# CONTROL LOOP PERFORMANCE MEASURES IN THE EVALUATION OF PROCESS ECONOMICS

**N. Vatanski[a], S-L. Jämsä-Jounela[a], A. Rantala[c], T. Harju[b]**

[a]*Helsinki University of Technology*
*Laboratory of Process Control and Automation*
*Kemistintie 1,02150 Espoo, FINLAND*
[b]*Metso Automation Inc. Helsinki, Finland*
[c]*Outokumpu Technology – Mineral Processing, Espoo, Finland*
*E-mail: nvatansk@cc.hut.fi*

Abstract: The number of control loops used in industry is growing continuously and there are problems in keeping them working at a satisfactory level. One reason for the poor performance is the lack of maintenance of control loops. Economical benefits can result from the better maintenance of control loops. In this paper the economic aspects of control loop performance measures are discussed. A strategy is proposed to evaluate the economics of control performance using control loop performance measures. In addition, a case study on an industrial process is also described. It is anticipated that the framework introduced in this paper may prove useful in presenting control quality in a common language understood by operators, engineers and management.

Keywords: Performance evaluation, control loops, economics, monitoring loops

## 1. INTRODUCTION

The number of control loops used in industry is growing continuously and there are problems in keeping them working at a satisfactory level. Numerous investigations have shown that the performance of feedback controllers in the process industry is not satisfactory, see (Ender, 1993). The reason for poor performance can be in their design as well as in the maintenance of control loops. A loop that has worked well at one time is prone to degrade over time unless maintenance issues are taken into account. There are several reasons for the degradation of control loop performance, and include faulty equipment, friction or stiction in valves, incorrect dimensioning of valves, input saturation, changes in dead time, inappropriate control structure or algorithm, bad tuning of the controller or changes in disturbance characteristics, poor selection of the sampling time, interaction with other loops, etc.

There are two main reasons for a lack of maintenance: one is that the staff has only limited time to carry it out, and the other is a lack of understanding of process control. Due to the limited time available to operating staff, the maintenance of controllers receives insufficient attention and most of it is done in the form of "firefighting". In other words, the operators interfere with the control loop operating state only if something goes wrong. Furthermore, due to a lack of understanding of process control, poor performance is sometimes accepted as normal.

Major economical benefits can result from better maintenance of control loops. As a result, a considerable amount of research has been carried out in the field of automatic control loop performance evaluation during the last decade. This branch of automatic control research has matured to the extent that a number of survey articles have already appeared see for example (Qin, 1998; Harris *et al*., 1999)

However, control loop performance assessment needs to be tied more closely to economic aspects. Only certain key loops are economically critical, and these are the ones that require top priority. A strategy for evaluating control improvement economics using control loop performance measures is proposed in this paper. It is anticipated that the framework derived in this paper may prove useful in presenting control quality in a common language understood by operators, engineers and management.

The paper is organized as follows: a short overview of performance assessment is presented in chapter two, and economical aspects of control loop performance measures are discussed in chapter three. Based on the discussion, a strategy for evaluating control loop economics using control loop performance measures is presented in chapter four. Finally, test results from industry that support the first step of the strategy are presented in chapter five.

## 2. CONTROL LOOP PERFORMANCE MEASURES

Automatic control loop performance evaluation methods have been developed for maintenance purposes in order to assist plant staff to interpret plant data if the number of control loops in the plant is high. The monitoring algorithm should sound an alarm when controllers are not performing as expected. The diagnosis algorithm should give decision support to help with the overall maintenance of the closed loops in a plant.

Implementing a number of dagnosis methods and running them online in a control system could be considered problematic. A more feasible approach to the problem is to have a performance monitoring algorithm running online which detects problem loops but does not distinguish between root causes. The root cause diagnosis can then be performed offline. The situation is depicted in figure 1.

Because of the special conditions for which control

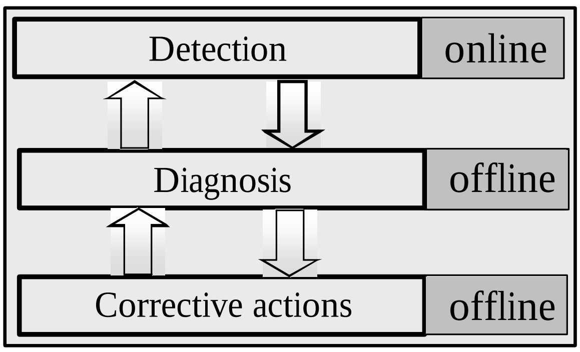


Fig. 1. Automatic control loop performance evaluation in a control system.

loop performance indices have been developed, there are some properties that are desirable for control loop monitoring algorithms. A list of some desirable properties of control loop performance evaluation monitoring methods has been presented in (Vaught and Tippet, 2001). Some of the most important properties of the algorithms are automated operation (online operation), no specific process information should be needed in calculating the performance measure, and the algorithm should be non-invasive and simple to interpret. In addition, it would also be desirable for performance evaluation algorithms to have a low error rate, no history in the calculations, and the possibility of problem prioritization. The list is not complete and some of the desirable properties are not attainable and in contradiction with each other. However, this list gives a picture of the nature of the algorithms required for automatic control loop performance evaluation.

At the present time more than one measure is needed to estimate the loop performance, and the available measures might not be sufficiently sensitive to detect incipient problems before they affect product quality. The evaluation methods developed can be divided into two categories: stochastic and deterministic methods. The most widely studied stochastic indices are those based on using of MVC (minimum variance controller) calculation as a benchmark. The variance of the process output is compared to the smallest, theoretically achievable variance, as initially discussed by Harris, (1989). One advantage of these methods is that they require only output data from controlled process and a priory knowledge of the dead time of the process or its estimation. Horch and Isaksson, (1999) proposed a modified performance index that is more robust with non-stationary systems. Eriksson and Isaksson, (1994) pointed out that a controller with a good MVC index does not necessarily have a good performance with respect to set point changes. Overviews of the research carried out on minimum variance control during the past decade have been presented by Harris (1999) and Qin, (1998).

Deterministic indicators are more informative in the case of a sudden load disturbance or a set point change. Various dimensionless indices for set point changes have been proposed in the literature, e.g. (Åström *et al*., 1992). Hägglund, (1999) dealt with the rejection of step disturbances and described it by means of the Idle Index. Swanda and Seborg (1999) used the dimensionless rise time and the dimensionless Integral of Absolute Error (IAE) index in set point changes. Two performance indices, the Absolute Performance Index (API) and the Robustness Index (RI) were introduced by Shinskey (1990).

It is also essential to detect oscillations in the system, caused by actuator friction, bad controller tuning or an oscillating load disturbance. These oscillations can be identified by means of autocorrelation functions or spectral analyses, see (Thornhill and Hägglund, 1997). Horch (1999) demonstrated a method for detecting stiction in control valves based on cross-correlation between process input and output. Hägglund (1995) presented an oscillation detection procedure that involved the calculation of IAE.

More recently, various research groups have developed multivariable extensions to the original Harris index, see (Harris, *et.al.*, 1996; Huang and Shah, 1999; McNabb and Qin, 2003; and McNabb and Qin, 2005).

## 3. ECONOMICAL ASPECTS OF CONTROL LOOP PERFORMANCE MEASURES

Successful control loop maintenance brings considerable economical benefits. However, the economic benefits resulting from performance assessment are difficult to quantify on a loop-by-loop basis. This is due to the fact that analysis of the economical effects of the control loop performance on overall plant performance is always case-sensitive. Each problem loop usually contributes in a complicated way to poor overall process performance. The economical benefits are derived from finding and fixing problem loops throughout a plant over a long time period. In this case, long-term data will show reduced off-class production, reduced product quality variability, lower operating costs and an improved production rate, see (Paulonis and Cox, 2003). In addition to these hard credits where direct savings are obtained, the control loop maintenance brings soft credits such as improved process operability i.e. improved responses to the operator actions, reduced number of operator interventions, reduced number of alarms reduced, etc. (Ketonen, 1998).

Relatively little research has been carried out on transforming control loop performance measures into economical values on a loop-by-loop basis. However, some papers have been published. Attempts have been made to transform a dynamic control loop performance measure into economical values. In the paper, the dynamic performance measure has been transformed into an economic measure by multiplying it by a weighting factor.

$$ISE = \int_{t=t_1}^{t_2} \left(y_t(t) - y_{sp}(t)\right)^2 dt \qquad (1)$$

$\Rightarrow$

$$€ISE = \int_{t=t_1}^{t_2} w_u \left(y_t(t) - y_{sp}(t)\right)^2 dt \qquad (2)$$

The problem with this approach is in finding suitable weighting factors. In this case the weighting factors were obtained using steady-state simulations and knowledge possessed by the plant operating staff. The author stated that more research is needed to develop means for providing reliable estimates of weighting factors.

For the evaluation of automatic control loop performance this approach has some disadvantages. An important requirement of automatic control loop performance evaluation methods is violated in this approach, i.e. that no or little process knowledge should be needed in algorithm set up. In this case, a substantial effort is required to obtaining these weighting factors. In addition, a deep understanding of the process and information about interactions between the control loops are needed.

Using the approach for automatic control loop performance may limit the usage of the economic measure obtained. This is due to the fact that control loop performance measures are a type of irreversible data compression. Some information is lost when the indices are calculated. More information is lost when the measures are further transformed into economic values.

Another factor is that most control loop performance measures are too simple to be transformed directly into economical values. In the simplest case, information about the magnitude of the set point, as well as information about the variance reduction, is needed in estimating the economical benefits of improved control. This is clearly demonstrated in figure 2. Most control loop performance measures do not include such information. More sophisticated information is usually needed in more complex cases.

## 4. STRATEGY TO EVALUATE CONTROL LOOP PERFORMANCE ECONOMICS

The control loop performance measures cannot be directly transformed into economical values. However,

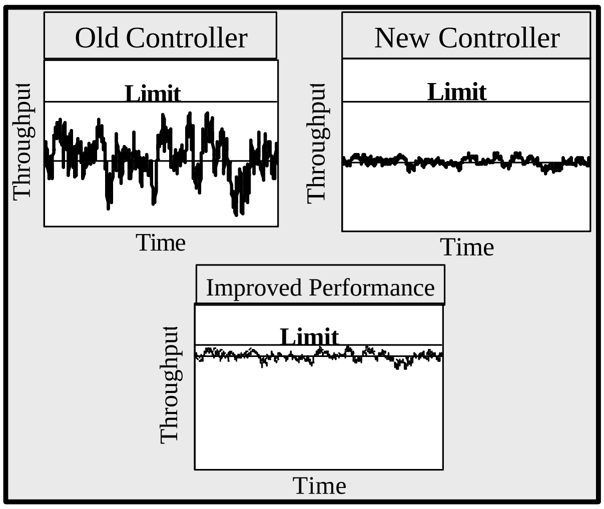


Fig. 2. Classical approach for estimating the benefits of improved control.

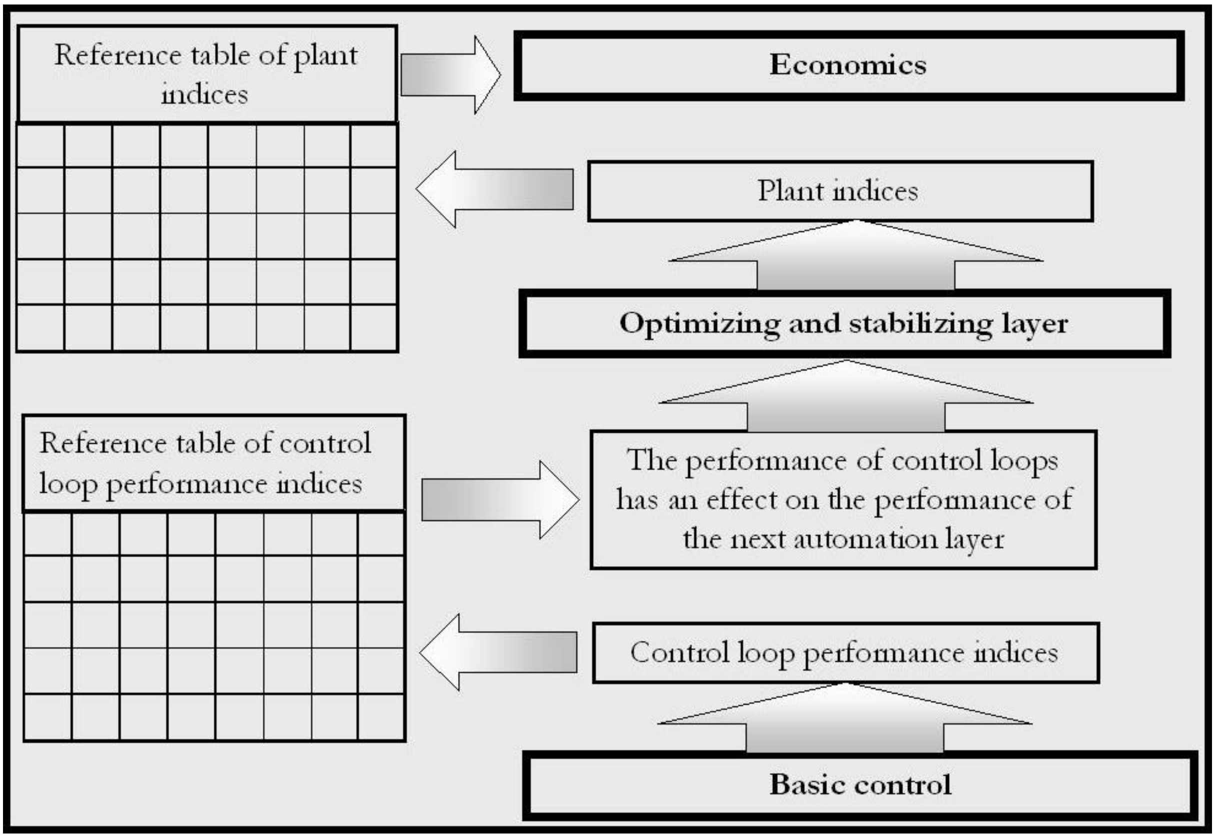


Fig. 3. A strategy for evaluating the effects on control loop performance on the overall process economy.

control loop performance measures are important in evaluating the economical benefits resulting from better maintenance.

A strategy for analyzing control loop economics using the control loop performance measures is developed in this work (Figure 3). In the strategy, control loops are monitored continuously using control loop performance measures. A specific reference table with alarm limits for each control loop and control loop performance measure is used to indicate whether the performance has decreased so much that it affects the performance of the next optimizing and stabilizing layer. If this is the case, a message is sent and different plant indices that are more suitable for economics monitoring with process knowledge are re-calculated. A separate reference table with plant indices on one side and monetary terms on the other is then used to quantify performance degradation.

The economical benefits become clearly evident on the basis of long term data after the problem loops have been found and fixed throughout a plant. The benefits include an improved production rate, reduced off-class production and product quality variability, as well as lower operating costs. In addition to these hard benefits, the soft benefits resulting from better maintenance will emerge. Such are a reduction of unnecessary preventative maintenance actions, improved facility stability and process operability, better advanced control performance, and increased equipment life cycle.

## 5. TESTING RESULTS

The first step of the strategy was tested. A monitoring program was developed to evaluate the performance of the control loops. The monitoring program was tested in real plant. The loops selected to be discussed in more detail in this section describe behaviour of an oscillating loop, a well-tuned loop, and a slow loop.

### *5.1 Oscillating loop*

The control loop describing oscillating behavior is used in the level control of the second of six flotation cells in series. Based on the output data as described in Figure 4, it can be concluded that the process was quite unstable, oscillation being almost 15%. The oscillation time was approximately 500-1000 seconds. The gain parameter of the controller was 0.8 and the integral time was 300s. From the index values calculated it can be concluded that the program predicts the oscillation of control loop. The values of the Harris minimum variance index (MV) are close to zero; the values for the Integral of Square error (ISE) and the oscillation indices are high. In addition the values for the index that detects saturation (saturation index, SI) are zero. Information

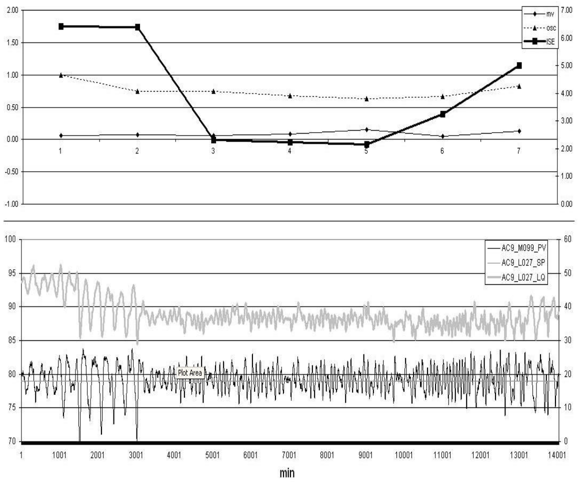


Fig. 4. Performance indices for the oscillating control loop

whether the value of the index is high or low was obtained from process specific knowledge.

*5.2 Well tuned control loop*

The controller loop describing good behavior is used in the level control of a tank. Based on the output data as shown in Figure 5, it can be concluded that the loop is faster than the loop in Figure 4. The controller used was a PI-controller, and the integral time was high with a value of 1200s. Because of integral action of the gain parameter of the controller was chosen to have a high value of 10.

From the calculated index values it can also be seen that the control loop is well tuned. The values for the minimum variance index, the oscillation index and the ISE index are very good. The values of the minimum variance are high; the values for the oscillation and ISE indices are close to zero.

A set point change at a time of 3000 seconds caused bad values for the minimum variance index, but these can be ignored since the minimum variance index wasn't planned to handle situations of that kind.

*5.3 Slow control loop*

The controller loop describing the slow behavior is used in the control of the back flow rate of $H_2SO_4$ to the tank. The loop is otherwise stable but big process disturbances cause big deviations from the set point. The gain parameter of controller was 0.5 and the integral time was 30s. From the index values calculated it also can be concluded that the control loop is slow. The values for the minimum variance and the saturation indices are close to zero, the values for the ISE index are high, and the values for the oscillation indices varied.

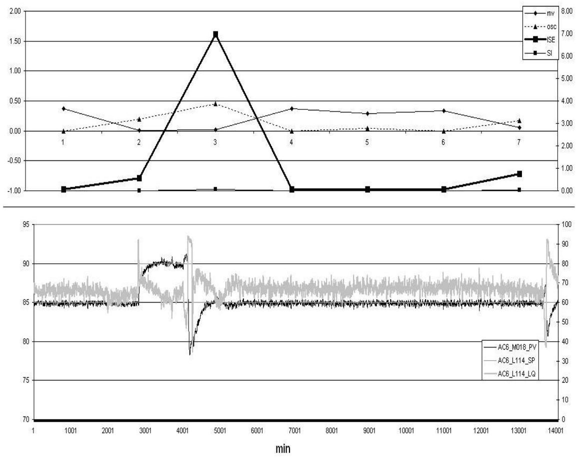


Fig. 5. Performance indices for the well-tuned loop

## 6. CONCLUSIONS

A short review of automatic control loop performance evaluation has been presented in this paper. Control loop performance measures have been developed for maintenance purposes. The greatest benefits from using these methods are obtained when the number of control loops in the plant is high (>200). The indices cannot, in most cases, be directly transformed into economical values due to the simplicity of the algorithms and the complexity of the connections between physical properties and economics. However, economical benefits are achievable over time. These benefits should be evaluated using plant-wide process economic assessment algorithms. A strategy for analyzing control loop economics using the control loop performance measures is proposed. Test results from industry that support the first step of the strategy are presented. It is anticipated that the strategy may prove useful in conveying control quality in a common language understood by operators, engineers, and management.

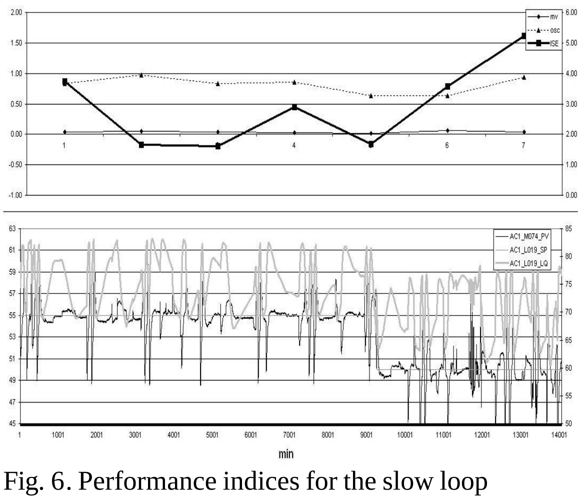


Fig. 6. Performance indices for the slow loop

## REFERENCES


Åström, K.J., Hang, C.C., P. Persson and W.K. Ho (1992). Towards intelligent PID control. *Automatica*, 28(1), 1-9.

Eriksson, P-G. and A.J. Isaksson (1994). Some Aspects of Control Loop Performance monitoring. In: *3rd IEEE Conference on Control Applications*, Glasgow, Scotland; IEEE: New You, 1029-1034.

Ender, D. B. (1993). Process control performance: Not as good as you think. *Control Engineering,* 40(10), 180–190.

Hägglund, T. (1995). A control-loop performance monitor. *Control Engineering Practice*, 3(11), 1543-1551.

Hägglund, T. (1999). Automatic detection of sluggish control loops. *Control Engineering Practice*, 7, 1505-1511.

Harris, T.J. (1989). Assessment of control loop performance. *Canadian Journal of Chem. Eng.*, 67(10), 856-861.

Harris, T., Boudreau, F., and J.F. Macgregor (1996). Performance assessment of multivariable feedback controllers, *Automatica* 3211 1505–1518.

Harris, T.J., C.T. Seppala and L.D. Desborough (1999), A Review of Performance Monitoring and Assessment Techniques for Univariate and Multivariate Control Systems, *J. Process Control* 9, 1-17

Horch, A. (1999). A simple method for detection of stiction in control valves. *Control Engineering Practice*, 7, 1221-1231.

Horch, A. and A. Isaksson (1999). A modified index for control performance assessment. *J. Process Control*, 9, 475-483.

Huang, B. and S.L. Shah, 1999. *Performance Assessment of Control Loops: Theory and Applications*. Advances in Industrial Control, Springer-Verlag, London, UK.

Huang, B., Shah, S.L. and K.Y. Kwok (1997). Good, bad or optimal? Performance assessment of MIMO processes, *Automatica* 33(6) 1175–1183.

Ketonen, M. Benefit assessment of automation investments in chemical process industries, *Acta Universitatis Ouluensis, Technica,* ISBN 951-42-4813-9.

McNabb C.A. and S.J. Qin (2003). Projection based MIMO control performance monitoring: I—covariance monitoring in state space, *J. Process Control*, 13(8), 739-757

McNabb C.A. and S.J. Qin (2005). Projection based MIMO control performance monitoring: II—measured disturbances and setpoint changes, *J.l Process Control*, 15(1), 89-102

Paulonis, M.A., and J.W. Cox (2003). A practical approach for large-scale controller performance assessment, diagnosis, and improvement. *J. Process Control* 13(2), 155-168.

Qin, S.J. (1998). Control performance monitoring, a review and assessment. *Computers and Chemical engineering* 23, 173-186.

Shinskey, F.G. (1990). Putting Controllers to the test, *Engineering Practice* 12, 96-106.

Swanda, A.P. and D.E. Seborg (1999). Controller performance assessment based on setpoint response data. In: *Proceedings of the American Control Conference,* 3863-3867.

Thornhill, N.F. and T. Hägglund (1997). Detection and diagnosis of oscillation in control loops. *Control Engineering Practice*, 5(10), 1343-1354.

Vaught, R. and J. Tippet (2001), Control performance monitoring: shaman or saviour, *Pulp Paper Canada* 102(9), 246-249.