

Modeling Manufacturing Processes to Mitigate Technological Risk

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INTRODUCTION

In today's manufacturing environment, systems and equipment are being asked to perform at levels not thought possible a decade ago. The need is to push process operations, product quality, equipment reliability, availability, and maintainability to unprecedented levels while maintaining cost structures consistent with budgetary constraints. There is also a demand to reduce operational and support costs, as well as, eliminate or minimize new capital investments in plant equipment due to lengthy return on investments which impact short-term capital recovery. In short, manufacturers are trying to invoke new measures to ensure plant performance while minimizing costs and extending the operational life of new and/or aging equipment.

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The only way this can be accomplished without jeopardizing plant safety is through new and innovative approaches in prognostic technologies.

The importance of this can be seen in how the industry views maintenance. It has been proposed that one out of every three dollars spent on preventative maintenance is wasted, implying that current predictive maintenance methods are ineffective in providing the level of oversight and management needed for manufacturing processes. Considering the corporate value of these expenses, one can begin to understand the need for new methodologies and approaches and appreciate the cardinal opportunity this represents for significant cost and energy savings.

There is another issue driving organizations to rethink how they spend their resources—downsizing. The loss of personnel, particularly those representing the corporate history in this area, has removed the experience base that companies have previously relied on to keep the plants and equipment running. This has become painfully clear in manufacturing facilities where unexplained increases in equipment shutdowns have resulted in revenue losses. These facilities have begun to understand the significance these skills play in proper maintenance and diagnostics. This realization has shifted the focus away from reacting to equipment failures to anticipating system and equipment needs, a proactive approach.

Given the need for innovative approaches, new sensors, systems, and methods for interrogating, diagnosing, and controlling systems must be developed. What will be required then, is an investment strategy and economic approach that mitigates the R&D risks for a company. This strategy must:

- guarantee no blind technology alleys;
- provide a holistic view and approach to solving the problem;
- provide a robust solution that is crosscutting;
- establish early decision points;
- establish short-, near- and future requirements; and
- match sensor/system requirements with customer expectations.

In order to achieve this, economic indices (operational and costs) have to be developed that quantify and qualify the ability of a proposed technology to meet the functional and operational

needs of a process. Therefore, the investment strategy has to provide control points in the development cycle (see Fig. 1) that can be used to access sensor capability. Integral to this is the economic model that provides a break-even analysis and sensor and system performance assessment based on the economic concentration of losses and the ability of a proposed sensor to meet systematic needs. This model becomes the tool by which a company can justify continued research and development (R&D) expenditures for new technologies. This model can also play a role as an economic diagnostic algorithm in a closed-loop control scheme.

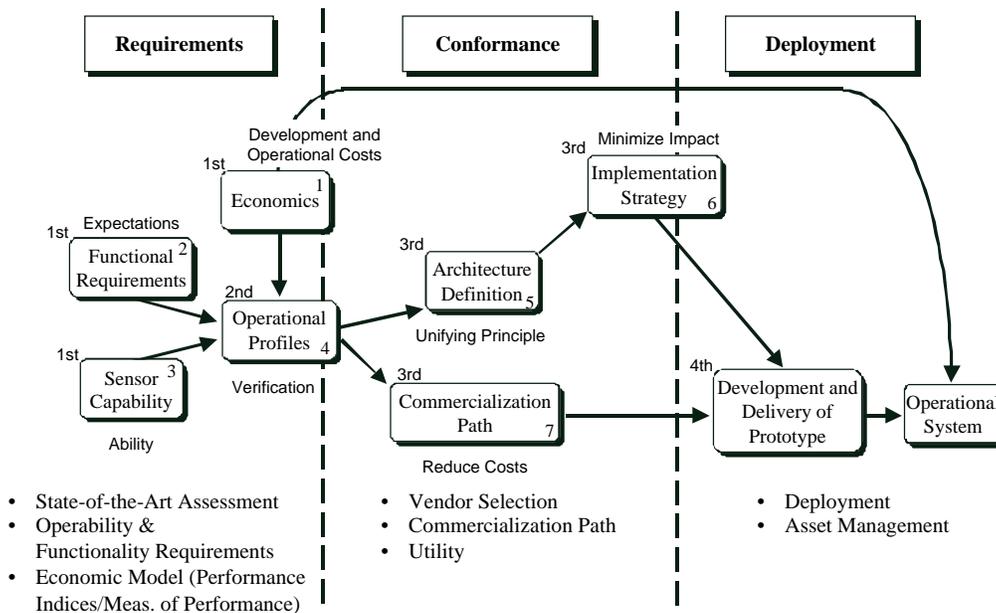


Fig. 1. CBM investment strategy for new technology insertion.

THE ECONOMIC MODEL

The Economic Model - A Justification and Strategy Tool

The economic model is a tool for determining the economically justifiable cost of R&D as weighed against the projected (future) costs of capital investments based on some fixed rate of return. This model provides a mechanism by which valid

comparisons can be made between proposed technologies to determine which will go forward and which will be suspended. It also provides an avenue for considering collaboration between sensor/subsystems; i.e., calculating the associated costs of deploying a complimentary system and its projected return on investment, reducing the economic risk. The future value of the projected price point is used as a fixed cost constraint in the development cycle. In the model, capital investments included implementation costs, system

downtime while deploying the sensor/system, impact on the infrastructure, education/training, and reduction of personnel due to the elimination of nonvalue-added tasks (see Fig. 2).

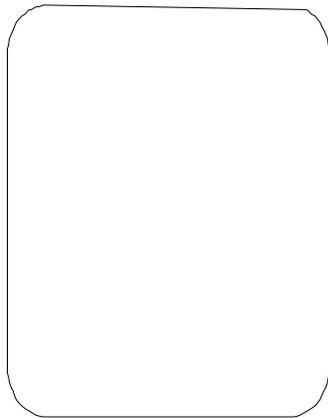


Fig. 2. When applied correctly, an economic model identifies hidden and support costs.

The role of the economic model as an R&D investment tool is extremely important when considering the differing views that may arise when dealing with collaborative industry partners. Differences occur when individual partners begin developing their own specific definition of economic viability and cost. When each is compared as a group, contrasting views of extent and need develop. Resolving this point of contention requires an economic model that provides the capability for a single partner to run strategic what-if scenarios using the operational bounds developed by the group. The results define a global control and decision point surface that can be used to suspend certain activities or continue others. Thus, decisions are not based solely on their functional capability but also on their economic content and value to the industry as a whole.

The Specific Functions of an Economic Model

The model has six specific functions.

1. Determine profit/loss for a particular process.

2. Tailor these numbers to a per product per customer basis for implementing control points in a closed-loop control scheme.
3. Deliver real-time economic data to allow sensitivity to production parameters, which enable real-time decision making at the process level.
4. Provide an interactive tool for economic assessment based on off-line statistical analysis and changes in customer base or needs.
5. Assessment tool for developing economic indicators to determine disposition of current technology activities.
6. A technology evaluator that drives innovation.

Function (1) provides the economic data that shows the average economic loss of a process as a result of off-operational performance. This assessment provides the economic justification for technology improvements. Function (2) targets the economic data particular to a product or customer providing specific information for a particular process. Function (3) can provide quantified data to a control point in the closed-loop scheme. Function (4) provides the user interface for parametric studies and what-if gaming exercises. Function (5) provides the measures by which proposed technologies will be graded. These indicators include functionality, operability, and utility as well as R&D costs to commercialization, fixed (manufactured) costs, per-unit variable costs, and final delivered costs (training/education/support). Function (6) (see Fig. 3) provides a tool to evaluate technologies based on their economic impact on the process. The evaluation includes conducting business as usual and identifying those opportunity costs that can be gained from advanced sensor/system design. When applied expressly, this tool can define effective measures of performance (both cost and operational) and a path for commercialization.

The Economic Model Architecture - Three Integrated Modules

The economic model consists of three components: Break-Even Analysis Module, Sensor Performance Analysis Module, and the System

Performance Analysis Module. Each is designed to analyze one aspect of the benefits to be realized by implementing a new technology or approach.

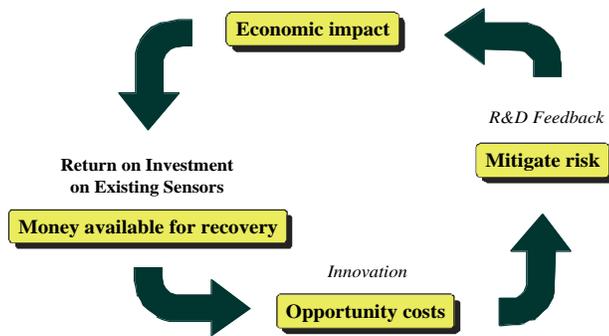


Fig. 3. Economic requirements will drive innovation and advanced sensor capabilities.

Break-Even Analysis Module (System Capital Costs for a Break-Even Period) – Economic decisions on capital investments are strongly influenced by the payback period. These time intervals are a selection criteria. This break-even constraint strongly influences the functionality of any new sensor, equipment, and/or system and obliges suppliers to consider the cost of the sensor/equipment and estimate the profits and/or savings the sensor/equipment will generate for a customer.

This module evaluates costs and savings by taking the following attributes into account: equipment costs, installation costs, training and operating, and troubleshooting. Cost savings from initial investments resulting from deploying a technology includes: reduced operations, reduced off-quality, reduced work-in-process, and tax benefits from depreciation and capital investments. The modules used in calculating the break-even period are listed below.

- **Labor Costs.** This module computes the hourly cost for five categories of employees involved in the process. The rates are derived from wages and fringe benefits for each category. This module also calculates the total number of support personnel needed which is used in determining the training and education costs.

- **Installation and Training.** This module calculates the costs of the equipment, contracted installers, machine downtime for installation, and training employees.
- **Operations and Maintenance.** This module calculates the monthly savings of operations and maintenance compared with the existing system. It assumes the manufacturer will perform the required repair and service for a fixed percentage of cost.
- **Reduction of Off-Quality and Inventory.** This module calculates the savings from off-quality and inventory reductions.

In addition to the above, the module also includes tax savings from depreciation of initial investment and after tax cash flow (timing of costs and savings).

Sensor Performance Analysis Module – A probabilistic model designed to assess the performance of a proposed sensor in terms of its capability to meet the functional requirements of the process (its added value). The model is based on conditional probability and takes into account both false positive and false negative impacts (total probability of false decisions per sensor). The module computes the total probability of truth and false decisions for the system; it accommodates combined sensors if several sensors/subsystems are integrated into the process. This probability is then factored into the System Performance Analysis Module to determine if the cost of implementing the system more than offsets the cost of not meeting the functional needs. This is accomplished by assigning operational and economic metrics to the probability function for each sensor/subsystem.

This module can be used to quantify (in a probabilistic sense) the added value that a particular sensor (or group of sensors) brings to a process.

System Performance Analysis Module – This module provides the model’s predictive capabilities. It has four basic functions: (1) determine profit/loss for a process based on its operation and downtime history, (2) tailor these numbers to a per product per

customer basis, (3) interact with the operator (i.e., on-line) to allow for what-if scenarios, and (4) deliver real-time economic data to enable real-time production decisions at the equipment, process, and plant level. It can use statistical data, user inputs, material status, and production diagnostics. The output from the module consists of predicted production costs and recommended process decisions. The first output can go to the user in response to queries or as alarm/alert signal. The second can be fed to a system to determine real-time control strategies. Figure 4 illustrates this flow.

The current System Performance Analysis Module uses a Taguchi function to calculate production losses. In this, the model reflects the progression from optimized to off-operational to catastrophic failure. It is a quadratic function rather than a step function. The underlying reason for this is that an operator (customer) always perceives a loss when the process is anything less than optimal. Thus, the model can internalize customer dissatisfaction with marginal operations.

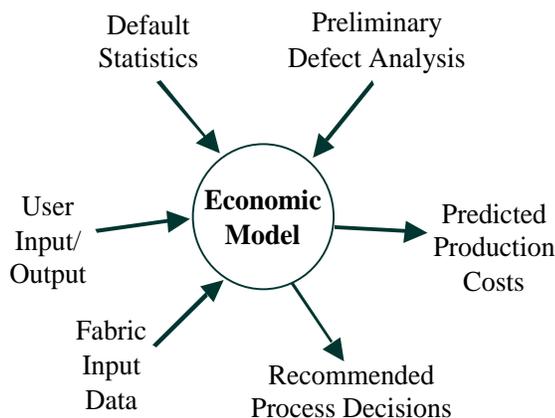


Fig. 4. System Performance Analysis Module as a real-time process.

EXAMPLE - THE COMPUTER-AIDED FABRIC EVALUATION (CAFE) PROJECT¹⁻²

Over the past 10 years, the U.S. textile industry has lost over 800,000 jobs to offshore competitors. It is envisioned that within the next 8 years, this

number will grow to over 1.0 million. To stem these losses, the textile industry entered into a cooperative research and development agreement (CRADA) with the Department of Energy (DOE) to leverage technologies and capabilities at the laboratories for the purpose of gaining an economic advantage. Several projects spun out of this relationship, one being the CAFE Project. Its purpose is to insert technologies that optimize process efficiency, increase cloth quality, reduce the number of seconds, eliminate nonvalue-added labor tasks, and provide an immediate feedback to the operators to remediate defects as they are being made. In order to achieve these goals, economic indicators (operational and costs) had to be developed to quantify the ability of a proposed technology to meet the functional needs of the industry. This required the development of an investment strategy that provided control points in the development cycle. A part of this strategy was the economic model that provided the Break-Even Analysis, Sensor, and System Performance Analysis Modules. For CAFE, the model was applied to commercial-off-the-shelf (COTS) equipment (accelerometers and acoustic devices) and new sensor/subsystems (microwave, ultrasonics, laser, vision, etc.).

The CAFE economic model was intended as a tool for determining the economically justifiable cost of R&D weighed against the projected costs of capital investments based on a fixed rate of return. This provided a defensible comparison between proposed technologies and a determination on which would go forward and which will be suspended. It also provided an avenue for considering collaboration between sensor/subsystems; i.e., calculating the associated costs of deploying a complimentary system and its projected return on investment. The model provided a mechanism for reducing economic risk for the industry partners. The future value of the projected price point was used as a fixed price constraint in development. In the model, capital investments included implementation costs, system downtime while integrating the system into the infrastructure, education/training, and reduction of personnel due to the elimination of nonvalue-added tasks. An additional benefit from the development of the

model is its use as a control point in the closed loop control scheme.

The CAFE economic model was implemented as an integral part of a baseline closed-loop control scheme. As shown in Fig. 5, it supported a managed process support paradigm (demand activated maintenance) based on contextual needs and not just process physics.

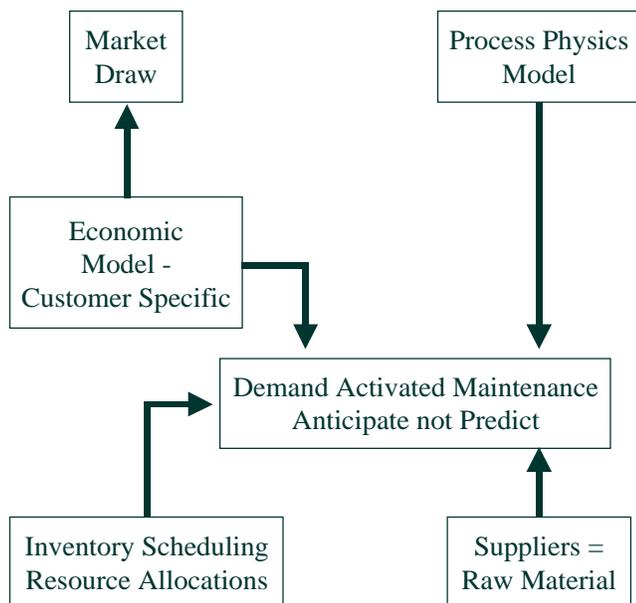


Fig. 5. The CAFE economic model used in the demand activated maintenance paradigm.

SUMMARY

An economic model is a tool for determining the justifiable cost of new sensors and subsystems with respect to value and operation. This process balances the R&D costs against the expense of maintaining current operations and allows for a method to calculate economic indices of performance that can be used as control points in deciding whether to continue development or suspend actions. The model can also be used as an integral part of an overall control loop utilizing real-time process data from the sensor groups to make production decisions (stop production and repair machine, continue and warn of anticipated problems, queue for repairs, etc.).

This model has been successfully used and deployed in the CAFE Project. The economic model was one of seven (see Fig. 1) elements critical in developing an investment strategy. It has been successfully used in guiding the R&D activities on the CAFE Project, suspending activities on three new sensor technologies, and continuing development of two others. The model has also been used to justify the development of a new prognostic approach for diagnosing machine health using COTS equipment and a new algorithmic approach.

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