

**THE ENGINEERING EQUIPMENT AND MATERIALS USERS' ASSOCIATION**

# **Analyser systems A guide to maintenance management**

**PUBLICATION 187**

**Edition 2**

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## Preface

EEMUA 187 is a publication designed to define 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 maximisation.

Maintenance organisation, prioritising 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 Publication gives guidance on performance target setting, strategies to improve reliability, methods to measure effective performance, and the organisations, resources and systems that need to be in place to allow this to occur.

The various subjects covered in this Publication are discrete items and can appear unrelated in the overall scheme of analyser maintenance procedures and strategies. The following flow path in Figure 1 ties the Chapters together in a logical sequence of approach.

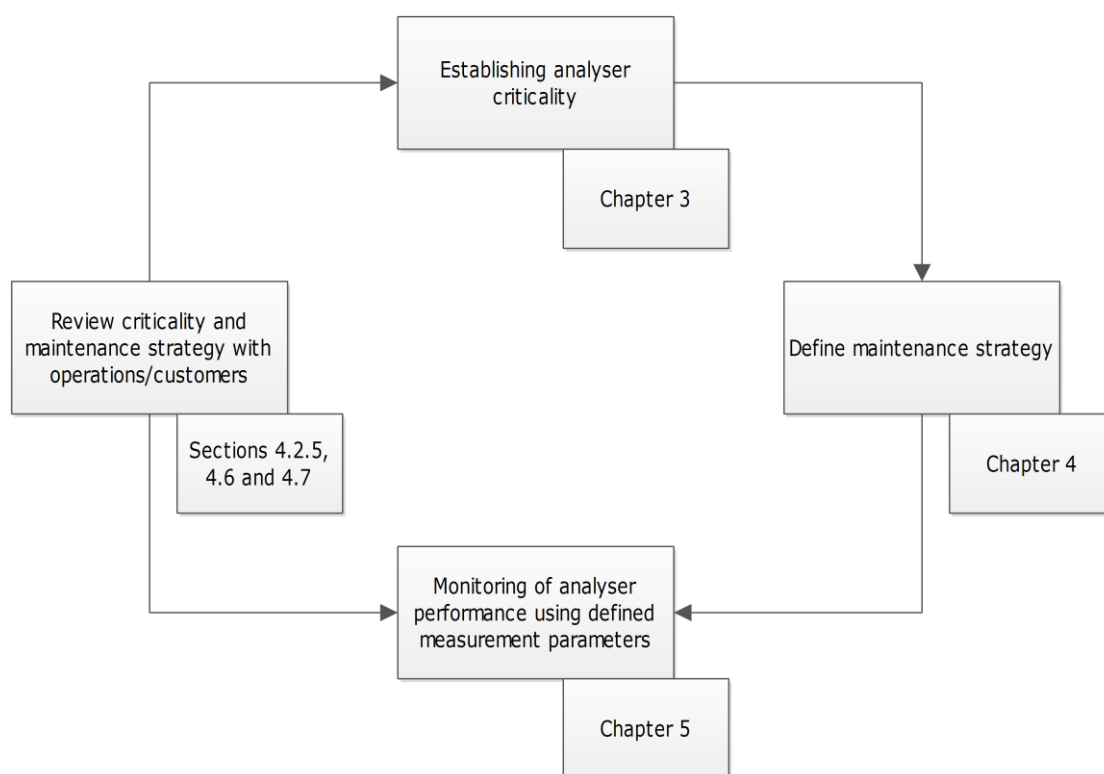


**Figure 1 Flow path detailing interrelationships of subject matter in EEMUA Publication 187**

This Publication provides a mechanism by which the criticality of an analyser can be determined by means of a risk assessment. The risk assessment is based on 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 prioritisation for maintenance and support. Such approaches are covered in Chapter 3.

A numbers strategy designed to allow the target reliabilities calculated by the risk assessments to be met are defined in Chapter 4.

Finally, mechanisms for tracking analyser performance and quantifying the performance as meaningful measures are presented in Chapter 5.

# 1. Introduction

## 1.1 Purpose of this Publication

This Publication 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 organisations, 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 the following reasons:

- **Safety and environmental.** One category of on-line analyser is 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 maximisation, the contribution will be dependent upon ability to perform its functional requirements on demand.
- **Asset protection and profit maximisation.** On-line analysers falling into this category are normally those impacting directly on process control. They may impact directly on protection of assets (e.g. corrosion, catalyst contamination, etc.) or product quality, or may be used to optimise the operation of the process (e.g. 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. It should be noted that the contribution of the analyser to reduction in 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 Publication focuses on the cost/benefits associated with traditional analyser maintenance organisations. Due to the complexity of modern analysers, support may be required from laboratory or product quality specialists, e.g. for chemometric models, who may work for other parts of the organisation. Their costs also need to be included in the overall maintenance cost.

## 1.2 Questions to be addressed

When considering on-line analyser systems and their maintenance the following key points list is useful in helping decide where gaps exist in the maintenance strategy.

.

- **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?
- **What is the value delivered by each analyser in terms of process performance improvement (i.e. improved yield values, improved quality, improved manufacturing cycle time and/or process cycle time, process safety (e.g. interlocks), environmental importance)?** Is this information readily available and agreed to in meetings with operations? Is the value updated periodically?
- **What is the utilisation 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 operator's views about the plausibility of the analyser data?
- **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 (SPC) 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?
- **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 lab measurements which relate to the analyser results?
- **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?
- **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?
- **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?**

- **Do you meet regularly with operations personnel to review analyser performance, update priorities, and understand production goals?**
- **Do you have a management framework that understands the value of the analysers and are committed to and supportive of reliable analysers?**
- **Do you know how much the maintenance programme costs each year and is there a 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, in order to improve plant operation versus world class manufacturing metrics to become the best process analysers possible.



## 2. Definitions

The following glossary aims to add further definition to the terms used in the text in the context of their use when describing activities associated with analyser systems. Similar words or phrases are listed with a common description.

**Availability (IEV (International Electrotechnical Vocabulary<sup>(1)</sup>) Number: 191-02-05).** The 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.

**Catastrophic failure.** The 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.

**Consequence.** A measure of the expected effects of an incident outcome case.

**Control system.** A system which responds to input signals from the process and/or from an operator and generates signals causing the Equipment Under Control (EUC) to operate in the desired manner.

**Diversity.** The performance of the same overall function by a number of independent and different means.

**Error / Failure / Fault / Mistake.** Definitions for these terms are given below.

- **Error (IEV 191-05-24).** A discrepancy between a computed, observed or measured value or condition and the true, specified or theoretically correct value or condition.
- **Failure (IEV 191-04-01).** The termination of an item to perform a required function.
- **Fault (IEV 191-05-01).** The 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.
- **Design fault:** A 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.
- **Undetected fault.** A fault which is not detected by a diagnostic check.
- **Mistake/human error (IEV 191-05-25).** A human action that produces an unintended result.

**EUC.** Equipment Under Control.

**Failed state.** The condition of a component, equipment or system during the time it is subject to a failure.

**Fault tree analysis (IEV 191-16-05).** An analysis to determine which fault modes of the sub-items or external events, or combinations thereof, may result in a stated fault mode of the item, presented in the form of a fault tree.

**Functional safety.** The 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.

**Hazard.** A physical situation with a potential for human injury.

**Maintainability (IEV 191-02-07).** The 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.

**Mean Time Between Failures (MTBF) (IEV 191-12-09).** The expectation of the operating time between failures.

**Mean Time to Failure (MTTF) (IEV 191-12-07).** The expectation of the time to failure.

**Mean Time to Repair (MTTR) (IEV 191-13-08).** The expectation of the time to restoration.

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

**Random hardware failure.** Failure occurring at a random time, which results from one or more of the possible degradation mechanisms 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.*

**Redundancy (IEV 191-15-01).** In an item, the existence of more than one means for performing a required function.

**Reliability (IEV 191-12-01).** The probability that an item will perform a required function under given conditions for a given time interval.

**Risk.** Risk is defined as 'the 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.

**Safety.** Freedom from unacceptable risk of harm.

**Safety Integrity (SI).** The probability of a safety related system satisfactorily performing the required safety functions under all the stated conditions within a stated period of time.

**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. SIL 4 has the highest level of safety integrity; SIL 1 has the lowest.

**Safety-related system.** A system that:

- Implements the required safety functions to achieve a safe state for the EUC or to maintain a safe state for the EUC.
- 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.

**Safety-related control system.** A 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.

**Safety-Related Protection Systems (SRPS).** Designed to respond to conditions on the EUC, which may also be hazardous, or if no action was taken, could give rise to hazardous events, and to generate the correct outputs to mitigate the hazardous consequences or prevent the hazardous events.

**Safety requirements specification.** The specification that contains all the requirements of the safety functions that have to be performed by the safety-related systems. The specification is divided into:

- Safety functions requirement specification.
- Safety integrity requirement specification.

**Software.** Intellectual creation comprising the programmes, procedures, rules and any associated documentation pertaining to the operation of a data processing system.

**System.** A system is defined to consist of a 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.
- hardware, software, human interaction.

**Systematic failures (IEV 191-04-19).** A 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.

**System life cycle.** The activities occurring during a period of time that starts when a system is conceived and ends when the system is no longer available.

**Top event.** The 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.

**Validation.** Confirmation by examination and provision of objective evidence that the particular requirements for a specific intended use are fulfilled.

**Verification.** Confirmation by examination and provision of objective evidence that the specified requirements have been fulfilled.

### 3. Classifying analysers using a risk based approach

Defining on-line analysers as being related to the functional categories of safety, environmental, asset protection or profit maximisation 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 based upon 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 (International Electrotechnical Commission) 61508-5<sup>(2)</sup>. However as this Publication is aimed at analyser maintenance priorities it must be noted that:

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

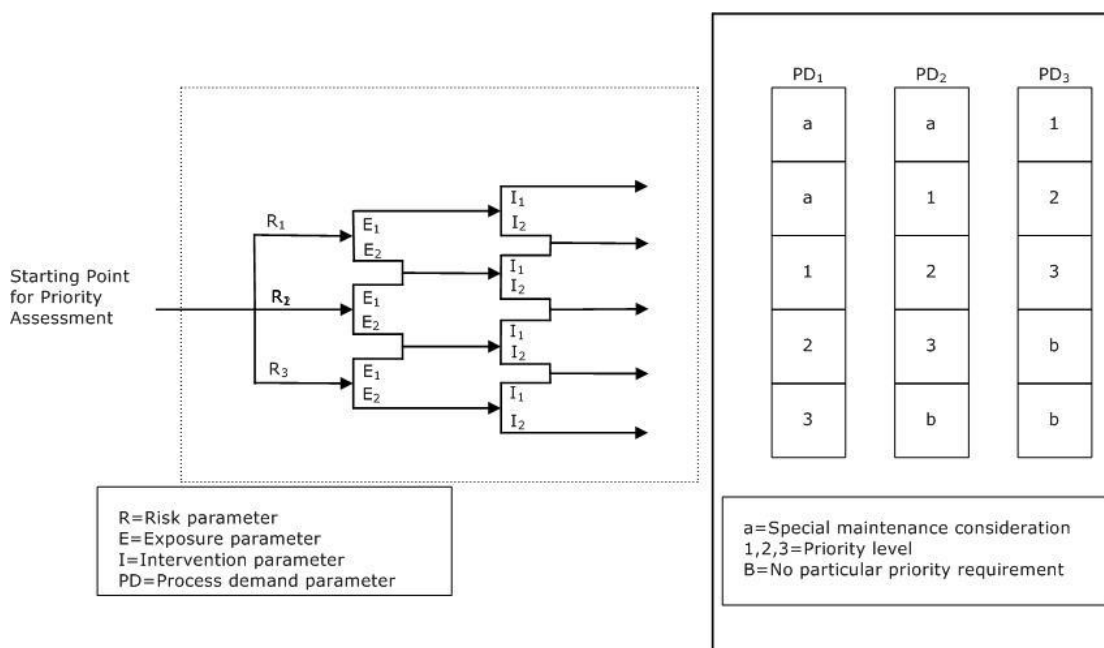


**Figure 2 Generalized risk graph**

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, e.g. plant damage, loss

of profit, environmental damage, and 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), e.g. high risk of immediate/short term damage, plant control scheme ability to function, environmental consent limitations, area sensitivity, or 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 prioritisation 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. The following table summarises a typical application of elements in the risk graph and explanatory notes are given in Sections 3.1, 3.2, 3.3 and 3.4.

**Table 1: Typical application of elements in the risk graph**

|                 | <b>Safety</b>                                                                                                                                                     | <b>Environmental</b>                                                                   | <b>Asset Protection</b>                          | <b>Profit Maximisation</b>                |
|-----------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------|--------------------------------------------------|-------------------------------------------|
| R <sub>1</sub>  | Multiple fatalities on or off site                                                                                                                                | Release causing permanent damage or major clean-up costs                               | Damage with major replacement costs              | Production profit margins high            |
| R <sub>2</sub>  | Fatality on or off site, injury (resulting in hospitalisation to a member of public or staff)                                                                     | Release causing temporary damage requiring significant clean-up                        | Damage with moderate replacement costs           | Production profit margins medium          |
| R <sub>3</sub>  | 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             |
| E <sub>1</sub>  | 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            |
| E <sub>2</sub>  | 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 |
| I <sub>1</sub>  | Unlikely that operator action will prevent or mitigate circumstances                                                                                              |                                                                                        |                                                  |                                           |
| I <sub>2</sub>  | Possible for operator to take action to prevent incident or to significantly reduce consequences where there is sufficient time and suitable facilities available |                                                                                        |                                                  |                                           |
| PD <sub>1</sub> | Demand is frequent                                                                                                                                                |                                                                                        |                                                  |                                           |
| PD <sub>2</sub> | Demand occurs on an average basis                                                                                                                                 |                                                                                        |                                                  |                                           |
| PD <sub>3</sub> | Demand occurs very rarely                                                                                                                                         |                                                                                        |                                                  |                                           |

### 3.1 Safety protection

IEC 61508 'Functional Safety: Safety Related Systems' defines the requirements for devices in all safety related systems. **Although this Publication is aimed at analyser maintenance priorities any safety-related analysers should have their maintenance and testing requirements determined using IEC 61508.**

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

The mean time between failures 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 utilised 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 procedures and rules laid down in IEC 61508. The above risk graph usage in this Publication is intended as a guide only to setting maintenance priority and is not intended as an alternative route to defining safety integrity levels (SIL's).

### 3.2 Environmental protection

The measurement of variables that 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  $R_1$ ,  $R_2$ , or  $R_3$  depicted in Table 1. It should be noted that environmental analysers are often used to record data but examples whereby analyser failure directly leads to consequential damage are far fewer.

An  $R_1$  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  $R_2$  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  $R_3$  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 Table 1 requires a determination to be made on the environmental status of the affected area.

Classification of an area as  $E_2$  would require the probability of causing harm to 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  $E_1$ . Alternatively, if environmental consent limits are imposed by the authorities, this will determine whether route  $E_1$  or  $E_2$  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, e.g. grab sampling and laboratory analysis, should be considered when selecting  $I_1$  or  $I_2$ .

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. Categorisation of process demand is primarily the responsibility of the process engineer, and not the analyser/instrument engineer.

Some examples of process demand and frequency categorisation are detailed as follows:

- **PD<sub>1</sub>**, a frequent demand can typically be considered to be one significantly exceeding the single annual demand defined in  $PD_2$ . The demand on either of the examples cited in  $R_3$  are almost perpetual (the need to record environmentally critical data is considered to place a continuous demand on the process).
- **PD<sub>2</sub>**, 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  $R_2$ , 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).
- **PD<sub>3</sub>**, an infrequent event, can typically be illustrated by the demand rate placed upon a CAM system such as the one described in  $R_1$  (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.

### 3.3 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 risk 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 (e.g. 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 sending 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.

### 3.4 Profit maximisation

Utilisation of analysers for maximisation of profits is extremely common, applications being numerous and varied, e.g. 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 maximisation 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 optimisation 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 analyser of interest can be maintained at the sample point on the column. Should the operator be alerted to the failure of the analyser, e.g. 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.

### 3.5 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 utilisation) and it also provides a basis upon which to prioritise support effort for routine maintenance and breakdown repair. This effectively helps to maximise analyser added value against support effort available. It may be necessary to use multiple analysers to reach the required performance target.

Depending on requirements within each functional category of the analysers, availability targets can be set against the categorisation numbers derived by the method outlined in Sections 3.2, 3.3 and 3.4. This is typical, based on industry wide experience; and examples follow in Table 2.

**Table 2 Best practice availability targets**

| Availability target (%) |        |               |       |        |
|-------------------------|--------|---------------|-------|--------|
| Category rating         | 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.*

### 3.6 Maintenance priority

For maintenance purposes it is necessary to set proof check frequencies which allow the performance targets in Section 3.5 to be met. This is achieved by considering the mean time to failure and mean time between failures 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 analyser's downtime.

### 3.7 Support priority

For support purposes it is necessary to differentiate between the analyser categories to avoid conflict of priority, e.g. which should be given priority; asset protection, profit maximisation, 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 straight forward manner using the following rules:

- Highest maintenance priority is given to the highest category analysers, e.g. 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 Maximisation.

*Note: If a priority rating greater than 1, i.e. an 'a' on the risk graph in Section 3, 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.*



## 4. Maintenance strategies

### 4.1 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, to minimise the impact of any failure. The mechanism involved to meet these aims is a combination of many facets and functions within an analyser support organisation.

Important parameters in achieving the above aims include: management systems and organisation; maintenance programs; technician training and competency; optimisation 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; optimising maintenance strategy; and key performance indicator setting and review.

Knowing where a maintenance organisation 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.

### 4.2 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 in their block. These maintenance strategies, rather than being applied independently, are integrated to take advantage of their respective strengths in order to optimise analyser efficiency within given constraints.

#### 4.2.1 Reactive maintenance

- Reactive maintenance is also referred to as breakdown maintenance, repair, fix when fail or run to failure.
- Maintenance, equipment repair, or replacement occurs only when the deterioration in an analyser's condition 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 an 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 are a high percentage of unplanned maintenance activities, high replacement part inventories, and inefficient use of maintenance effort.
- A purely reactive maintenance program ignores the many opportunities to influence analyser reliability.

#### 4.2.2 Preventative or Planned Maintenance (PM)

- Preventative or Planned Maintenance (PM) 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 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.

#### 4.2.3 Condition based strategy

- Also known as predictive maintenance, condition based strategy uses primarily Statistical Process Control (SPC) calibration/validation techniques, visual inspection, data comparison and trend data to assess analyser condition.
- Replaces arbitrarily timed maintenance tasks with maintenance that is scheduled only when warranted by the analyser's condition.
- 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:
  - Tests against limits and ranges (SQC).
  - Data comparison.
  - Trend analysis.
  - Correlation of multiple technologies (expert system).