Assessing Risk of Innovation

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ABSTRACT

Today's manufacturing systems and equipment must perform at levels thought impossible a decade ago. Companies must push operations, quality, and efficiencies to unprecedented levels while holding down costs. In this new economy, companies must be concerned with market shares, equity growth, market saturation, and profit. U.S. manufacturing is no exception and is a prime example of businesses forced to adapt to constant and rapid changes in customer needs and product mixes, giving rise to the term 'Agile Manufacturing'. The survival and ultimate success of the American Manufacturing economy may depend upon its ability to create, innovate, and quickly assess the impact that new innovations will have on its business practices. Given the need for flexibility, companies need proven methods to predict and measure the impact that new technologies and strategies will have on overall plant performance from an enterprise perspective.

The Value-Derivative Model provides a methodology and approach to assess such impacts in terms of energy savings, production increases, quality impacts, emission reduction, and maintenance and operating costs as they relate to enabling and emerging technologies. This is realized by calculating a set of first order sensitivity parameters obtained from expanding a Taylor Series about the system's operating point. These sensitivity parameters are invariant economic and operational indicators that quantify the impact of any proposed technology in terms of material throughput, efficiency, energy usage, environmental effects, and costs. These parameters also provide a mechanism to define metrics and performance measures that can be qualified in terms of real economic impact. Value-Derivative Analysis can be applied across all manufacturing and production segments of our economy and has found specific use in steel and textiles. Where economic models give the cost of conducting a business, Value-Derivative Analysis provides the cost to conduct business.

Benefits derived from conducting a Value-Derivative Analysis include:

- Reduced operating, support and life-cycle costs through a better understanding of technology impacts
- Energy and waste stream reduction impacts through integrated modeling
- Identification of technologies that are cost-sensitive to infrastructure
- Defensible technology selection
- Identification of cross-cutting technologies
- Ability to map technology needs onto functional requirements
- Track technology and innovation impacts on the enterprise
- Determine true worth of technologies and total cost of ownership

INTRODUCTION

In today's manufacturing environment, systems and equipment are being asked to perform at levels not thought possible a decade ago. The intent is to push process operations, product quality, and equipment reliability to unprecedented levels while pursuing cost reduction initiatives. Companies realize that this is contradictory in nature - to want to increase process efficiency and productivity without spending the necessary resources to achieve the goal. This violates an economic equivalent to the first law of thermodynamics - you can't get something for nothing. Then why do companies pursue this line of reasoning in the face of new technologies and their potential benefits? It is believed that it stems from the fear that there exists an economic equivalent to the second law of thermodynamics for new innovations –

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you can't even break even. The question is then, WHY?

It is due, in part, to a combination of new corporate strategies and the new economy. Company growth now exists alongside equity, a new economic parameter that doesn't necessarily equate to profit. As detailed in ISA's (The Instrumentation, Systems and Automation Society - www.isa.org) InTech Magazine [1], profit is optional, what is important is market shares, equity growth, and market saturation. According to ISA, profit occupies the fourth position on the list of economic measures of performance. What this points out is that companies no longer rely on the old economic indices such as profit, revenue, dividends, or investments (R&D) to determine their complete worth. They now rely on metrics that are sometimes speculative in nature, increasing stock prices but not necessarily the company's growth. The problem then, is how does a company balance R&D expenditures against investment risk? The fact that companies are reluctant (anxious) to take on the responsibility of managing these risks associated with new technologies compounds the issue. They see a tremendous amount of uncertainty associated with calculating total process impact and fear the mysticism that may be required for such a venture. What is needed is a methodology and approach that takes the guesswork out of calculating the total cost/benefit for any new technology or innovation. This is what the Value-Derivative Model provides, a new tool for developing and managing investment strategies and risks.

The Value-Derivative Model mitigates risks by first identifying the potential benefits for all processes/subprocesses that can be derived from new technologies or innovations. This is realized by calculating approximations to the first order sensitivity parameters (first derivatives) obtained from expanding a Taylor Series about the system's operating point. These sensitivity parameters are invariant economic and operational indicators for a process that quantify the impact of any proposed technology in terms of material throughput, efficiency changes, energy use, environmental effects, and costs. The model then develops a set of coupled equations from these parameters that links the entire enterprise system together, so that total impact can be calculated. The key to the model is the evaluation of the sensitivity parameters.

The complete list of benefits derived from implementing a Value-Derivative Model includes:

- Calculate process and economic impacts resulting from technology selection (savings in costs, product, energy, efficiency) for a particular process
- Contrast and compare several technologies for a particular process (alternative analysis)
- Strategize / what-if planning based on a set of criteria – risk management
- Select best technology mix based on several criteria (optimization)
- Track process and economic impacts from technology insertion
- Calculate total impact on an enterprise and total cost of ownership for a particular technology
- Contrast / compare cross-cutting technologies across different processes

The Value-Derivative Model can/will have a major impact on business and engineering decisions to select and incorporate new technologies and innovations into processes. The metrics or measures of performance that are derived from the model are well defined and can be used to track technology impacts across the enterprise and over extended periods of operation.

CONDUCTING A VALUE-DERIVATIVE ANALYSIS

Figure 1 shows the six steps required for conducting a complete Value-Derivative Analysis. They are

1. Calculate the Value-Derivative Sensitivity Parameters
2. Develop In-Depth Process Understanding
3. Conduct a Technology Assessment
4. Analyze Plant / Enterprise Impact
5. Identify Cross-cutting Technologies
6. Optimization / What-if Strategies

Each step will be described in detail in the following sections. A seventh step, Return on Investment (ROI) calculation, shown in dashed lines will not be discussed in this paper.

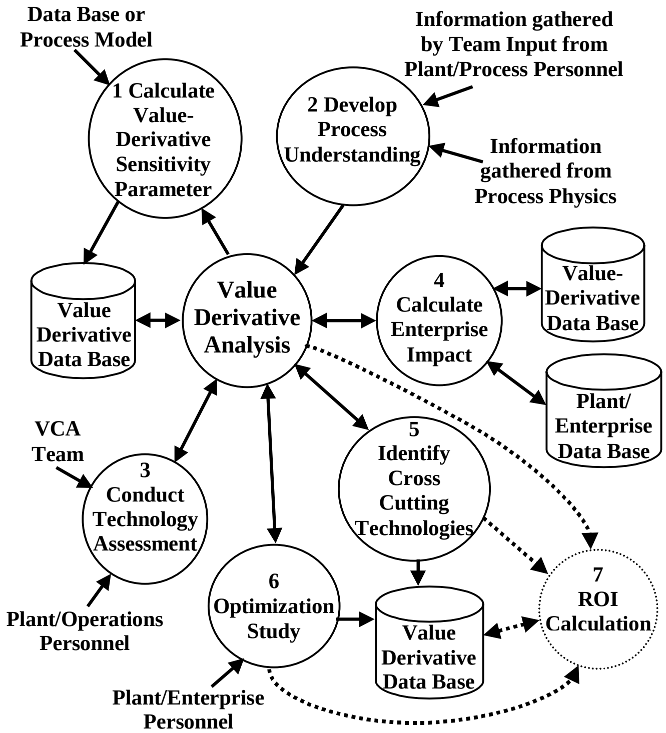

Figure 1 Process flow diagram for Conducting a Value-Derivative Analysis

Step 1 - Conduct Value-Derivative Analysis

The Value-Derivative Model is based on a set of value-derivative sensitivity parameters that are used in all calculations. These parameters are based on a total derivative calculation and are approximations to the first partial derivatives of a multiple variable function. The total derivative concept is derived from the use of a Taylor Series Expansion about an operating point. These parameters are invariant to a process and provide a good measure of performance by which in process and cross process comparisons can be made. Short derivations of these parameters are detailed in following section and are defined below for reference.

ΔEnergy/ΔEfficiency = > Change in process energy / unit change in efficiency

ΔEfficiency/ΔCosts = > Change in process efficiency / unit change in costs

ΔCosts/ΔProduct = > Change in process costs / unit change in product

Other sensitivity parameters can be calculated directly or derived as ratios of other sensitivity parameters.

Another figure of merit derived from these sensitivity parameters is the total power contained within the facility for a particular parameter. The calculation is as follows:

$$\partial X_i / \partial X_j = \sqrt{\Sigma (\partial x_i / \partial x_j)^2}$$

where i and j = costs, efficiency, energy and $i \neq j$.

Step 2 - Develop In-Depth Process Understanding

A requirement for conducting a Value-Derivative Analysis is developing a complete understanding of the process: its product flow, material changes, and procedural steps used in the making the product. This understanding also includes identifying energy use, material residence time, and maintenance and operational procedures. This microscopic view of the process is needed to resolve balance of plant issues and to help understand energy, material, and time management as it applies to the current process. In the course of conducting the Value-Derivative Analysis, a detailed process flow diagram is developed. Roll-ups from these process flow diagrams are then developed along with energy and time management diagrams.

Some of the process variables extracted from the diagrams are used in the calculation of the first order value-derivative sensitivity parameters.

Step 3 - Conduct A Technology Assessment

Using the information extracted from the process flow diagrams, a technology assessment can be conducted for each manufacturer or company. Plant managers and technical representatives for each of the individual subprocesses are asked to sit in on a session to review the findings of the process flow activity. They are also asked to identify new technologies and needs (or innovations) that are considered important to enhancing their operational performance or increasing overall process efficiency. During the review, any proposed need or technology candidate is identified and listed along with its current operating profile, desired profile, and any figures of merit associated with its use. Included in this analysis is the identification of the operational impacts that these technologies will have on the enterprise/plant/process. These indicators include,

Variance defined as labor, maintenance, or productivity

Impact defined in terms of operations, throughput, or quality

Priority Ranking defined in terms of high, medium, or low for the particular process step and numerical (1-10) as it would relate to the entire process.

These indicators provide a measure of importance for each technology or innovation as determined by the plant and technology personnel.

Step - 4 Calculate / Enterprise Impact

After the new technologies and innovations have been identified along with their respective variance, impact, and priority ranking, their economic and process impacts are calculated for the enterprise system. These measures of performance will be in terms of cost saving or yield increases if it were deployed. During a typical study, usually one or the other is given.

Given these economic indicators, the model then calculates three additional parameters; energy, efficiency, and per-process cost savings. Their units and calculations are presented below.

Energy Kw-Hrs/Year (Kw-Hrs/Ton)*(Tons-Saved/Year) (1)

Efficiency[2] % Yield Increase $Tons_{tech}/Tons_{in}$ (2)

Costs $/Year (Tons-Saved/Year)*(Fixed+Variable-Cost/Ton) (3)

These parameters, along with other process data, are used in the subsequent analysis and comparison.

Step 5 - Identify Cross-Cutting Technologies

The next element of the Value-Derivative Analysis is identifying technologies by function and level of technology maturation. This requires classifying them as either emerging / enabling and operational / production and categorizing them by function.

The definition of the four classification terms is as follows:

Emerging: Requiring extensive research and development before the technology can be deployed.

Enabling: Requiring a level of development and engineering before the technology can be deployed.

Operational: Influences variance costs but not necessarily through production.

Production: Influences bottom line production and is assessed as complete costs = variance + fixed.

This categorization scheme will define for each technology its functional requirements and grouping and will enable the identification of cross-cutting technologies to maximize R&D investment dollars

Step 6 - Optimization Study

The last element in conducting the Value-Derivative Analysis is selecting the optimal mix of technologies based on some stated criteria. The optimization scheme to implement this (algorithm or heuristic) will use the economic and process impacts derived from the Value-Derivative Analysis Model coupled with the value-derivative sensitivity parameters to search for an optimal solution in the value space for a given set of hard and soft constraints.

The different optimization approaches include:

Risk Analysis: Risk analysis will determine the process and economic impact of a new operational strategy.

If only one operational strategy is to be analyzed the process and economic impact analysis becomes a straightforward activity using the coupled equations of the enterprise model if the product mix ratios are maintained. However, the optimization module can also provide a parametric analysis for *f(x)* based on per-unit-changes of Pi. If more than one operational strategy is to be analyzed concurrently, the optimization model uses the enterprise's couple equations to estimate changes in *f(x)* assuming the same product mix ratios. As before, the module can also provide the parametric analysis figures for each operational strategy, and ultimately suggest the best implementation sequence for the given operational strategies.

Alternative Analysis: Alternative analysis deals with contrasting and comparing two or more operational strategies.

The optimization module can calculate changes in *f(x)* for each operational strategy using the coupled equations, and provide a ranking based on production cost savings, additional throughput and energy savings assuming the product mix ratios are not changed. As before, the module can also provide the parametric analysis figures for each operational strategy.

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[2] Current efficiency calculation is based on gains relative to current product throughput. It is proposed that efficiency should be calculated on gains relative to product lost = (1-(T_{lost}-T_{gain})/T_{lost})).

Enterprise Analysis: Enterprise Analysis will select the operational strategy or group of operational strategies that will maximize or minimize an objective function given a set of criteria.

Since the sensitivity parameters are invariant for each process regardless of the operational strategies, the module can optimize the enterprise through a two-step procedure as follows. The first step of the optimization algorithm will select the process or processes that meet a set of multi-goal criteria based on the information contained in the sensitivity parameters. The second step will then select the operational strategy or group of operational strategies that maximize the benefits of the process(es) as reflected by *f(x)* and without violating the constraints.

Multiplant Optimization: Multiplant optimization will be used when a organization has more than one manufacturing facility.

If we assume that no transfer takes place between *n* plants, we can create a new

$F(x)=\sum^{k} f_k(x)$ for k = 1,…n and n = number of plants

Then, we can approximate the multiplant sensitivity parameters for common processes across the plants using the power measure as shown below. At this point, we can use the enterprise analysis approach explained above.

$$P_{a,b} = \sqrt{\sum_i \left(\frac{\partial x_a}{\partial x_b} \right)^2}$$

{*a,b* efficiency, product, energy, savings; a≠b} {*i* = process steps in plant}

VALUE-DERIVATIVE ANALYSIS – EXPANSION OF A TAYLOR SERIES AND THE ACCOMPANYING SENSITIVITY PARAMETERS

As stated previously, Value-Derivative Analysis is based on calculating a complete set of value-derivative sensitivity parameters and using them in a coupled set of equations to calculate the impacts on a process from a proposed technology or innovation. The assumption is that the proposed technology or innovations will not change the way manufacturing is made but will affect the operational efficiencies about is current operating point. Given this, the process can than be modeled as a first order Taylor Series expansion with changes being affected as a linear combination of the operating point and the influence of the first differential on a derived benefit. These process gains (production, efficiency, energy, and quality) can be estimated as incremental changes to the operating point. The mathematical formulation of this is defined by the following equation

$$f(x) = f(x_0) + f'(x_0)(x - x_0) + .. + \frac{f^n(x_0)(x-x_0)^n}{n!} + Rn \quad (4)$$

where Rn is a remainder and is ignored in this formulation. This is considered a generalized polynomial expansion about an operating point x_0. In this formulation x_0 is the current plant operating point.

In this expansion, we are only interested in the first and second terms, more specifically the $f'(x_0)$ which is the generalized differential approximation or value-derivative sensitivity term.

The generalized differential approximation (sensitivity) is expanded in general terms as a linear combination of ratios of total differentials of the process changes due to technology innovations, i.e. product, energy, and efficiency. The expansion is

$$\Delta f_{Tech} = \frac{\partial E}{\partial N}\Delta N + \frac{\partial N}{\partial C}\Delta C + \frac{\partial C}{\partial P}\Delta P + \frac{\partial P}{\partial E}\Delta E + \varepsilon \quad (5)$$

and is known as the total differential of a function. Here, E, N, C, P are the energy, efficiency, savings, and product, respectively. ε is the error associated with the approximation and is ignored in the value-derivative model.

Taking the ratios of the predicted incremental changes due to a particular technology or innovation can approximate the partials. Using these approximations, Eq. 5 becomes,

$$\Delta f_{Tech} = \frac{\Delta E}{\Delta N}\Delta N + \frac{\Delta N}{\Delta C}\Delta C + \frac{\Delta C}{\Delta P}\Delta P + \frac{\Delta P}{\Delta E}\Delta E \quad (6)$$

where

$$\frac{\partial E}{\partial N} \approx \frac{\Delta E}{\Delta N},\ \frac{\partial N}{\partial C} \approx \frac{\Delta N}{\Delta C},\ \frac{\partial C}{\partial P} \approx \frac{\Delta C}{\Delta P}, \text{ and } \frac{\partial P}{\partial E} \approx \frac{\Delta P}{\Delta E}.$$

ΔE, ΔN, ΔC, and ΔP are the process differential changes due to a particular technology solution or innovation for energy (kw-hrs), efficiency (% change in yield), cost (dollars), and product (tons), respectively.

In theory, the differential changes can be expanded into their own total differential. Using Eq. (5), the total differential is

$$\Delta f_{Tech} = \frac{\partial f}{\partial x_a}\Delta x_a + \frac{\partial f}{\partial x_b}\Delta x_b + \frac{\partial f}{\partial x_c}\Delta x_c + . \quad (7)$$

Expanding ΔE in its functional terms,

$$E_{Tech}\,(\text{temp, material, product, etc...})$$

and using the general expansion (7), the energy differential becomes

$$E_{Tech} = \frac{\partial E_T}{\partial Tem}\Delta Tem + \frac{\partial E_T}{\partial Mat}\Delta Mat + \frac{\partial E_T}{\partial Prod}\Delta Prod + etc \quad (8)$$

These generalized equations are presented as a reference point for following a generalized line of reasoning using a Taylor Series expansion and first derivatives, (value-derivative) sensitivity parameters, in an expanded series of coupled equations to model the enterprise system.

Figures 2 and 3 show a plot of these sensitivity parameters for two plants where a Value-Derivative analysis was conducted. One of the most interesting features of these plots is the non-linearity of each set of sensitivity parameters associated with each process step. This variability precludes picking one process step and achieving maximum or minimum benefit at a single step. Thus requiring Step 6 - Optimization Study in the Value-Derivative Analysis.

Once these parameters are known, process impacts from technologies and innovations can be calculated directly and easily by simple multiplication, i.e., given an increase in product yield resulting from a new technology, then cost savings, energy savings, and efficiency increases can be calculated as

$$Cost_{Saving} = Product_{Tech} * (\Delta Costs/\Delta Product) \quad (9)$$

$$Energy_{Saving} = Product_{Tech} / (\Delta Product/\Delta Energy) \quad (10)$$

$$Efficiency_{Saving} = Cost_{Saving} * (\Delta Efficiency/\Delta Costs) \quad (11)$$

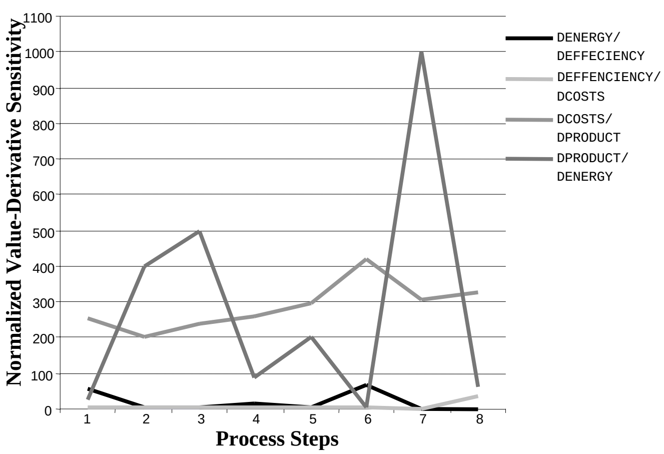

Figure 2 Company 1 Normalized Sensitivity Parameters

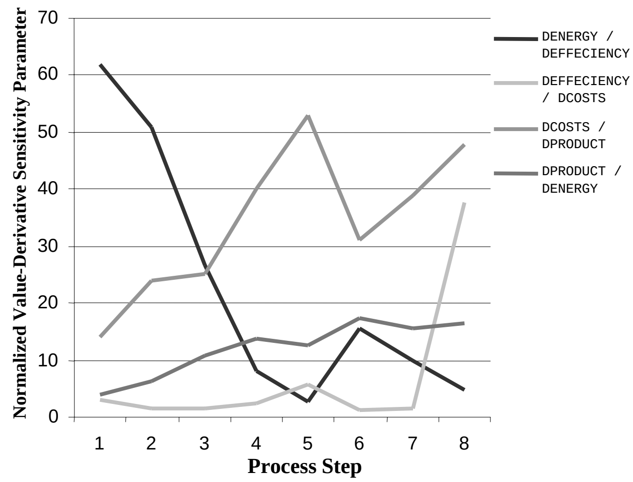

Figure 3 Company 2 Normalized Sensitivity Parameters

CONCLUSIONS

In the new economy, companies will be looking at R&D investments as a means to increase market share and equity along with revenue, profit, and dividends. They will be concerned with understanding the technology's complete impact, what its total cost of ownership will be, and what the uncertainty and risk associated its R&D investments is. In light of this, companies will be looking for ways to reduce or eliminate these fears. The Value-Derivative Model will help in this by making available to these companies a new tool for developing and managing investment strategies and risks.

Value-Derivative Analysis accomplishes this by providing a methodology and approach to assess complete technology impact in terms of material throughput, efficiency changes, energy use, and cost savings. These impacts are quantified through the value-derivative sensitivity parameters.

The benefits derived from conducting a Value Derivative include:

- Quantifying the impact that a particular technology has in a plant in terms of economic benefits, energy saved, efficiency increases, and product gains.
- Providing metrics for a strategic decision making process.
- Identifying unique parameters that can be used to characterize a system's performance.
- Developing an enterprise model.
- Contrasting and comparing different technologies for a particular process or across the enterprise.

- Selecting best technology mix based on a set of criteria (optimization).
- Calculating total impact on an enterprise and total cost of ownership.
- Tracking process and economic impact over time.
- Strategizing (risk management) based on expectations.

The Value-Derivative Model can have a major impact on how companies manage risk and make R&D investment decisions in the future.

REFERENCE

[1] Nicholas Sheble, "New Economy Distracts Many But Can't Thwart Genius", InTech, The Global Source for Instrumentation, Systems, and Automation, ISA Publication, January 2001.