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The Economics of Advanced Automation

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Abstract:

Advanced plant automation applications incorporate a wide variety of devices and software including "smart" sensors and other " smart' equipment, improved software tools for modeling/ analysis/ forecasting, and enhanced networking. These applications take advantage of the extraordinary developments that have been and are occurring in the computer and communication area and they are increasingly used in the Chemical Process Industries (CPI) including Aromatics units. One limitation to their use has been the difficulty in accurately estimating the expected economic benefits from installation of these applications on a sound quantitative basis. Many unsupportable claims on potential benefits are made. In this paper, the methodology for estimating these benefits is presented. Some of the subtleties in analysis that are not often recognized are explained. A case study illustrating the method is presented.

The Economics of Advanced Automation

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Introduction and Background:

We are all aware of the extraordinary developments that have been and are occurring in the computer and communication area. Continuing decreases in the cost and size of computing elements and continuing increases in the availability of communication bandwidth are reported almost daily. These developments have affected many things including the manufacturing activities of the Chemical Process Industries (CPI). These developments have been incorporated into the basic control elements in the plant, sensor, transmitters, and control valves, leading to better control and earlier detection of anomalous conditions. In addition, advanced analytical and predictive technologies such as multivariable predictive constraint control (MPCC) are also based on these developments. One continuing question has been "What is the economic value of these devices and technologies; how much is the improved control worth?"

This question has been considered previously in several papers including references 1, 2, and 3. The analysis usually refers to the figure below or a similar one as part of the explanation. The variability of the controlled variable is analyzed under normal operation and produces a pattern as shown on the left side of the chart. The controlled variable has an operating target that is set some amount in a conservative or safe direction away from the limit. This limit generally refers to some physical limit in the plant such as a maximum temperature or maximum valve opening or to a product quality specification limit. After the new devices or the new technology is introduced the variability of the controlled variable is reduced. With this reduction, the operating target can be moved closer to the limit. Generally this new target is more economically advantageous than the old one and the economic difference is projected as the value of the new installation.

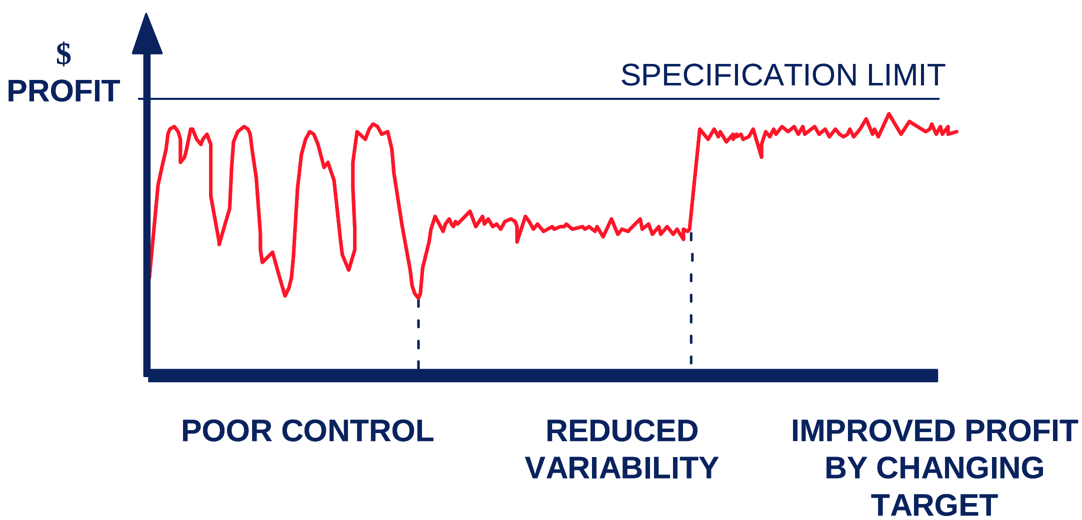

Figure 1 - Economic Benefits of Reduced Variability

While there is nothing incorrect about this analysis, there are a number of subtleties that do not seem to be generally recognized. It is the objective of this paper to review some of these issues and describe how they can be evaluated.

Discussion Example:
To aid in the discussion we will use an example which corresponds to a typical situation. The simple two product distillation column below has feed and product values as listed. Note that both products have tiered pricing that is discontinuous. If the product is within specification it has one value. If it is out of specification it has a different lower value. This is very common for all unit operations, not just distillation.

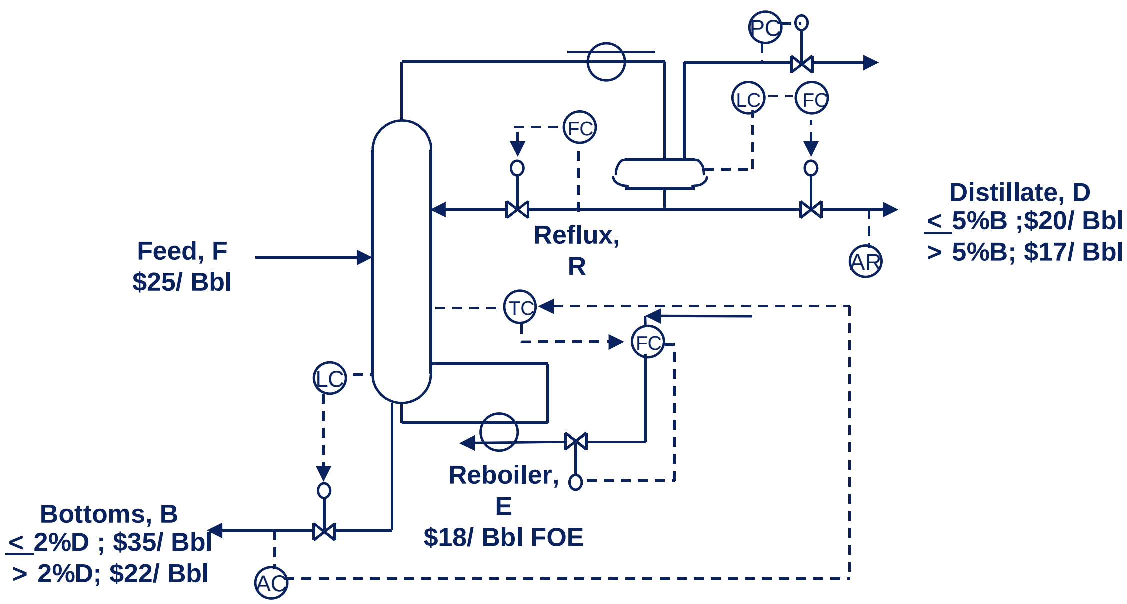

Figure 2 - Example Distillation Column

With these prices, the product value from the column is shown below for constant reflux operation with perfect control, i.e. no variability. As we decrease the temperature controller setpoint on the lower half of the column, the bottom product will increase and the percentage of top product in the bottom will increase. As the amount of the more valuable bottom product increases, the total product value increases. There are two discontinuities in the value function. The first, which occurs when the bottoms composition is about 1.0 % corresponds to the top product moving from off specification to on specification. The second occurs when the bottom product goes off specification. Under these conditions, the optimum operation is to operate as close to the specification as possible without exceeding it.

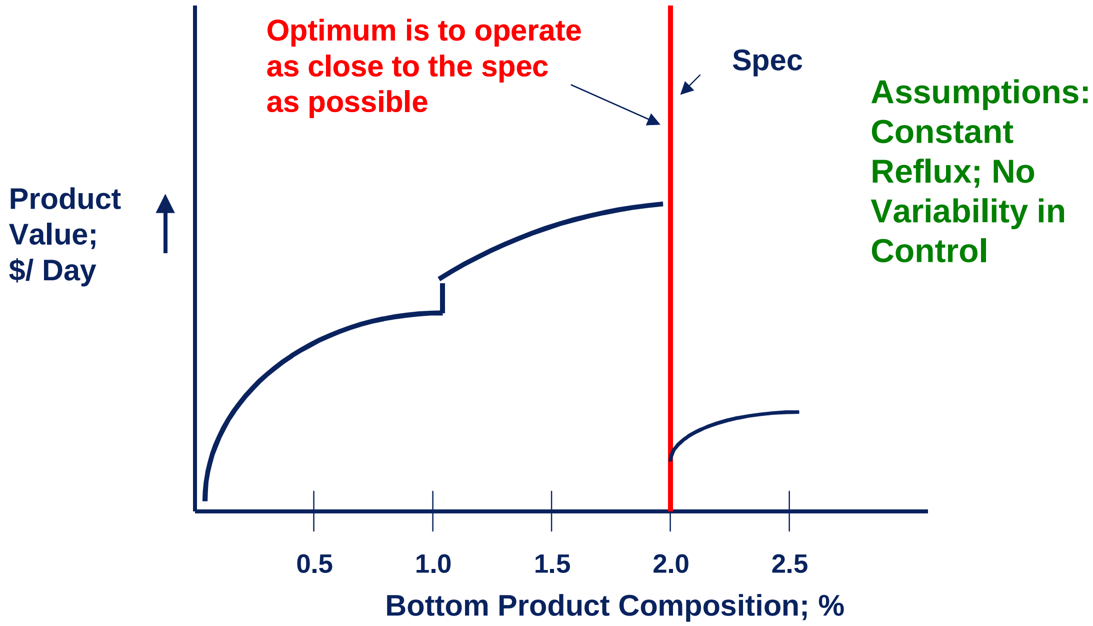

Figure 3 - Product Value versus Bottom Composition

In the graph above, the reflux is constant. Let us examine the economics of the situation where the reflux is varied at constant bottom composition. This is shown in the figure below. As the reflux is increased the cost of energy for the separation increases, roughly linearly. As we increase the reflux at constant bottoms composition, the separation improves, the amount of heavy material in the overhead decreases and the amount of bottoms product increases correspondingly. Hence, the product value increases. However, this increase is not linear. As we increase the reflux, we get less and less of an effect and the value approaches an asymptote. The profitability of the separation is the difference between the value of the products and the cost of energy, which is also plotted on the graph. We can see that this profit has a definite maximum at the point where the difference between the two curves is maximum. For many columns this maximum will be in the unconstrained region of operation though its position obviously depends on the relative value of the products versus energy.

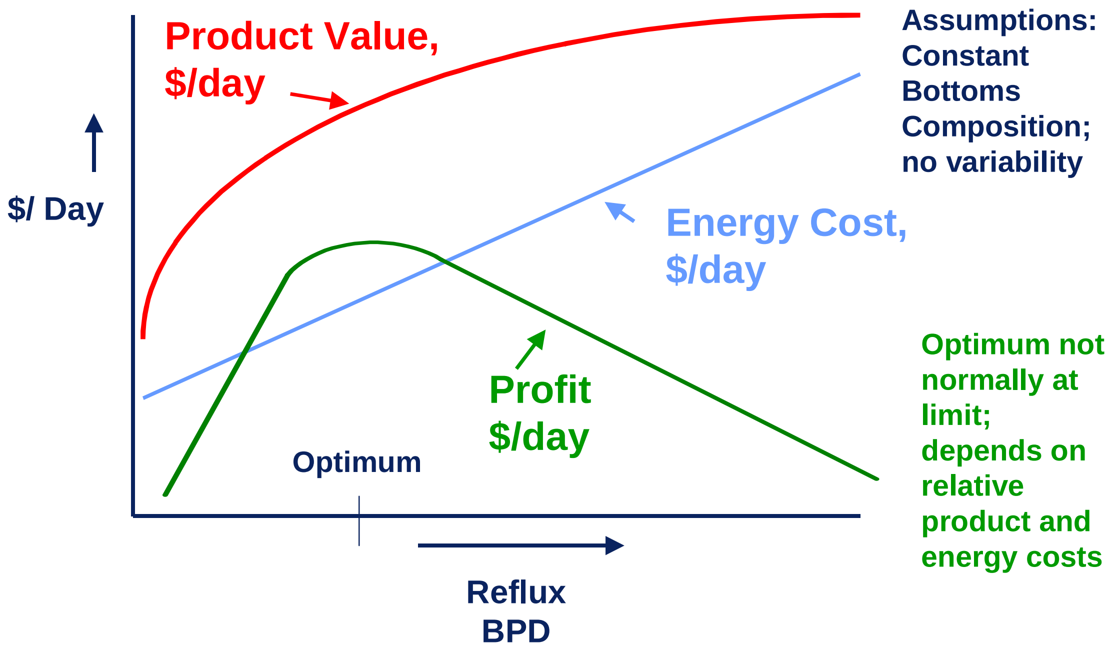

Figure 4 - Economic Value versus Reflux

Effect of Variability

The last two figures have been plotted as if there was perfect control with no variability. Of course in practice there is always variability and we need to incorporate it into our analysis. As is standard, we'll represent the variability in our controlled variable measurement from Figure 1 as a normal or Gaussian distribution with the shape as shown below.

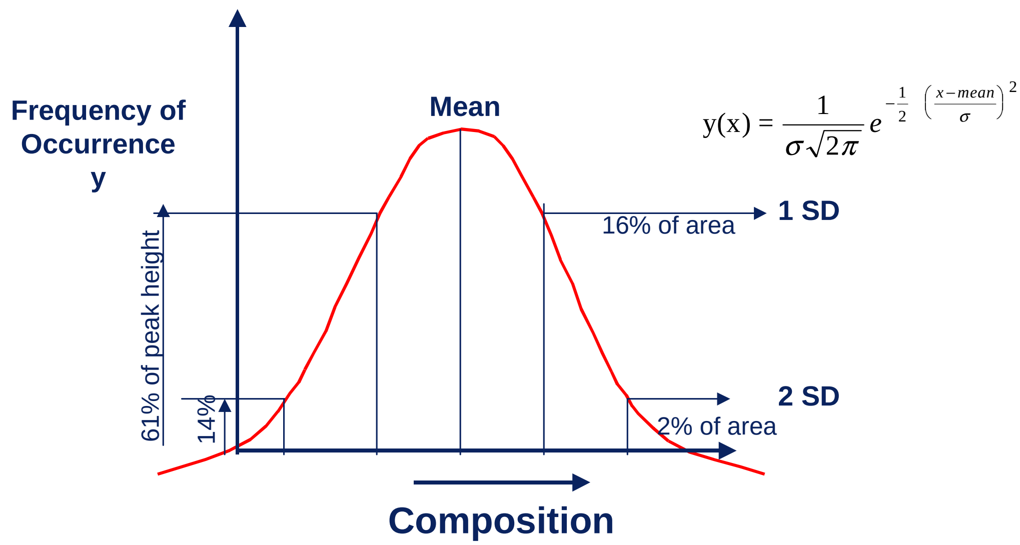

Figure 5 - Normal Distribution

To calculate the actual or mean value of the products from the column, the weighted average composition based on the initial distribution is used as shown below. The percentage at each composition is multiplied by the value at that composition to determine the value. There are a number of implied characteristics in this calculation. The first is that there is no analytical solution for this case - we have to evaluate the mean value numerically. The second observation is that the mean product value does not correspond to the value at the mean of the product compositions (also the operating target). This is because of the non-symmetrical nature of the objective function and the low value of off spec material.

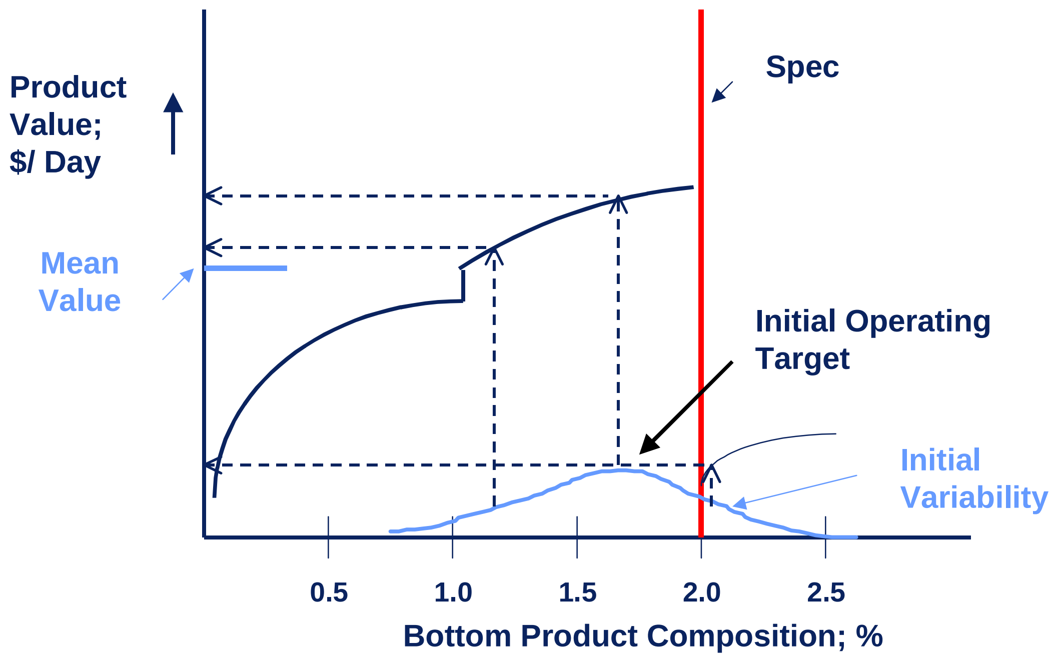

Figure 6 - Mean Product Value

If we reduce the variability of the controlled variable by whatever mechanism, we get the distribution shown in the figure below. This reduction could be due to improved valve performance, to reduced measurement error, or to advanced control functionality. *Note that, perhaps surprisingly, the mean product value is increased even though the setpoint is not changed.* This effect occurs whenever the objective function is nonlinear. Reducing the variance increases the mean product value for any nonlinear objective function, even discontinuous ones. This is *not* the case for continuous linear objective functions where the expected value of the objective function is constant and independent of the variance.

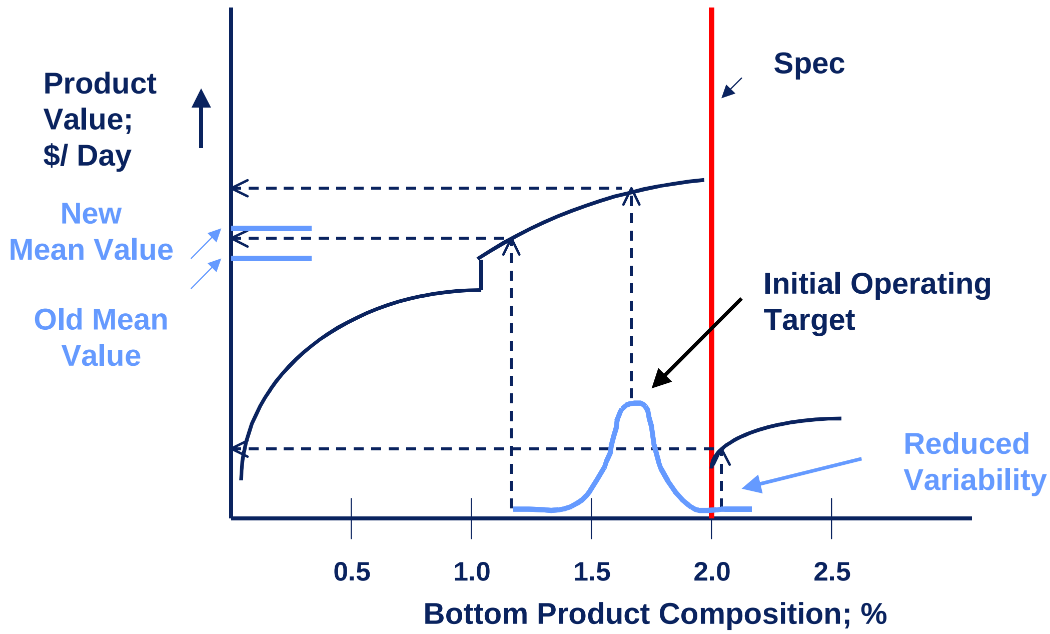

Figure 7 - Mean Product Value, Reduced Variance, Same Target

However, we can increase the mean product value further by moving the operating target closer to the specification as shown below. The profit increase over the base case is the difference in the mean profit as shown. *One seldom noted characteristic is that there is an optimum setpoint that maximizes profitability for any given variance.* As the target is moved closer to the specification, the value of the on-spec material increases but the amount of low valued off-spec material also increases. There is a specific target at which the marginal increase in on-spec material value just equals the loss in off spec material value, and this is the optimum. The optimum cannot, in general, be calculated analytically though it can be found by standard numerical techniques.

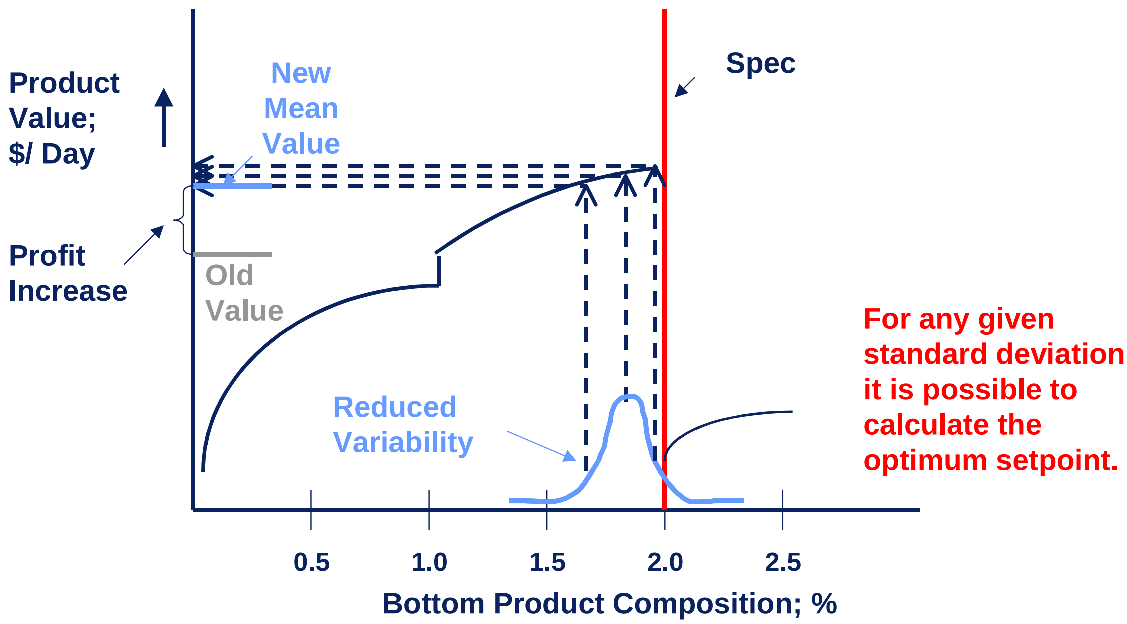

Figure 8 - Mean Product Value, Reduced Variance, Changed Target

Effect of Variability on Optimum Performance

Next consider the optimum reflux operation as illustrated in Figure 9. Assume that there is variability in the reflux. This might be caused by a defective or mis-sized valve/ pump or more normally by external disturbances to the column that cause the reflux to be changed to compensate. For example, if there is a change in feed composition the amount of overhead material may increase or decrease significantly. This can cause the level in the overhead receiver vessel to move close to either the upper or lower limit. Under these conditions it would be necessary to compensate by changing the reflux flow to hold the level in bounds. Given that this variability can be represented by a normal distribution we can calculate the expected value of the objective function as shown. *This expected value of the objective function again does not correspond to the value of the objective function at the mean value of the distribution.*

In Figure 10, the effect of reducing the variability is shown. *Even though the mean value of the distribution is the same, the expected value is now increased.* Again, this is a general characteristic of non-linear objective functions - reducing variability increases the expected value at the same target. *Moreover, if the objective function is locally quadratic, as it often is, and the variability is represented by a normal distribution, we can calculate its expected value analytically as described in reference 1 and the effect of reduced variance analytically.*

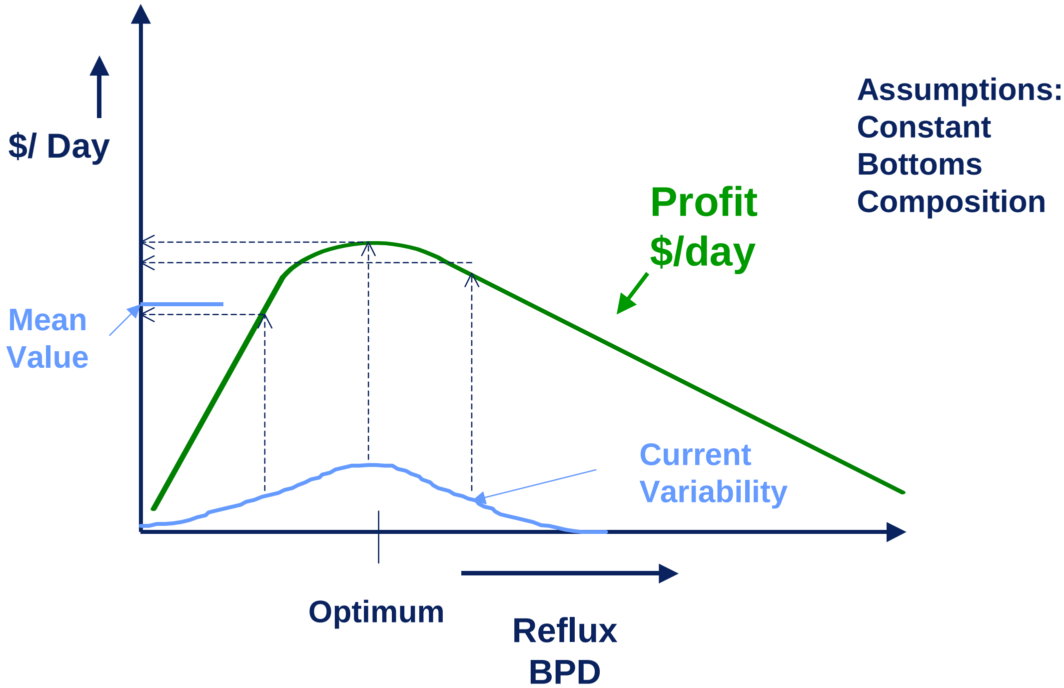

Figure 9 - Effect of Variability on Expected Value of the Objective Function

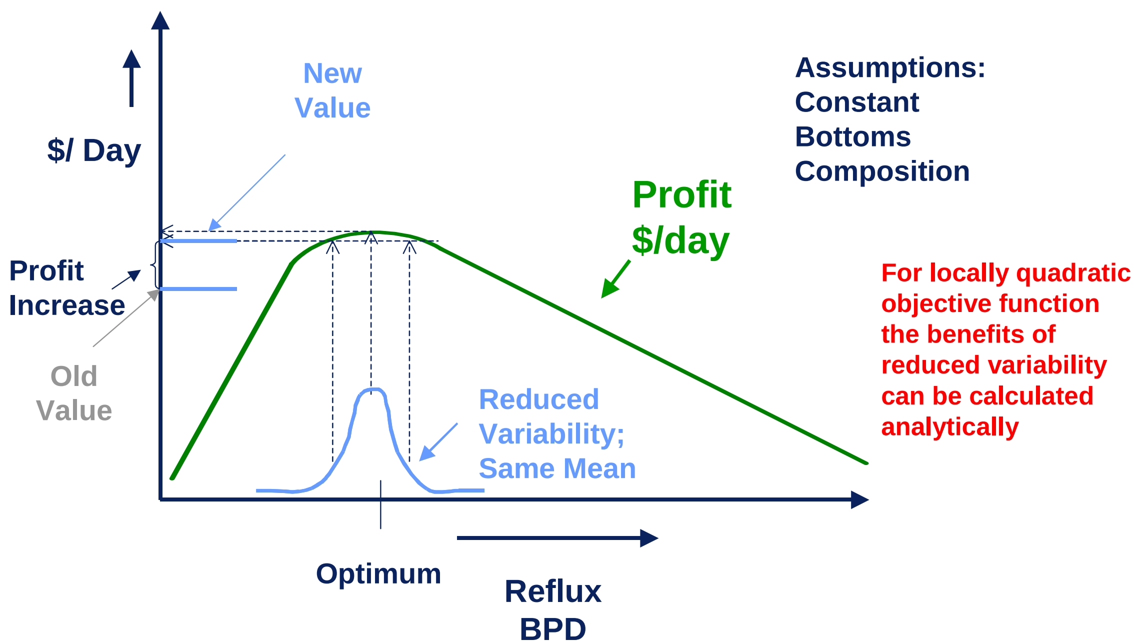

Figure 10 - Effect of Reduced Variability at the Same Target

Effect of Non-Normal Distributions

Figure 11 below shows actual data from a commercial splitting column in an aromatics plant with the limit toward the left side of the chart. Note that the distribution is not well represented by a normal distribution. It is one-sided with a rapid rise up to peak and a "tail" away from the specification. This type of curve is relatively common where there is a specification with a significant economic or operational penalty for violation.

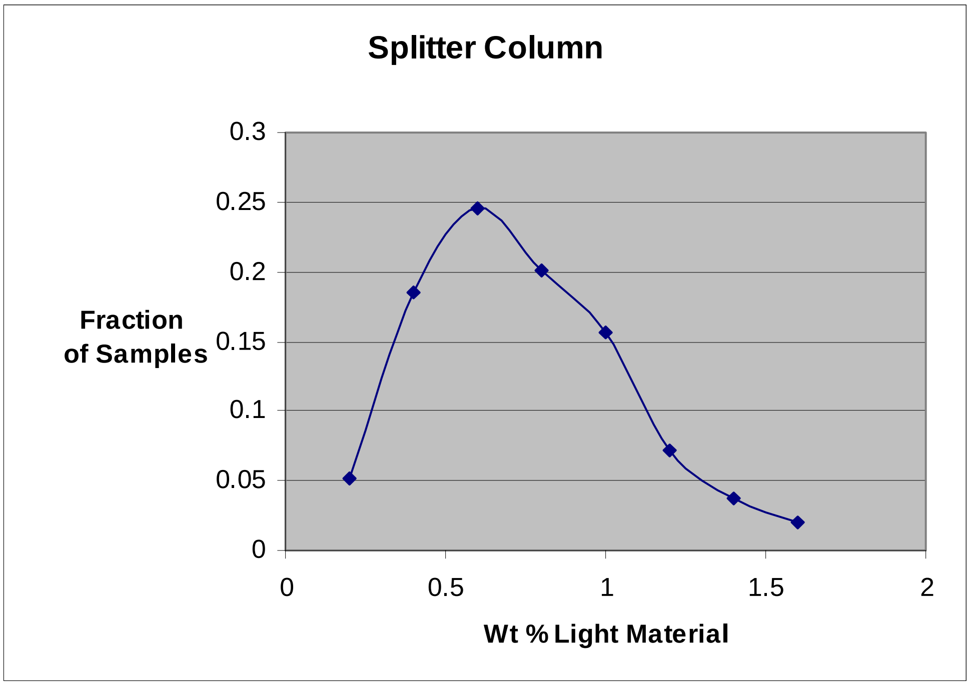

Figure 11 – Non-Normal Distribution

Fortunately, our overall conclusions on the effect of variability reduction are still valid even though the distribution is non-normal. Additional complexity does arise, however, we must now evaluate benefits numerically rather than analytically.

Case Study:
The data below is taken from an analysis of improved recovery of a valuable aromatic chemical from an aromatics downstream unit. The analysis looked at the variability of control on the column and the benefits that could be gained by improved automation, in this case addition of online analyzers and advanced control.

	Current	New
Column Feed, BPD	3615	3615
Purge Composition		
Average, wt%	87	
Standard Deviation, wt%	18.65	9.3
Purge Flow, BPD	61.5	30.8
Sidestream Flow, BPD	2641	2672
Sidestream Composition, wt%	93.63	93.69
Standard Deviation, wt%	3.69	1.84
Incremental value, $/yr		$59,000

Note that even though the flows to this particular column are small, there are real benefits from reduced variability in operation.

Conclusions:
The benefits from advanced automation are generally expressed as reduced variability in operation. In this paper we have looked at the methods for calculation of the economic effects of this improved variability. Although the principles used for this calculation are well known, there are several important details that are less well appreciated. This paper describes some of these details and their implications. The overall conclusion, though, that reduced variability is beneficial to operation remains unchanged.

References:
1. Stout, T.M.; and R.P. Kline; “Control System Justification,” Instrumentation Technology (Intech); September, 1976; pp. 51-58
2. Latour, P.L., J.H. Sharpe, and M.C. Delaney; "Estimating Benefits from Advanced Control," ISA Transactions, Vol. 25 (4), 1986, pp 13 ff
3. Muske, K. R.; and C.S. Finegan; “Analysis of a Class of Statistical Techniques for Estimating the Economic Benefit from Improved Process Control,” CPC VI; (2001) pp. 408-412

For more information:

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