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Determining the true economic value of improved plant information

A new method is proposed for estimating benefits of the technology

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"The system will provide us with better information for better decision-making."

"The investment will increase our flexibility in operations, permitting us to better react to market opportunities."

"With integrated information across the enterprise, we will be better able to utilize our resources."

"This enabling technology is a strategic investment that transcends normal justification."

The above statements may be familiar to those who have reviewed the proposed justification for new investments in process plant information technology. While these assertions may be correct, they are insufficient to serve as a basis for significant financial investments.

Why are they insufficient? As the Meta group has repeatedly noted,[1] the average information system investment for ERP corporate information systems has a *negative* net present value, i.e., the average company would have been financially better off without the investment. While there is no equivalent independent study of process plant information-technology investments, there have been many project failures and an even larger number of disappointments. Clearly there is a wide variability in return on investment for these technologies.

Most in the field can point to some successes where they believe that these investments have produced value and other instances where they have not. There can certainly be many reasons why an investment does not achieve its designated return, including poor implementation and institutional resistance to changing business practices. However, a major reason is a lack of clarity on the sources and magnitude of the expected economic return from the system. Moreover, without a clear definition of expected benefits, it is difficult—if not impossible—to post-audit the installation to determine if the benefits were actually received.

Without an estimate of actual benefits and a general acceptance of these estimates, it is difficult to sustain access to required organizational resources for long-term system support. Suppose your plant manager asks you whether the information technology investment that you just spent eight months and half a million dollars implementing has delivered any quantifiable business value. How would you respond?

All companies have limited capital availability for investment. Investments in information systems or other technologies that improve information availability have to compete for funds against alternative investments in equipment, facilities and other system applications. The overall requirement is to focus investments on those areas where there are solid returns, where there is real business value rather than simply interesting technology. Moreover, it is still necessary to determine *which* investments in improved information to make from the wide variety of potential options and *how much* it is justified to spend on them.

Decisions about such investments are sometimes made based on "strategic considerations" or "improved flexibility," or based on the particular prejudices of the key decision-maker or the communication skills of the internal champion. This is not to be overly dismissive. If someone has been promoted to the role of key decision-maker, his or her decisions and intuitions have probably been right more often than wrong. Good managers are normally good decision-makers. The issue is that the environment today has possibly changed and yesterday's practices may no longer be valid. The discipline of rigorous financial analysis needs to be extended to these information-technology investment evaluations and decisions.

Why is this a problem? What is special about information-technology investments? Ultimately, the value of any financial investment comes from increased production value at the same costs, or the same production value at lower costs or lower overall invested capital. Information technology doesn't actually do anything directly to create these conditions. It provides us with a better basis for making a decision that will lead to increased value. What is the value of an investment that gives us the option of taking action? How is the value of information that allows the *possibility* of making a better decision assessed?

In one sense, the answer to the questions raised is simple: *The value of information technology is the expected value of decisions made with it, less the expected value of decisions made without it.*

However, this just changes the question to the equally hard one of how to calculate this expected value.

The focus here is with technology whose primary purpose is to provide better information about the current and past state of the plant than would be available without the investment. Such potential investments might include real-time historians and other plant databases, "smart" instrumentation to provide improved diagnostic information on instrumentation and equipment, improved data analysis software and/or improved user interfaces. In some cases, infrastructure investments, i.e., improved plant networks would fit the proposed model.

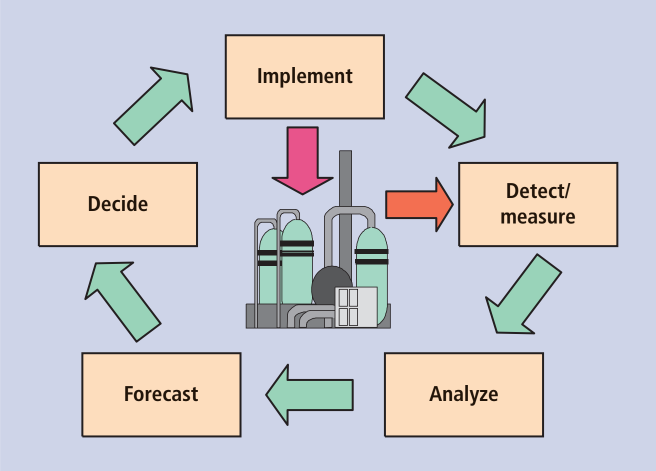

FIG. 1 The decision cycle for plant operations is a useful model for organizing and categorizing advanced system-oriented technologies in the production area.

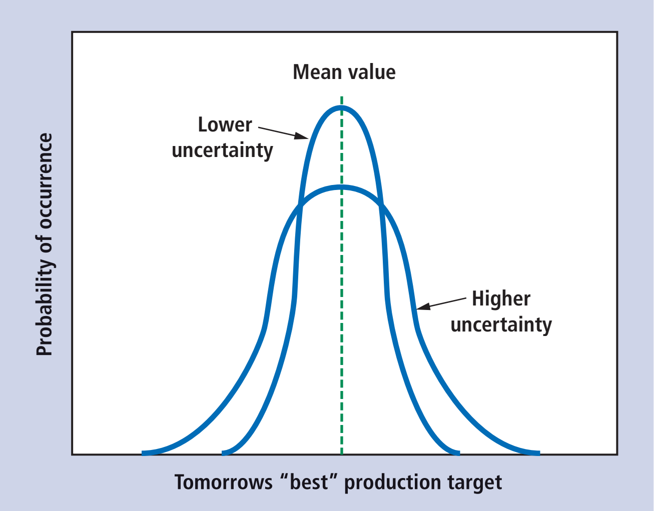

FIG. 2 The uncertainty in the choice can be represented by a probably distribution vs. targets.

Of course, information-technology investments may yield a clear reduction in production costs for performing a required business function. For example, a laboratory information system that automatically retrieves information from laboratory analyzers may reduce the requirement for manual data entry. A data aggregation system may reduce the time required by production staff to retrieve required data. If labor costs for these activities can actually be eliminated or shifted to higher-valued activity, there will be a net quantitative benefit. Such benefits would be in addition to those discussed here.

There also can be other reasons for installing these technologies beyond a strict financial analysis. Some information-technology investments are mandated to meet regulatory or financial accounting requirements. These fall into the "cost of doing business" category and the right strategy is to meet the requirements at the lowest possible total cost of ownership. Information technology can also provide infrastructure requirements for another system, i.e., an information system required to aggregate data for a scheduling system or a production accounting system. Investment costs and return on such investments should be considered as part of the overall system evaluation.

Finally, some smaller investments, or even some large ones, can have very obvious and high ROI and don't require more detailed analysis. With these investments, the action should be to install them as soon as possible, start capturing the benefits and not waste time on further analysis. The subject of this article is investments that don't fall into one of these simpler categories.

Background and previous work. Among system applications, attempts to quantitatively estimate the benefits of modern information technology have been popular since the early days of its use. A search for books on Amazon.com on this subject at the time of preparing this article resulted in 55,477 citations: almost 1,000 in the past four years alone. A recent survey by Berghout[2] identified over 60 distinct approaches to evaluating benefits. Some recent books on the subject are by Thorp[3] and Digrius and Keen.[4]

Not all of these commentaries are favorable toward information-technology investments, most notably the books by Paul Strassman,[5] who uses a macroeconomic approach to analyze their benefits, and a recent article by Carr,[6] who considers individual corporate competitive factors. Restricting the subject to typical manufacturing information and automation technology, there are fewer previous references on benefits. Koppel[7] presents an approach based on typical manufacturing costs and revenue components.

Decision cycle. As discussed in a previous article,[8] the decision cycle for plant operations (Fig. 1) is a useful model for organizing and categorizing advanced system-oriented technologies in the production area.

An opportunity, a problem or a deviation from plan is observed. The first step is to *measure* conditions in the plant or *detect* changes of state to bound the situation and provide base data. At this point, there is a preliminary definition of the scope of the problem/opportunity and, most importantly, how much time is available to develop an answer.

Next the data are *analyzed* to obtain the best possible estimate of current system (plant) performance and its history, to potentially spot an anomaly, identify the uncertainties and estimate cost and time requirements for obtaining more information. This further refines the problem/opportunity statement and relevant time frames. The outcomes of future alternative action scenarios are forecast. The criteria for *decisions* are developed and a recommended action plan is proposed, including timing. Based on preferences (maybe prejudices) and system constraints—again, most particularly, time constraints—a plan is actually *implemented.*

After this, the cycle repeats. Examples of decisions made in this framework include what products to produce and when to produce them, decisions on the resources required for production including feedstocks and manpower, and decisions on when to perform maintenance on particular equipment.

Note that this is not a universal model for all plant decisions. It is not the way decisions are made on who to promote, who should be designated for working a particular shift and a host of other similar questions. It is, however, similar to decision models in other areas where choices must be made to solve an operational problem with time constraints.

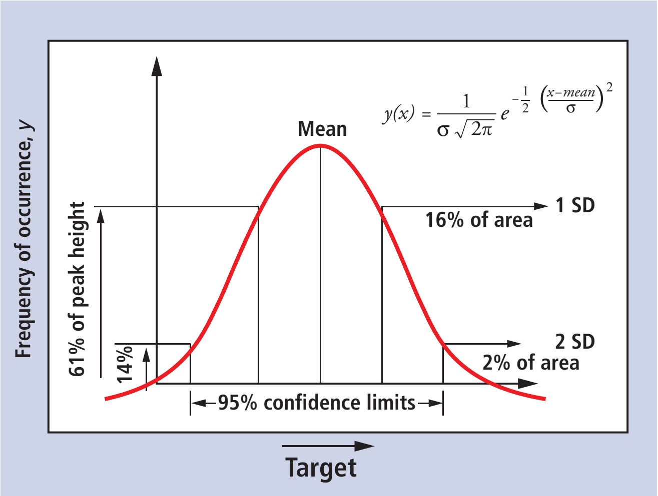

FIG. 3 Commonly, the 95% confidence limits denote the range on the axis that contains 95% of the distribution and that corresponds to roughly two standard deviations from the mean.

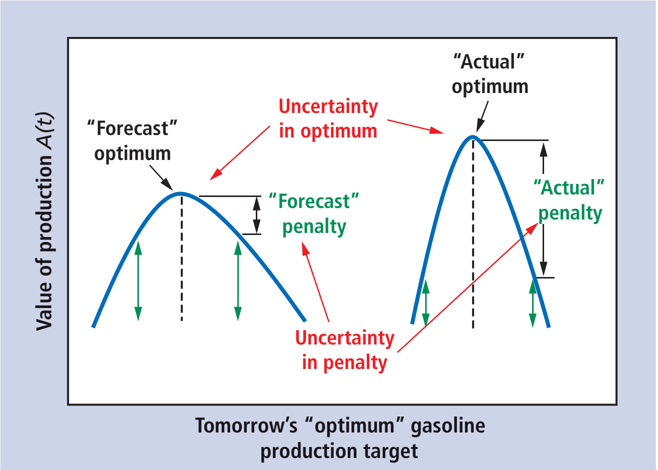

FIG. 4 If the value curve is relatively flat, there is a small penalty for nonoptimum operation.

The popular "six sigma" process has its define, measure, analyze, improve and control (DMAIC) steps.[9] DMAIC entails defining a problem precisely, measuring to bound and clarify it, analyzing the business process associated with the problem to identify the problem's root cause, improving the process by considering alternative solutions and selecting and implementing the best one, and controlling the process through ongoing measurement to ensure that the problem does not recur. The US Army has its similar observe, orient, decide and act (OODA) loop that it uses to understand battlefield issues and evaluate technology, organization and procedures.[4]

In this article, the focus is on potential investments that improve the *detect/measure* and *analyze* components of the cycle. An issue raised by these investments, and a common point of debate/confusion is that their value is only recognized when an actual decision is implemented. As stated previously, what is the value of information that offers the *potential* to improve a decision/plan?

Previous work on decision modeling is also extensive. The book by Raiffa[10] is considered a thorough, modern introduction to the overall subject. One significant area of decision modeling in a plant operations environment has concerned abnormal event responses as noted in a recent survey.[11]

Modeling uncertainty. To analyze this question, the concept of uncertainty and its relation to decisions is central. Obviously, the future is unknown and actual outcomes from decisions are always uncertain. In the general business environment, these uncertainties come from unexpected changes in general economic and market conditions and from competitor actions. For a production plant, these effects are observed as unanticipated changes in prices and demands for feedstocks, products and utilities. In addition, there are unscheduled equipment outages, shipping and receipt schedule changes and many other disturbances. Intuitively, it can be recognized that these uncertainties increase as the projection extends further into the future.

For analysis purposes, it is necessary to model these uncertainties. This is perhaps best explained with an example. Assume that the requirement is to set a "best" target for tomorrow's plant production by whatever criteria are used for "best." The uncertainty in the choice can be represented by a probability distribution function versus various targets (Fig. 2) with the most likely "best" value at our chosen target and declining probabilities as the production moves away from the chosen value. If the uncertainties are assumed small, a high probability would be attached to the chosen value and a very narrow range of possible alternative "best" values expected. If, however, the uncertainties are determined to be large, they can be characterized with a flatter distribution (Fig. 2). If the probability distribution is assumed Gaussian or normal, uncertainties can be characterized in terms of the normalized standard deviation or variance of the distribution function.

Commonly, the 95% confidence limits denote the range on the axis that contains 95% of the distribution and that corresponds to roughly two standard deviations from the mean (Fig. 3). A small confidence limit means low uncertainty and a large one means higher uncertainty.

In summary, the value of an information investment lies in reducing the uncertainty distribution function, i.e., reducing the confidence limits of the projected "best" operating policy going forward. We "move the clock forward" and improve our ability to forecast future policies. This is not a surprising result. Claude Shannon,[12] in his well-known analyses and theorems, defines "information" in communication theory as reduced uncertainty by the receiver of the information about the information source. However, how is this reduction converted into economic value?

The value of a decision. Fig. 4 shows a typical plant decision scenario. Assume that the "optimum" or "best" operating policy for the plant has been determined, and this generates an expected economic profit. Production amounts plus or minus from this optimum will result in an overall production value less than optimum. If the forecast value of the production assumes a quadratic form with a maximum at the optimum value, its shape is as shown in Fig. 4. If the value curve is relatively flat, there is a small penalty for nonoptimum operation, defining the penalty as the loss in value for one unit of production more or less than the optimum.

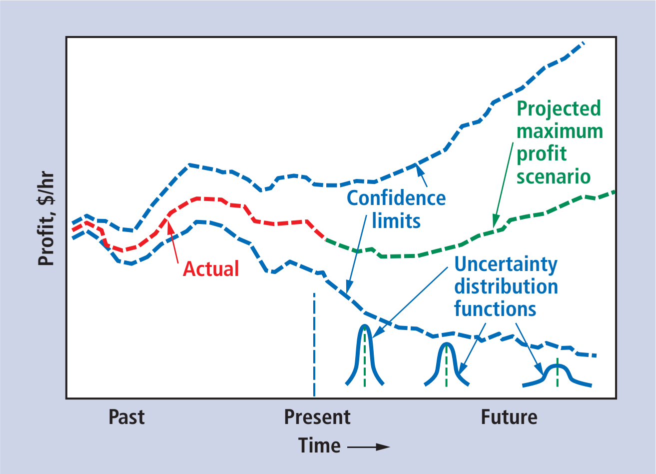

FIG. 5 The uncertainty in the optimum operation limits can be represented by the lines of constant confidence limits.

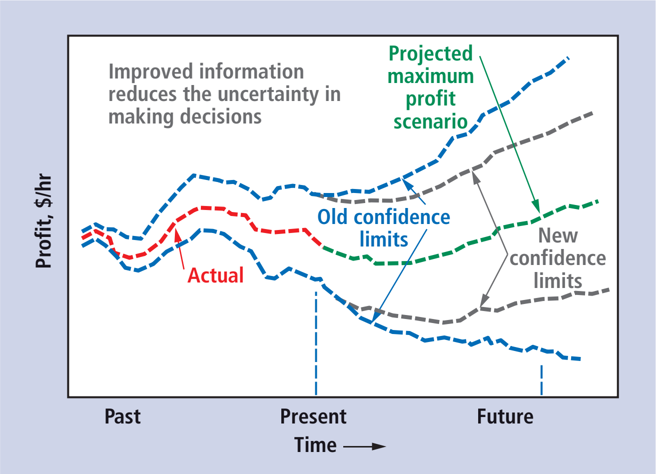

FIG. 6 Information-technology benefits can generate value by reducing future uncertainty in projected cash flows.

This penalty is sometimes called the marginal value. If the curve is steep, there is a large penalty. Two types of uncertainty are possible. The actual optimum may be different than the forecast optimum. In addition, the actual penalty for nonoptimum operation may be different than the forecast. Both the optimum and the penalty can be modeled as random variables with a given mean and variance.

The uncertainty in the optimum operating policy can be represented by the lines of constant confidence limits in Fig. 5. As stated before, this uncertainty is expected to increase the further into the future the policy is projected. A similar figure for the uncertainty in the penalty for nonoptimum operation can be developed.

The value of a decision can be taken in standard financial terms as the expected present discounted value of the forecast after-tax cash flow, $EA(t,\sigma)$. This can be expressed mathematically as:

$$E\left[A(t)\right] = E\left[\int_0^\infty A(t,\sigma)e^{-rt}\mathrm{d}t\right]$$

where r is the appropriate discount rate.[13] The question now becomes: "What is the appropriate discount rate?"

An example may make the answer clearer. Suppose you have the choice of buying a US treasury bond for $100 that will almost surely return $105 in one year. You also have the alternative choice of buying a stock that is projected to be worth $105 in one year, but it could be worth more or it could be worth less. The uncertainty in the value of the stock can be characterized by saying that the expected value in one year is $105 with a standard deviation of 12% (typical for an individual stock). A rational investor would always pay less for the stock than the bond. Indeed, in standard financial analysis,[4,7] the amount you would be willing to pay (assuming the stock has a covariance of 1 with your overall portfolio) is:

Price = expected value of asset at end of period/(1 + *risk-free discount rate for period* + *k* times *standard deviation of expected value*)

P = ($105)/[1+ 0.05 + k (0.12)] = $95.62; for k = 0.4 (a typical value)

where k = market price of risk, i.e., the amount by which the return of the stock must increase over the risk-free bond to compensate for the risk.

The appropriate discount rate to use for an investment is the risk-free rate plus an adjustment factor equal to a constant times the standard deviation. In other words, risky assets are worth less than stable assets of the same expected value, which confirms our intuitive bias.

By analogy, the appropriate discount rate for the future value of a decision depends on its uncertainty with a high value justified when the uncertainty is high and a lower one when the uncertainty is less. This leads to the central point of this article:

Information technology investments can generate value by reducing future uncertainty in projected cash flows and the economic reflection of this effect is to reduce the required discount rate and hence to increase the expected value of the decisions made with the information.

This effect can be seen in Fig. 6.

Another way of looking at the effect is shown in Fig. 7. Consider the discrete equivalent of the integral above for the limiting case where the after-tax cash flow *(ATCF)* is forecast at a constant $A per year, and the discount rate is r (r less than 1). Then the value, V, of the asset is given by the formula below. As r gets smaller, the value increases.

$$V = \sum_{n=1}^{n=\infty} \frac{A}{(1+r)^n} = \frac{A}{r}$$

As the standard deviation of the expected value is reduced, the net present value increases. Asymptotically, at zero standard deviation or "perfect" certainty, the expected value equals the net present value with no uncertainty premium. At the other end, if the uncertainty is high enough, the current expected net value becomes very small.

Some corollaries: This approach to value analysis leads to some associated propositions.

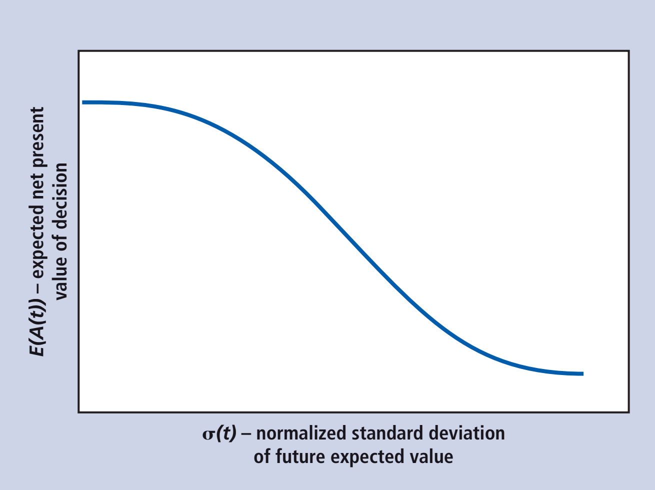

FIG. 7 As the standard deviation of the expected value is reduced, the net present value increases.

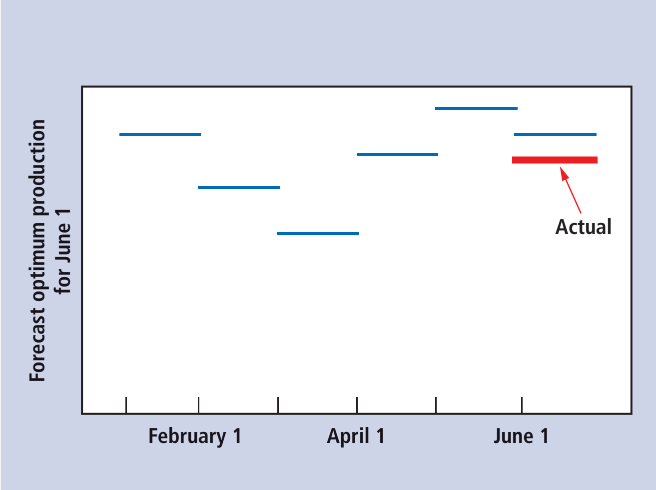

FIG. 8 This same procedure can be used to post-audit the installation.

The greater the uncertainty in the business and production environment, the greater the potential benefits from the information technology. If there is little uncertainty, there is little value to reducing it.

Similarly, if there is no flexibility in operation, i.e., the plant production is fixed and no set of alternative actions is possible, then the information-technology investment has little or no value in the context of this analysis. Similarly, if the information technology does not affect the decisions that have the most economic impact, its economic return will be diminished.

If the optimum for production is flat, which means that there is not much difference in economic value with different production levels, the value of improved information is also less.

The principle of diminishing returns applies to information-technology investments just like everything else. The highest valued investments will be those with the highest uncertainty adjusted marginal value. Improving forecast accuracy from 50% to 90% will be more valuable than improving it from 90% to 99%. There is a limit to the improvement in accuracy of a decision that will be realized from improved information due to the inherent uncertainty of outside events.

Example. Consider a 100,000-bpd refinery. Assume an *ATCF* of \$2/bbl (the US average for 2001). For simplicity in this example, assume the projected cash flow is constant for future periods. Further, assume the base case one-year forecast standard deviation is 20%. This leads to a base-case discount rate for evaluating cash flows from the refinery of 13% ($0.05 + 0.4 \times 0.2 = 0.13$).

Consider the case of an investment in a new real-time historian database for the refinery. The software will provide a platform to collect actual versus planned plant performance, provide a collection point for information about current operation and demands, and provide an enabling platform for other applications. If it is assumed that the software will reduce the one-year forecast standard deviation by 1% with no change in the standard deviation thereafter, the benefits are:

$$\frac{1}{1+0.12} - \frac{1}{1+0.13} \times 100{,}000 \times \$2 \times$$

$$360 \text{ (days operation/yr)} = \$568{,}900 \text{ per yr}$$

In other words, if the net present value of the required investment and increased maintenance and support costs was less than \$568,000, the investment would result in an increase in plant financial value. Other assumptions can be similarly evaluated. This investment could then be compared with others on an objective financial basis to select those that would increase plant value the most.

How to obtain the data. One obvious question concerning the previous analysis: How are the confidence limits and standard deviations of the forecast required for the analysis obtained? The answer: These can be derived from a statistical analysis of successive standard planning forecasts for the same future time period combined with an analysis of the actual production. In other words, the forecasts for the week of June 1 prepared on March 1, April 1, May 1 and June 1 are compared with the actual and ex post facto optimum production for the week. Typical data are shown in Fig. 8.

This same procedure can be used to post-audit the installation. If the information system has benefits, the standard deviation of the forecast should decrease. **HP**

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