

THE ENGINEERING EQUIPMENT AND MATERIALS USERS ASSOCIATION

Guide to the development and implementation of on-line analyser applications

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ENGINEERING EQUIPMENT AND MATERIALS USERS ASSOCIATION

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1. Introduction

This EEMUA Publication is intended as a guide for non-analyser specialists to assist in the development and implementation of on-line analyser applications. It covers how to determine if an on-line process analyser is justified and provides details of the information required to ensure the analyser is correctly selected, purchased, installed and maintained.

The intended users and uses of this Publication are:

- Companies with little or no experience in applying on-line analysers;
- Companies who do not have experienced on-line analyser specialists;
- Instrument engineers with limited experience with on-line analyser systems;
- Vendors, to better understand how end users apply analysers;
- To help ensure analyser systems integrators are correctly specifying on-line analysers; and
- To help ensure analysers in process package systems are correctly specified and installed.

This Publication is not intended to cover:

- Detailed analyser system design and installation guidelines - refer to *EEMUA Publication 138 Design and installation of on-line analyser systems*⁽¹⁾;
- Detailed procurement and bid evaluation guidelines - refer to *EEMUA Publication 226 Design and installation of on-line analyser systems: Guide to technical enquiry and bid evaluation*⁽²⁾;
- Guidelines for analyser maintenance - refer to *EEMUA Publication 187 Analyser Systems: Guide to maintenance management*⁽³⁾; or
- Guidelines for analyser calibration and validation – refer to *EEMUA Publication 175 EEMUA Code of Practice for the calibration and validation of process analysers*⁽⁴⁾.

2. Justification

2.1 Why use on-line analysers?

Modern chemical industries including pharmaceutical, fine chemicals, petrochemical and food manufacturing require real time optimisation and control of the manufacturing process to produce the maximum economic benefit and efficiency to ensure survival in a competitive global arena. This, together with the need to minimise manning levels from both a process and analytical perspective, whilst still ensuring product quality and compliance with all safety and environmental regulations are all drivers towards the use of on-line process analysers.

However on-line analysers are expensive to install and maintain. Therefore they should only be installed if there is a well-defined cost benefit or for safety, health and environmental reasons. Examples include providing a layer of protection and safety for plant personnel and assets, to monitor and warn of possible pollution concerns, and to monitor and alert personnel to hazardous environments.

From a process and product quality control standpoint, the use of analysers contributes to an increase in profit. This can be achieved by controlling the process to optimize the use of raw materials, reduce or eliminate waste, increase energy efficiency, increase the proportion of value-added components in products or intermediate streams, to ensure on-specification products with the minimum product quality give-away, and if possible to certify product for shipment or sale.

This is achieved because analysers provide frequent (continuous or cyclic) analytical information on key process analytical properties which allows rapid continuous control and optimisation of the process, including identification and correction of off-specification product or undesirable operating conditions. Analyser precision is also usually better than the laboratory reference method, allowing closer targeting to specification. Some of the pros and cons of on-line analysers versus off-line laboratory analyses are summarised in Table 1.

Table 1 On-line versus off-line analysis

OFF-LINE	ON-LINE
Measurement is made under optimum laboratory conditions. Laboratory procedures must be followed correctly.	Sampling and measurement is automatic (expect repeatable results).
A manual sample needs to be taken by plant personnel: • May be hazardous; • Sample may not be taken correctly; • Sample quality may change during sampling, transport to the laboratory and during transfer to the laboratory apparatus, e.g. loss of light ends.	Sample remains enclosed. This reduces hazardous emissions and no loss of sample.
Cannot be used directly for continuous automatic control.	Minimum time delay. Can be used directly in automatic control loops and applications.
Need a laboratory technician to analyse sample - may not be available out of hours.	Available 24hrs/day.
Can be time consuming.	Requires sample conditioning. Compromise between good sample conditioning and minimum time delay.
Trained laboratory technicians are required.	Trained analyser maintenance technicians are required.
	Set up may vary for different plant conditions.

In all cases, the on-line analyser benefits should be reviewed on a regular basis to ensure they are still justified.

Potential alternatives to on-line analysers if suitable laboratory support is not available or not available 24 hours/day are at-line analysis, portable analysers or inferential control models.

At-line analysis involves plant operators taking manual samples and making a manual analysis in suitable analytical equipment located in the plant area. There may be cost savings in only having slightly modified laboratory apparatus rather than a custom fully automated on-line analyser. However, at-line analyses cannot be used directly for continuous automatic control; manual samples (with the associated disadvantages given in the table above) still need to be taken. Consideration must also be given to the safe operation and a suitable operating environment for the at-line analytical equipment, e.g. operation in areas with potentially flammable atmospheres and the need for suitable weather protection and temperature controlled enclosures.

Portable analysers are normally limited to a few simple measurements, e.g. gaseous oxygen, water conductivity and pH etc. They must be suitable for the environment and area classification where they will be used. Also, portable analysers cannot be used directly for continuous automatic control and still require suitable process sample points and sample conditioning.

Inferential control models predict the required analytical property based on other routine continuous process measurements, e.g. flow, level, pressure, temperature etc. The models are developed using the results of a series of manual laboratory samples

analysed for the property of interest and the associated process variables at the time each sample is taken. The modelling techniques used can range from simple linear regression to advanced neural networks. The development, validation and on-going maintenance of inferential models requires specialist knowledge and support so should only be considered where this specialist support is locally available. The precision level of the inferential model is normally not as high as the precision level of the equivalent on-line analyser, and in many cases it may not even be possible to develop practical usable models. Inferential models are normally only useful when there is little or no variation in the quality of the plant feed.

2.2 Overview of typical analyser installations

There are three main categories of analyser:

- **Safety analysers:** These include personal safety monitors, plant area and building toxic and flammable gas detectors, e.g. LEL, hydrogen sulphide, carbon monoxide, chlorine, hydrogen fluoride and oxygen deficiency. Process analysers can also be used as inputs to process protective instrument (emergency shutdown) systems. However using process analysers as inputs to process plant protective instrument systems should be avoided if possible as the analysers may need to be duplicated or triplicated to achieve the required availability. It is preferable to use conventional instruments (flow, level, pressure, temperature, vibration) wherever possible or to use other mitigations e.g. relief valves.
- **Environmental monitoring analysers:** These typically measure discharged water quality and stack emissions to the atmosphere, e.g. pH, conductivity, dissolved oxygen, chemical oxygen demand and turbidity for water and SO_x/NO_x, CO, particulates and hydrocarbons for stack gases.
- **Process optimisation (profit) analysers:** These measure process chemical composition, e.g. specific hydrocarbons, oxygen, CO, hydrogen sulphide, total sulphur; or process physical properties, e.g. viscosity, density, distillation point, flashpoint for product quality control and release.

The main elements of an on-line process analyser system are as follows:

- **Sample point or tap:** connection where sample is taken from process.
- **Sample probe:** a probe inserted into the process line to ensure a representative sample is taken.
- **Sample transport lines (fast loop):** the sample take-off and return lines between the process and the analyser system to bring sample to the analyser within the required response time and to return sample to the process wherever possible.
- **Sample conditioning system:** brings sample to conditions required for input to the analyser, e.g. pressure, temperature, flow, filtration and coalescing.
- **Sample recovery system:** used to return low pressure liquid sample to the process that cannot be returned directly via the fast loop.
- **Analyser enclosure:** house, shelter or cabinet used to provide weather protection and the correct environmental conditions to ensure the required analyser performance (reliability and precision) is achieved.
- **Validation and calibration system:** components required to check analyser performance against a known reference (standard) and recalibrate the analyser when necessary.
- **Manual sample point:** facilities in sample system (or directly at process line) to take a cross reference manual laboratory sample in a safe and representative way.

A typical on-line analyser installation is shown in Figure 1:

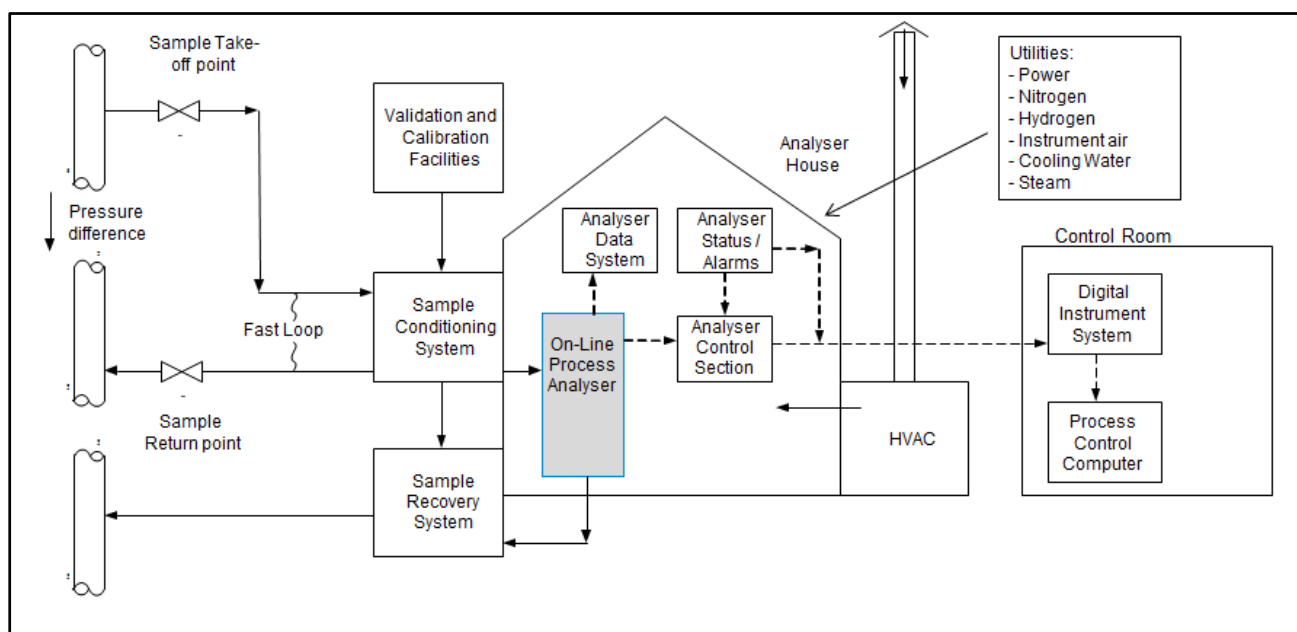


Figure 1 Typical analyser installation

2.3 Defining the business need

The business need is normally straightforward; for process optimisation (profit) type analysers it requires the development of a business case where the initial project installation costs plus the ongoing maintenance and running costs are more than covered by the value (payback) the analyser delivers versus the alternatives (e.g. no analyser, routine laboratory results etc.). Most companies' internal business procedures have some minimum hurdle (return on investment) that must be met before proceeding with a project. This is often measured in terms of discounted cash flow (DCF).

There are various mechanisms that contribute to the profit type analyser payback which will be industry and site specific. Some examples are:

- Reducing product quality giveaway – using the analyser to control the process or blending closer to the final product quality specification;
- Avoiding product quality incidents – using the analyser to ensure off specification product is not manufactured or released;
- Optimising yield of higher value products or intermediate streams;
- Minimising product degradation and reprocessing costs;
- Improving energy efficiency of boilers, furnaces, distillation columns and reactors;
- Controlling and optimising conversion in reactors; or
- Controlling products and intermediate streams for purity and breakthrough or reduction of impurities.

One important point is that profit type analysers usually only achieve their payback if they are used in some kind of automatic control system or application. Analysers that are installed for "monitoring" purposes rarely achieve the full payback if they require manual intervention by operators to capture the payback as it is often counter intuitive to make changes to a stable process even if it is not optimised.

The business justification for safety and environmental analysers is different as in many cases these can be non-discretionary, e.g. required by regulations or legislation, or because there is no alternative to adequately ensure safety of plant personnel.

Safety analysers are normally installed as a result of a risk analysis. They are used to mitigate a risk from a higher unacceptable risk category to a lower acceptable risk category. The value of a safety analyser can be measured as a reduction in ISO safety units if this approach is used at a site.

Environmental analysers are generally installed because they are required by regulations, e.g. European Industrial Emissions Directive⁽⁵⁾ or as part of the plant operating permit. There can be a quantifiable financial impact if there are fines, if the plant must be shut down if there are no analysers installed, or when the analysers are not in operation. Environmental analysers can also be used to help avoid fines or bad publicity due to exceeding permissible emission levels of certain pollutants. In this case a company may decide to install the analysers as part of their own internal environmental policies anyway.

The guidelines given in this Publication for developing analyser projects should all still be applied to safety and environmental analysers other than developing the specific financial (profit) incentives where this is not applicable.

2.4 How to estimate potential payback (profit type analysers)

2.4.1 Analyser economics and payback justification

This section includes a description and some typical examples of the basis for profit type analyser payback calculations. Knowledge of plant process costs and product values are required. This cost information will come normally from the company business planning or internal accounting groups.

As discussed above, profit type analysers can add value in the areas of process optimization, product quality and yield efficiency maximisation. However, analysers also have ongoing operational costs as well as their initial purchase cost. Therefore the analyser validation/calibration, utility and maintenance costs need to be factored into payback calculations. The approaches described in literature vary from simple scenarios to complex formulae. In most cases drilling down into more details from the simple economic relationship:

$$PROFIT[P] = INCOME[I] - COSTS[C]$$

Where $[I]$ is the selling price for the products produced and $[C]$ is production costs, i.e. cost of plant and feedstock, energy and utility costs plus the added analyser purchase and maintenance costs.

If $[P]$ is greater with an analyser than for alternative methods e.g. routine laboratory analyses then justification for purchasing the analyser exists. In reality the solution is more complex involving factors such as variable product prices and utility/feedstock costs.

An example of this would be the purity of an overhead take off product from a distillation tower. In this case, the higher purity of the overhead results in a lower loss of product to the bottom stream but the associated increased reflux ratio requires greater energy costs. If improvements in the target product purity based on the volume produced are significantly greater than the increased energy costs then an on-line analyser can be justified.

Example basis for product upgrade (or prevention of downgrade):

$$\text{Annual Payback} = [F] \times [D] \times [V] \times [Y] \times [A] + [LC] - [M] - [AUC] - [PUC]$$

Where:

[F]	=	Expected totalised volume of stream per year with analyser control
[D]	=	Delta value of upgraded product - base product per unit volume
[V]	=	Percentage of additional (or reduction if minimising loss) stream flow achieved by using an on-line process analyser to upgrade product versus routine laboratory samples (expressed as a decimal i.e. 20% = 0.2)
[Y]	=	Proportion of time per year when plant is operational. Nominally this will be 1 (i.e. 365d/365d) if in full time operation
[A]	=	Percentage of time expressed as a decimal that analyser is available and utilised in the control application when plant is in operation
[LC]	=	cost reduction in laboratory samples (e.g. 3/day) when analyser is installed
[M]	=	Estimated annual analyser maintenance costs (can use actual costs when data available after analyser installation)
[AUC]	=	Estimated annual analyser utility costs
[PUC]	=	Estimated increase in annual process utility costs (if applicable) needed to achieve upgrade in product through use of analyser control e.g. increased reboiler energy costs

Example basis for gas fired furnace operating energy reduction:

$$\text{Annual Payback} = [F] \times [HV] \times [EC] \times [EEI] \times [Y] \times [A] - [M] - [AUC]$$

Where:

[F]	=	Totalised annual volume of fuel gas without oxygen analyser control
[HV]	=	Energy content of fuel gas (usually LHV)
[EC]	=	Local site energy cost per unit energy content
[EEI]	=	Percentage improvement (reduction in fuel fired) expected by use of an oxygen analyser for firing rate control (expressed as decimal)
[Y]	=	Proportion of time per year when plant is operational. Nominally this will be 1 (i.e. 365d/365d) if in full time operation
[A]	=	Percentage of time expressed as a decimal that analyser is available and utilised in the control application when plant is in operation
[M]	=	Estimated annual analyser maintenance costs (can use actual costs when data available after analyser installation)
[AUC]	=	Estimated annual analyser utility costs

See Appendix A for example calculations for a fractionator and a furnace.

Simplified maximum theoretical payback calculations often assume the analyser is available and utilised 100% of the time it is needed (the above examples make an allowance for this) and can be used to exactly hit the desired control target to achieve maximum payback, i.e. they make no allowance for the precision of the analyser. More detailed calculations can allow for an offset from the theoretical optimum target based on the analyser precision. This is especially important in final product quality applications where a target or release offset is used to ensure product is not manufactured or released off specification. In this case the payback must be calculated based on the offset target rather than the actual final product quality specification.

2.5 How to estimate potential installation, training and maintenance costs

Installation, training and maintenance costs will depend on the specific analyser type and the current site infrastructure. For an on-line analyser installation, the following costs will need to be considered when determining if an analyser is justified:

- Initial hardware purchase costs;
- Site installation costs;
- Project implementation costs;
- Training costs;
- Annual maintenance costs (parts and labour); and
- Annual running (utility) costs.

2.5.1 Initial hardware purchase costs

Analyser vendors and analyser systems integrators can provide an initial budget quotation for the analyser and associated analyser systems hardware. The costs that need to be included are:

- Specific type of process analyser;
- Sample conditioning system including fast loop components;
- Sample probe;
- Analyser calibration and validation facilities;
- Sample recovery system if spent sample cannot be directly returned to process via the fast loop;
- Manual sample point for cross checking analyser to laboratory (may be part of sample conditioning system);
- Suitable analyser enclosure (walk-in analyser house, weather protection shelter or local cabinet as applicable). If available, spare space in an existing analyser house or shelter in the same process unit should be used to minimise costs otherwise the full costs for a new house or shelter will need to be included; and
- Packing and delivery of hardware to site.

2.5.2 Site installation costs

The following items need to be included in the site installation costs. As these are normally site implemented items, the internal site cost estimators should be able to assist in the development of these costs:

- Connections on the process lines for the sample take-off and return points (existing process lines may need to be hot tapped if they cannot be taken out of service or if an overall plant maintenance turnaround is not scheduled in the period when the analyser needs to be installed);
- Supply and installation of the sample transport lines from the process take-off and return connection points to the analyser enclosure;
- Installation of the analyser enclosure and associated systems on-site (a new analyser house or shelter will require a suitable concrete foundation pad);
- New power supply feeder in a local substation;
- Supply and installation of electrical power cables from the substation to the analyser enclosure (including new trenches for cables if required);
- Connections to the nearest utility supply headers as required (instrument air, plant nitrogen, steam, steam condensate return, cooling water, cooling water return, potable water);
- Supply and installation of piping and tubing connections from the utility connection points to the analyser enclosure;

- Supply and installation of instrument signal cables between the analyser enclosure and the control room; and
- Digital control system input slots and configuration.

2.5.3 Project implementation costs

As well as the hardware and physical site installation costs, there will also be some site labour costs associated with the project development and implementation which should be included in the overall cost estimate if these are not covered by the normal site overhead costs. These will include:

- Instrument/analyser engineer project development time;
- Project management and project engineer support time;
- Design/drafting office time;
- Installation supervision if this done by sub-contractors; and
- Control engineers time to develop associated control application.

2.5.4 Training costs

If it is a new type of analyser for the site, the maintenance personnel will require both theoretical and hands-on training from the vendor on the specific analyser. The maintenance personnel will also require general training on the sample conditioning system and the analyser house or shelter systems if a new analyser house or shelter is being supplied. The cost for this can be covered in the budget cost estimates from the analyser vendor and/or the analyser systems integrator if one is being used.

2.5.5 Annual maintenance costs

The overall maintenance costs need to cover the analyser and associated systems (sample conditioning system, analyser house etc.). They should cover both the maintenance technicians expected preventative maintenance time and all expected consumable spare parts. If there is already a similar analyser installed on-site, the actual maintenance costs for this can be used as an estimate for the costs for the new analyser.

If it is a new type of analyser for the site, the analyser vendor and/or analyser systems integrator can provide information on expected maintenance costs (time and spare parts) with their budget quotation.

If the analyser will not be maintained by site technicians, the cost of a service contract can be obtained from the analyser vendor or other suitable sub-contractor supplier of these services.

2.5.6 Annual running costs

This should include the utility running costs and the costs of any special certified samples and gases or laboratory analyses for validating and calibrating the analyser. The analyser vendor and/or the analyser systems integrator can advise the expected utility consumption for the analyser and the analyser enclosure which can then be used to estimate the annual costs based on the local site utility costs.

The analyser vendor can also advise the expected consumption of validation materials based on the initial recommended validation frequency. The cost for these can then be obtained from an appropriate certified gas mixture or certified sample supplier. If validation will be done via laboratory sample cross checks, the cost of the required number of laboratory analyses should be included in the annual running costs. The local site laboratory should be able to advise their cost for the specific type of laboratory test.

3. Application specification details

This Chapter covers the information needed from process design engineers, the end users of the analyser (plant operators and process control engineers) and the analyser maintenance group to initially justify the analyser and ensure the analyser and associated system design and operation will meet all measurement and performance expectations in order to capture the intended benefits.

An example of an analyser application data sheet template that can be used to collect and document all the information needed to develop an on-line analyser application and installation is given in Appendix B. It details the application and process data required to determine the type of analyser and to develop the technical purchase specification and installation design. This data sheet can initially be used when determining if the analyser application is justified and then to provide the basis for the full technical specification data sheet (See Chapter 4) for the analyser and associated analyser systems purchase if the project proceeds. Some of the more significant items which are captured on the application data sheet are discussed in more detail below.

The information covers five main areas:

- Analyser justification;
- Performance specifications;
- Sample point location and process data specifications;
- Analyser installation design; and
- Analyser maintenance and cost of ownership.

3.1 Initial analyser justification and alternatives

As noted in Chapter 2, process analysers are expensive to install and expensive to maintain compared to other process measurement devices, e.g. flow, pressure and temperature devices. Therefore, they should only be installed when there is a clear financial benefit or where they are required to ensure safety or meet environment regulations.

The analyser justification should be fully documented on the application data sheet.

This should include the full basis and calculation for the financial benefit or description of the non-discretionary basis for the safety or environmental need.

The improvement in safety ISO risk units should be documented for safety analysers if the site uses this methodology.

If the analyser is being used for any legal purposes, e.g. environmental emissions, document details of all standards and regulations that must be met and include details of any special certification or testing requirements.

A preliminary cost estimate for the complete installation must be developed. This should include the analyser system hardware, installation costs, project overhead costs, maintenance and running costs as detailed in Section 2.5. Budget quotations can be obtained if necessary from vendors for the analyser, analyser sample conditioning system and analyser housing. For profit type analysers, these costs must be compared with the benefits (payback) to ensure sufficient return on capital invested is being obtained. The cost estimate can then also be used to secure the correct project approval and funding.

Alternatives as detailed in Section 2.1 should also be evaluated before proceeding with an on-line analyser installation to determine if they can capture a significant part of the

benefits for profit type analysers at a lower cost, e.g. periodic laboratory analyses, at-line analyser, portable analyser or inferential model based control. The results of this evaluation should also be documented in this section to confirm that the alternatives have been considered and rejected.

3.2 Performance specifications

The following items must be defined to properly develop the analyser application to ensure it provides the required measurement(s) and performance to fully capture the identified benefits.

3.2.1 Measurement requirements and use

Describe the specific components and properties to be measured together with the operating envelope (minimum and maximum expected values).

Description of how the analyser will be used to capture the intended benefits, e.g. in closed loop process control or more usually as part of a higher level control application. Details of plant properties or parameters that will be automatically controlled to optimise the process based on the on-line analyser readings.

Note: profit type analysers that are installed for “monitoring” purposes only and which require direct manual operator action to control or correct the process rarely achieve the desired payback. If it is not possible to use the analyser in some type of automated control scheme then it probably should not be installed in the first place unless it is being used to gather continuous data for regular off-line plant optimisations.

3.2.2 Measurement precision

Define the required measurement precision. This should include the required precision (repeatability and accuracy versus referee method) and the required sensitivity (smallest measurable change) required to realistically achieve benefits.

3.2.3 Measurement response time

The maximum acceptable response time for the analyser system needed to achieve effective process control or to meet safety or environmental needs should be defined. The total analyser system response time is a combination of the analyser response time and the analyser sample transport and conditioning system response time. The type of analyser must be selected and sample transport and conditioning system designed to meet this requirement.

The expected analyser response time can be obtained from analyser vendors. For cyclic type analysers this will be the analyser cycle time for the specific application. For a continuous analyser this will normally be quoted as response time to T90 (90% of value) for a step change. This may determine the type of analyser if a fast response time is required

The analyser transport system and sample conditioning system can usually be designed to give a response time of less than 90 seconds but can be faster if required.

The total process dead time for control should also be estimated and added to the total analyser system response time to give an indication of the overall system response time to process changes in relation to the point at which the process is controlled.