Web-Based Economic Optimization Tools for Reducing Operating Costs

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Abstract:

The water and wastewater industries have many areas or "islands" of operations that offer significant opportunities to lower costs while maintaining or even improving operating performance via advanced real-time optimization software. The concept of optimization can be considered as having two ideas: 1) that of evaluating multiple options based on real-time data from the supervisory control system, and 2) making a choice on what option to peruse based on pre-defined cost models.

For example, in a situation where two or more pieces of equipment can perform a function, real-time optimization selects the most efficient equipment for the task. In a pump station, there can be multiple pump elements with varying efficiency, making it possible to economically assign flows among them based on their efficiency. One of the largest costs in water treatment is electrical energy. The balancing of storage capacity against the time-of-day electrical costs is an area that can be very effectively addressed with advanced optimization software. Pumping networks, aeration blowers, and chemical utilization are also areas where modeling and optimization technology can reduce costs and improve the operational effectiveness.

An optimization program that can communicate to the supervisory control and data acquisition system (SCADA) can perform this task, as it has access to all of the data necessary to perform the calculations to be executed in a real time environment. In addition, "what-if" studies can be facilitated for understanding the impacts on electrical contract changes, time-of-day demand ratchet clauses, storage requirements against pumping capacity, and cost functions of the operation.

The ideal optimizer would provide this integrated capability. It would be a generic solver for the mixed integer linear/nonlinear optimization problems in plant operations.

This paper provides an overview of advanced real-time linear and non-linear optimization and reviews an equation-derived, model-based approach to economic optimization. It will also examine software and hardware requirements, the use of web-based graphical user interfaces, modeling techniques and capabilities, mathematical considerations, and the ability to utilize optimization in either open- or closed-loop control.

Background:

Optimization and advanced control solutions have been successfully employed for a number a years. Advanced mathematical models, neural networks, and fuzzy logic techniques designed to find optimal control solutions were developed in various academic and research environments. These optimization technologies were initially expensive and difficult to implement and they required significant expertise. They were primarily employed in sizeable process and power-industry applications with substantial economic incentives to maximize production while minimizing operating costs. With the progress in both optimization technologies and computing platforms, these techniques are now widely available and inexpensive and can be successfully employed in virtually any process control application including water and wastewater treatment plants.

There are a number of areas where advanced control and optimization are applicable to the water and wastewater industries. Government and municipal agencies are under pressure to control operating costs while also meeting ever-stricter environmental regulations. In addition, under GASB 34 (Government Accounting Standards Board), municipal owners of water and wastewater facilities must define the value of their assets and report depreciation and other expenses. This, in turn, focuses attention on the management and stewardship of those assets. Optimizing the use of assets is one approach to better management.

Challenges for Optimization

Areas that may benefit from a close review of operations and optimization of resources include:

- Energy consumption
  - Efficient use of pumps – water distribution pumps, lift pumps, main sewage pumps, etc.
  - Efficient use of aeration blowers
- Chemical costs
  - Chemical usage
  - Residence time vs. flow
- Area-wide maintenance management
- Resource optimization
- Equipment usage and performance
- More effective utilization of maintenance and operations personnel

Approaches

A macroscopic look at the possibilities for operational improvement would include

(1) listing the equipment that could be optimized, (2) systematically assessing the current performance of that equipment, (3) benchmarking the existing characteristics of that equipment's operating profiles, and (4) prioritizing key areas for detailed analysis. Before investing in a generic software package, owners have typically utilized the services of specialty consultants, if in-house expertise is not available, to perform a review of current conditions and to estimate cost benefits for specific software applications.

With respect to equipment performance, the process is as follows for each identified unit.

- Collect process information, machinery health information, and nameplate design data for each piece of equipment.
- Analyze the efficiency of pumps, motors, and blowers, etc. Standard test codes are widely available to perform these calculations in real time.
- Track actual performance against design specifications
- Provide status data to the computerized maintenance management system (CMMS) and other systems

A product known as a Global Performance Advisor is one example of a program that provides this information. This is a standalone software application that communicates to the DCS or SCADA system via OPC or an application program interface (API), performs the calculations, and provides the results back to the control system, to a plant historian, and/or to a data server, depending on the application. It provides standard calculation algorithms per the test codes, configurable through a user friendly Windows®-based graphical user interface tool and presents the results locally via graphical displays and to the control system, historian, or data server for report generation. The results of these calculations can also be delivered to the plant computerized maintenance management system.

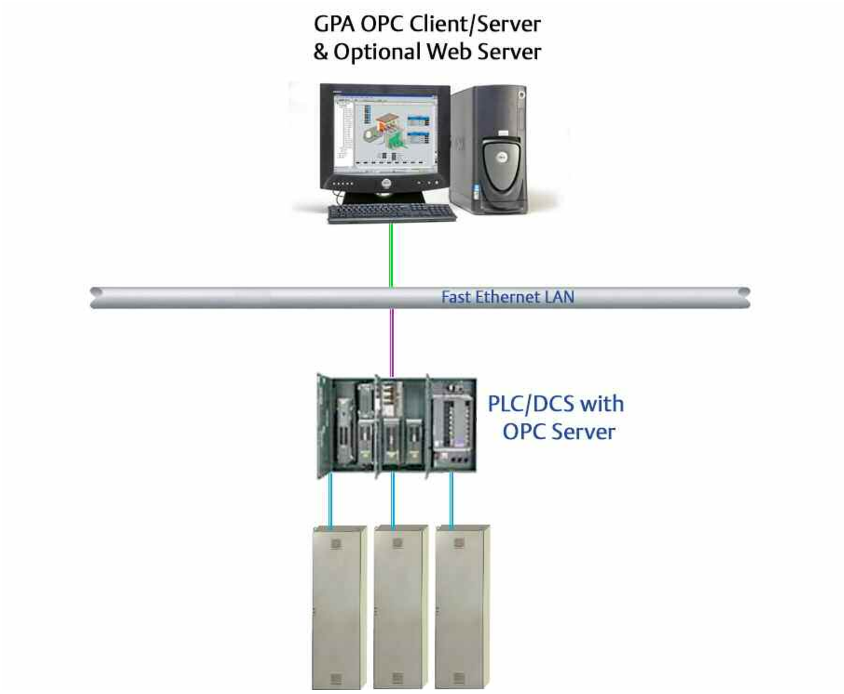


Figure 1 Typical Global Performance Advisor (GPA) architecture Using LAN Connectivity and OPC.

A data replay capability allows the user to do a "what if" historical analysis of the performance data. For instance, if a bad or poorly calibrated sensor is discovered, the data can be corrected and the efficiency calculation rerun using historical data to get a true efficiency number. This feature also allows equipment performance to be compared against previous results.

What is Optimization?

Optimization requires two conditions. First there must be options or choices available, such as two or more pieces of equipment available to perform a task. Second, there must be a value to maximize or minimize (i.e., there must be an agreed upon performance measure involved [the objective function]). Whenever there is a situation where a choice has to be made, and one choice is more favorable than another, then optimization is possible.

With respect to the water and wastewater industries, optimization is possible for an individual process, an entire plant, or a district-wide distribution or collection system. Some of these possibilities are:

- Economic dispatch of pumps in a water treatment plant, or in a single pump station
- Optimization of main sewage pumps or aeration blowers
- Aeration system power savings

- Chemical usage / residence time vs. flow
- Area-wide maintenance management
- Optimize the economics of the entire plant (or utilities complex)
- Model plant equipment
  - Pumps, flow networks, reactors, digesters/methane production
- Model buy and sell contracts
  - Chemical purchase, electricity demand clauses, etc.
- Monitor equipment performance
- Meet all quality commitments
- Operate within constraints and existing business rules
- Optimize entire plant to single objective function

A General Purpose Optimizer for Real-Time Operation

A general-purpose solver can be provided for mixed integer linear/nonlinear optimization problems that run on a Windows-based personal computer. The software provides the user with the ability to find a solution of x (vector of independent decision or manipulated variables) in the feasible regions such that the local/global minimum or maximum value of the objective function is obtained.

An optimizer should provide the following types of solvers:

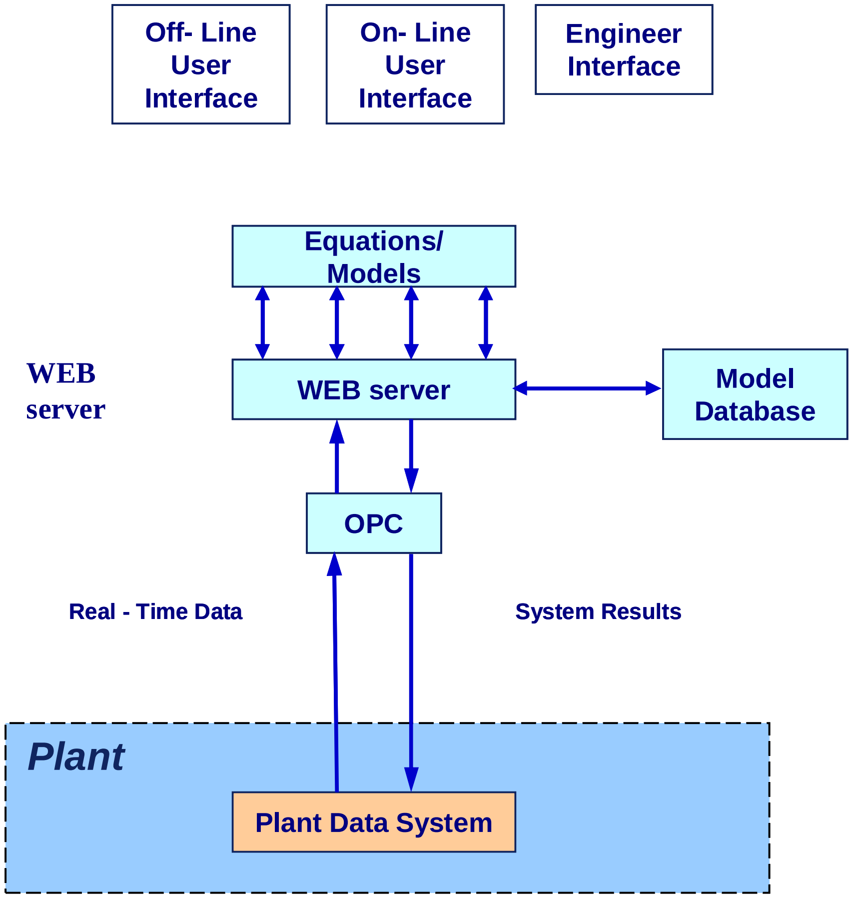
- Linear/Quadratic – This solver is used when all the constraints and dependent variable functions are linear. The objective function can be linear or quadratic.
- Generalized Reduced Gradient (GRG) Nonlinear – finds solutions to problems where the objective function and/or constraint and dependent equations are non-linear but smooth (no breaks).
- Evolutionary – is good for problems that are non-linear and contain non-smooth functions.

The user may pick the solver that best converges onto a solution, try different approaches, or combine solvers to get the optimal solution.

All of the solver engines available in the optimizer support mixing analog and integer variables. Most manipulated variables, coefficients, and dependent variables are real numbers, but they can also be integer (1,2,3,…) or binary (0,1). This is required in order to model equipment that can be ON or OFF, or to manage sequencing problems. An example of this is a variable speed pump that can be on, off, or set at a particular operating point (e.g., 50%) in conjunction with other pumps that may be capable only of ON/OFF operation.

Figure 2

Optimizer Components



Functional Aspects of Optimization

An equation-derived, model-based approach to economic optimization provides advanced control capabilities unattainable by traditional control systems. Variables such as energy, pump efficiency, power consumption, and chemical usage have a cost or credit (negative cost) associated with it. These costs, along with flow demands and equipment availability that can be constantly updated, would reflect the current conditions in the models. A cost-based target function can be used for the optimization and this function can consider these and maintenance costs (where applicable). This makes it possible to optimize for lowest cost or lowest consumption. The ideal economic optimizer has both offline and online modes of operation.

Model Capability

Theoretically, the models involved in reflecting the plant and equipment arrangements to support the decision making process should possess one or more of the following features:

Nonlinear — Most plants' pump efficiency versus head curve characteristics have a nonlinear aspect in that there is a family of curves. The traditional regression strategy does not fit these curves accurately, so a feedforward neural network model can be used instead.

Time varying — Many models considered have more or less slow time-varying characteristics. Due to equipment aging, performance degradation, and process drift, these models need to be updated constantly. Energy cost and regulatory policy change also introduce variations to the models. Fortunately, the state-of-the-art networking technology easily allows any of the models to be updated in an on-line setting.

Dynamic — Many of the technical, economic, and regulatory processes involved in the optimization decision making have a dynamic aspect. The dynamics can be slow or fast.

Optimization Problem Mathematical Form

$$Min_x \quad J = f(x)$$

$$s.t.\begin{cases} g(x) \le 0 \\ h(x) = 0 \\ x_{i\,\min} \le x_i \le x_{i\,\min} \end{cases}$$

The ideal optimization software that can provide the user a method to find a solution for x (a.k.a. a vector of independent decision variables) in the feasible regions (which are determined by a set of equality/inequality constraints), such that the local/global minimum (or maximum) value of the objective function J is obtained would be a great benefit to the optimization engineer.

The optimization function should use state-of-the-art methods (e.g. genetic algorithms, mixed integer programming, LP/quadratic, GRG nonlinear, and evolutionary solvers) and allow the user to define manipulated variables, define coefficient or constant variables, define dependent variables, and define constraints. The different values of the coefficients determine different cases or scenarios of the same problem for optimization "what-if" scenarios.

The user must be able to define the manipulated variables (MVs). They should also be able to define coefficient or constant variables (CVs), as well as define the dependent variables affecting the models. The constraints need definition when there are physical, operational, or economic limits of the plant equipment. The different values of the coefficients can determine the different cases or scenarios of the same problem for analysis.

How to Construct an Optimization Problem

The user must define the manipulated variables, the coefficients or constant values, the dependent variables, and the constraints. Different values of the coefficients define different cases or scenarios of the same problem. The optimizer should provide user entry forms to define these parameters and to manipulate them.

The optimizer can be run in two modes: online and off-line. The off-line mode contains a graphical user interface to build the optimization problem (model). Multiple optimization problems can be created and tested, providing a “what if” capability. The online version is configurable from the off-line GUI. It uses live process data from the plant control or SCADA system and displays advisory results to the operator. In addition, the results can be delivered directly to the control system as set points for control operation, if desired. Many customers will run the optimizer for several weeks or months in an advisory mode and compare its results to actual best practice operation. Once proven, closed-loop control is initiated.

An Example: Pump Optimization

To construct a pump optimization solution, consider a group of five pumps, two of which are VFD pumps and three are ON/OFF only pumps. Data is collected for each pump, including flow, pump head, pump efficiency, electrical cost, and nameplate data, including pump curves if available.

Information is added via the graphical user interface (Figure 3). Results are shown as in Figure 4.

Figure 3.

Pump Optimization

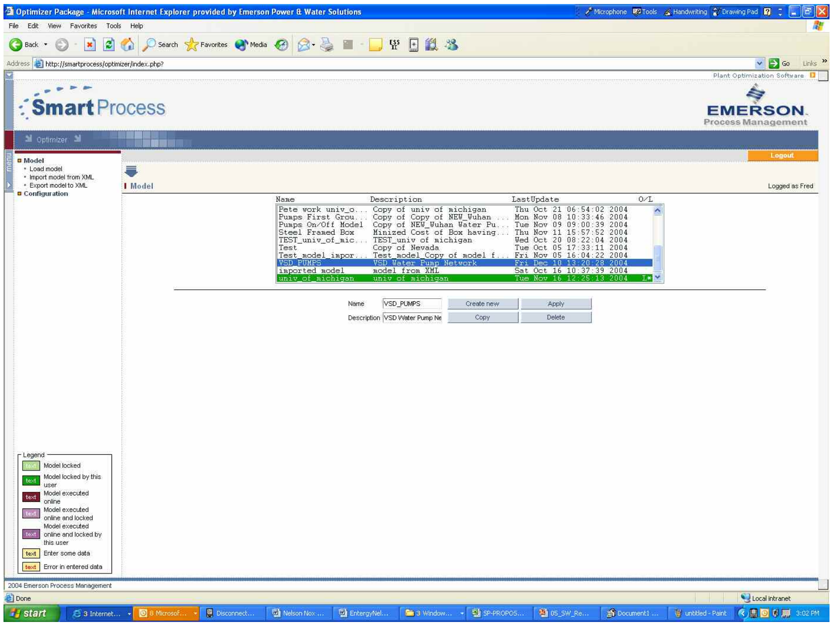
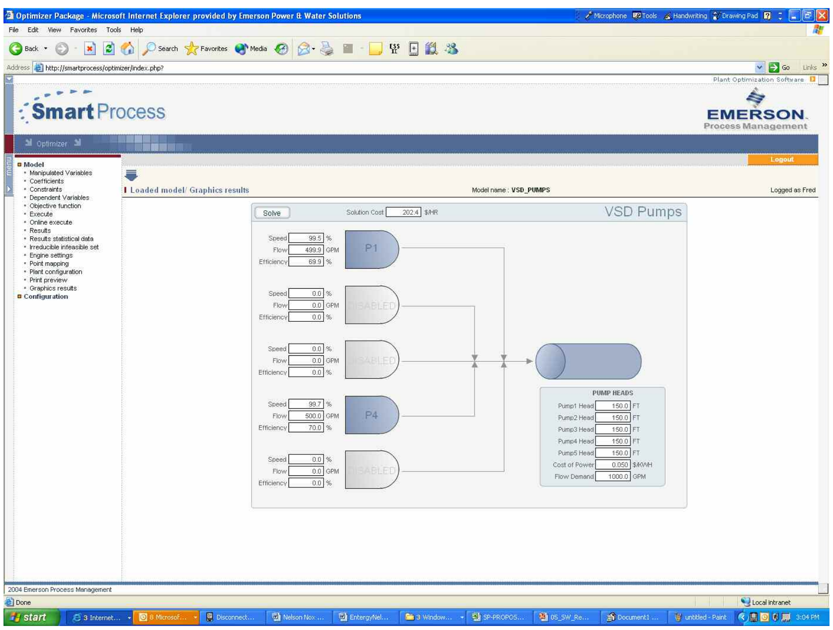


Figure 4.

"What if" Pump Results



Web-based Data Delivery

Equipped with a web-based user interface, the ideal economic optimizer offers a number of features, including:

- Multiple users can access and perform what-if scenarios at the same time.
- Users can easily create new models and modify existing models. It would also permit configuration and online start/stop optimization process initiation from the user interface.
- A highly flexible online advisory program for utilization of recommended changes to the operating process status is provided.
- Closed-loop control constraints of the plant model to actual plant capability for the current conditions are available.

Data can be delivered to historians, maintenance management packages, and other users in the form requested (graphics, reports, etc.) with appropriate access permissions in place.

Data Integration Capabilities

The information accessible today to control equipment and to manage physical assets has grown tremendously in the last twenty years. Smart instruments deliver not only process and sensor information, but calibration history and advanced diagnosis capabilities over digital busses. Control systems are capable of collecting tens of thousands of process data points, security information, and CCTV signals. The basic PLC can provide adequate control capability, but there are many other uses for process data besides control. These include equipment diagnosis, rotating equipment monitoring, and performance monitoring and optimization (as we have seen). The information so derived can be provided to computerized maintenance management systems (CMMS), laboratory information management systems (LIMS), and geographical information systems (GIS), as well as to financial and plant engineering design systems. The implementation of this type of data integration can be a major task if the processes and interfaces are not well planned in advance. An enterprise data historian that integrates data from a variety of sources (real time and off-line), and that provides various web based services, is one way to integrate these capabilities.

Conclusion:

Combining a state-of-the-art performance monitor with an ideal optimizer can benefit water and wastewater facilities' cost management. New possibilities arise for examining the operational aspects against known and observed economic factors. The plant equipment and unit operation characteristics can now be evaluated easily for optimum economic benefit.

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