance techniques and technologies to each analyser application.

Using root-cause analysis and predictive analysis to maximize maintenance effectiveness.

Finding the cause of the problem quickly, efficiently and economically.

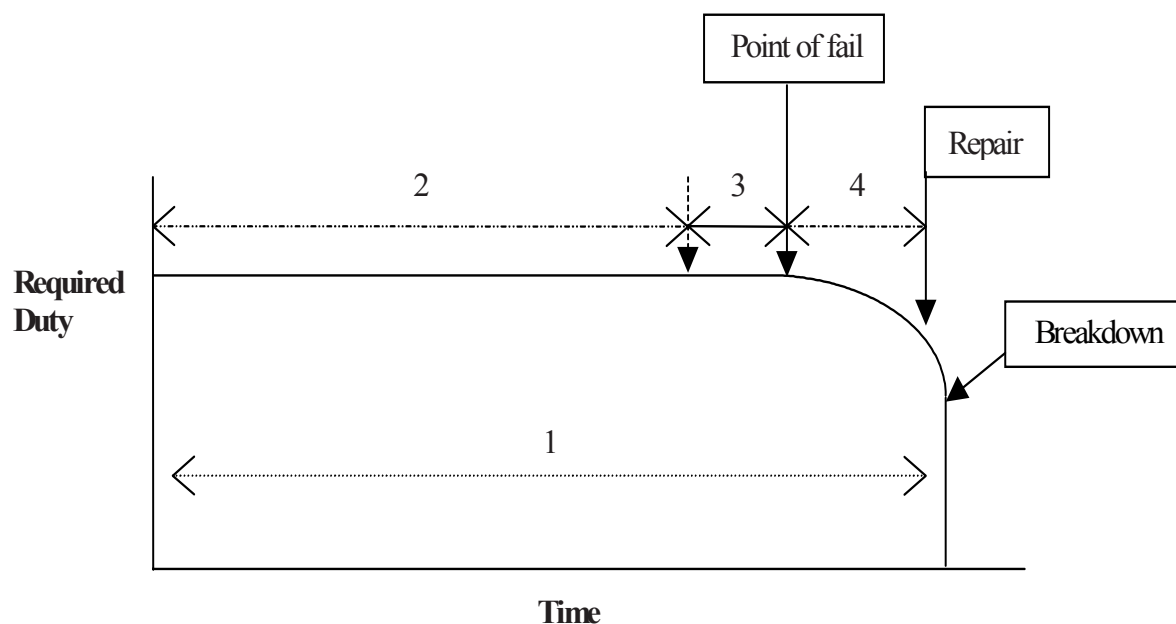
Correcting root cause of the problem, not just working on its symptoms.

Providing a system that will prevent the problem recurring.

A proactive maintenance programme is the keystone of the RCM philosophy.

5.2.5 Optimizing maintenance strategy

With reference to the concepts of RCM introduced in 5.2 an optimum maintenance strategy can be adopted, as shown in Figure 3, commensurate with the failure-mode pattern.



IEC 1686/05

Figure 3 – Maintenance strategy

- 1 A thorough daily inspection should be made to identify little problems and prevent them from growing into big problems. These daily inspections must be more than just an operator recording instrument readings. A trained, dedicated crew that performs a thorough visual inspection will minimize the likelihood of minor problems developing into major reliability issues. Additionally, minor problems can usually be corrected with basic tools allowing maintenance activities to be performed as part of the inspection activities. When minor problems are allowed to become reliability issues, the result is often unacceptably high in the form of reduced uptime, productivity, yield and quality and higher cost for maintenance including the possibility of increased capital cost for replacements. Daily checking is maintained throughout the life of the analyser; practical experience will allow the frequency to change, but it must be reverted to if there is a personnel change.
- 2 During this period, SPC with verification checks is used to maintain the accuracy of the analyser, the frequency of checks dictated by the control chart and operator confidence (for example, if the analyser is on sentinel duty).
- 3 Time-based PM kicks in condition-based maintenance (period determined by expected life, experience, etc.). This may mean increased verification/calibration checks to determine the point of fail which is expected in the near future, all data still under SPC.
- 4 This is where the calibration parameters are monitored (if available) to determine and plan the optimum time for repair.

The ultimate goal is for the majority of maintenance to be in the condition-based and proactive-based modes.

Appendix 4 gives an example of a flow chart to assist in decisions on which maintenance strategy is most suited to which analyser system.