

The Path to Profit Optimization at OMU

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Abstract

Owensboro Municipal Utilities (OMU) is a municipally owned and operated electric utility based in Owensboro, Kentucky. OMU's Elmer Smith Station is a coal-burning facility consisting of two units (one cyclone and one T-fired) with a combined capacity of 425 MW. It is under continuous pressure to reliably and cost-effectively deliver electricity to its ratepayer owners.

OMU believes that to improve the plant's profitability, it needs to improve its ability to understand the financial impacts of its operational and maintenance actions. The plant had invested in instrumentation, control and data systems (e.g. Metso DCS, Black and Veatch's Online Performance Monitoring (OPM) system, OSIsoft PI data historian, and Invensys AvantisPro CMMS), but it was having difficulty extracting the knowledge necessary to make financially-motivated decisions. To that end, OMU invested in NeuCo, Inc.'s integrated performance, maintenance and profit optimization systems, to enable the plant to perform comprehensive, real-time cost and revenue analyses and determine opportunities for improving profitability. The system brings together process, fuels, and maintenance data so plant personnel can better understand the impacts of their actions and decisions, and prioritize their work activities (including project evaluation and scheduling) based on profitability impacts (combining efficiency, capacity and reliability.) It leverages first principles models, heuristics rules and neural network optimization to achieve optimized actions and, ultimately, maximum profitability.

This paper will discuss the implementation and methodology of a real-time profit and maintenance management system at OMU's Elmer Smith Station and how it's helping OMU to become more efficient and profitable.

Introduction

OMU and ESS

Owensboro Municipal Utilities (OMU) is an electric, water and telecommunications utility owned by the City of Owensboro, Kentucky. Owensboro, a city of 54,000, lies on the southern banks of the Ohio River, one of the United States' major waterways, and is located in the Illinois coal basin. While the relatively high sulfur content is an impediment to its use, the low delivered cost of this coal makes the region home to some of the lowest cost power plants in the United States.

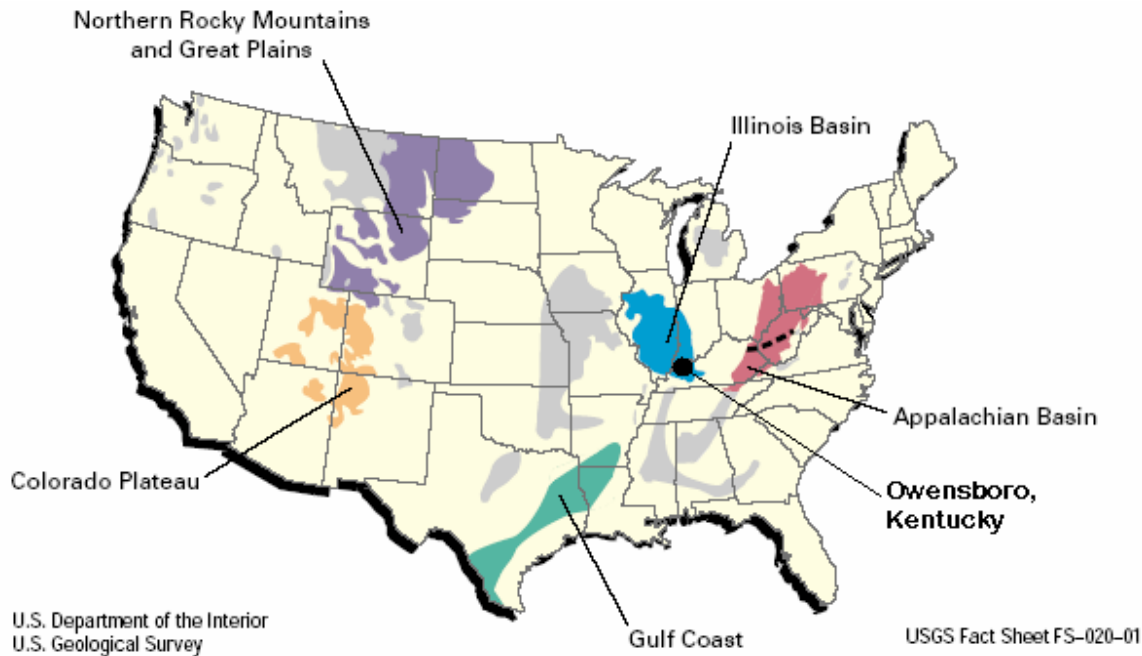


Figure 1: United States Coal Regions

OMU's sole generating station, the Elmer Smith Station, is a two unit coal-fired electric generating station. Unit 1 is a 151 MW unit with a 1,050,000 pounds per hour Babcock & Wilcox cyclone boiler paired with a General Electric 1800psi / 1000°F / 1000°F tandem compound turbine-generator commissioned in 1964. The boiler was retrofit with overfire air followed by a selective catalytic reduction (SCR) system. Unit 2 is a 265MW unit with a 1,900,000 pounds per hour Combustion Engineering tangential fired boiler paired with a General Electric 2250psi / 1000°F / 1000°F tandem compound turbine-generator commissioned in 1974. The boiler was retrofit with Advanced Boiler Technology low NOx burners with separated overfire air system, followed with a Hamon anhydrous ammonia selective non-catalytic reduction (SNCR) system. The station also has a Wheelabrator limestone, open spray tower, forced oxidation flue gas desulfurization system, common to the two Units, designed to remove 96% of sulfur dioxide.

OMU's Smith Station is considered to be proactive on environmental compliance and is one of the lowest cost plants in the nation.

Profitability Definition

Public Utilities in the United States are typically regulated by state commissions which are most generally concerned with rates charged to local (requirements) consumers while maintaining high standards of service. The rates charged must meet a standard of fair and reasonable, while the rate of return to the utility company must be sufficient to attract necessary investments. Sales-for-resale (coordination) rates, as well as interstate transmission rates, are regulated by the Federal Energy Regulatory Commission (FERC). Uniform accounting methods are required and rate recovery methods while not identical are similar for state or federal regulation. Government owned utilities in the United States typically follow similar methods for collection of their rates.

“Efficiency in electricity supply is attained through a variety of operating and investment decisions. It requires purchasing fuel and other inputs at lowest possible cost, properly maintaining existing plants to avoid costly outages, dispatching plants on an economic basis, installing the right amount and type of generating and transmission capacity at minimum cost, and retiring plants that are economically obsolete.” Federal Energy Regulatory Commission RM85-17-000 (Phase I) Regulation of Electricity Sales-for-Resale and Transmission Service Notice of Inquiry May 30, 1985.

As part of a regulated utility rate setting case, utilities estimate maintenance expenses and coordination sales revenues for a future test period. The utility stockholders profit from savings below the estimated expenses and suffer from higher maintenance expenses. Likewise all coordination sales revenues above the estimate benefit stockholders. Variations in fuel costs are typically passed through directly to customers through the fuel adjustment clause. In this form of regulation, there is little incentive to trade lower fuel costs (lower fuel quality) against higher maintenance costs or higher operations costs.

Likewise, the traditional emphases for US power plant managers have been cost control, plant efficiency and availability. Best of class plants were recognized for their achievements, while others received criticism for their substandard performance from their state public utility commission through periodic audits and more recently through performance based rate regulation. This led to a system where the costs of generation were optimized independently. Fuel buyers bought the lowest cost coal that met boiler design specifications, operations tried to keep efficiencies as high as possible, and maintenance managers tried to make their budget while maintaining availability. Management methods focused on cost control of rate base estimated costs. Techniques included budget based methods, activity based costing systems aimed at reducing administrative charges, benchmarking categories of costs such as staffing levels or boiler maintenance costs per MWH, or performance monitoring and improvement systems.

As implementation of the Clean Air Act Amendments of 1990 began, SO₂ and NO_x allowances were thrown into the picture along with an environmental manager trying to meet an emissions budget. Plants had to choose whether they would comply by lowering emissions or purchasing emission allowances. Some plants elected to switch to higher cost compliance coals, with lower sulfur levels, however these costs were passed on to the ratepayers through traditional fuel adjustment clauses. Certainly these changes pale into comparison to the onslaught of changes due to deregulation. Wholesale competition added an entire new level of complication to the

picture, plant profit. New merchant plants are now being constructed where the focus is strictly on the bottom line.

While most generation costs in the United States are still governed by some type of a regulatory body, the trend is certainly moving toward a deregulated environment with market-based electrical rates. Non-discriminatory transmission rates are already in place. Sales between utilities no longer operate on a cost-plus or split-savings market, but see market pricing set on a bid basis typically driven by incremental fuel costs. Incremental generation costs can vary over the course of the day, from dump power at night or low cost coal generation in the shoulder hours to oil or gas-based combustion turbines on peak. Likewise, price variations are caused by time-of-day demand moving along the stepped supply curve. The supply curve is characterized by definite steps between heat rates and fuels.

The day is coming in the United States when maximizing your returns under rate recovery formulas will take the back seat; the new paradigm is maximizing the differential between the market and costs at the highest level of generation output. Costs can no longer be considered independently of other variables. The timing of generation derates or outages and the maximization of generation output are factors that can't be ignored. Probability of failures must be weighed against the opportunity costs of scheduled maintenance downtime.

As a municipally-owned utility, OMU already has the incentive to look at total generation costs netted against total market revenues. Currently, OMU sells its excess generation on a long term contract. With revenues somewhat fixed under this cost-based contract, OMU's incentive is currently limited to lowering total generation costs. For example, savings through tradeoffs between fuel costs and maintenance levels go directly to the ratepayers. In the future, higher market "profits" through off-system sales will lead to better returns to its owners. The city could receive higher transfers while the ratepayer owners will receive benefits through lower rates.

Data Overload

Data Sources

So how does one optimize "profits" in this new era? It's all about making optimum decisions! What do you need to make the best decisions? The right data integrated in the right format – right now! Certainly most utilities are like OMU and there is no shortage of data. To the contrary most utilities as well as most companies in general suffer from data overload in today's digital world.

OMU installed a Metso Distributed Control System (DCS) for both units as well as on the Flue Gas Desulfurization system in 1995. Shortly thereafter, OMU added OSIsoft's PI data historian giving desktop access to most process data instrumented in the plant, over 6000 points. Seemingly overnight, OMU went from pneumatic controls and analog gauges to more data than we knew what to do with.

While OMU had more data than ever available, we realized even more data was needed electronically to support optimum decisions. In 2000, OMU purchased the PC based AvantisPro Computerized Maintenance Management System (CMMS) from Invensys. AvantisPro was

selected in part because of its open architecture. In addition, OMU developed databases in house to track fuels and byproducts, as well as lab data. OMU utilizes pc-GADS, a commonly used program by power plants in the US, to track derate and outage events. To begin leveraging some of the data, OMU invested in the Black and Veatch On-line Performance Monitoring (OPM) system which performed heat balance and performance calculations.

Power Plant Desktop

While all of these programs provide useful data, and perhaps among them contain the right raw data, the data is not integrated in the right format. OMU had a vision to display the sources of all costs (accounting and process data) through a single window, the Power Plant Desktop. OMU and Black & Veatch began the development of this system designed to assist the intuition of management, operations and maintenance in prudent decision making. Data would be presented in a format that suited each decision maker's purpose. Cost data, process data, and maintenance data displayed on the same screen.

The software lacked robustness as it was based around Microsoft Excel which limited the abilities of the system. While output could be stored back to PI, OSIsoft's Process Book was somewhat limited in its display abilities. This led Black and Veatch, and ultimately OMU, to team with NeuCo. NeuCo's sophisticated ProcessLink[®] optimization software platform was built to handle large-scale, diverse and distributed optimization problems, and was the ideal environment to integrate the many types and formats of data into a common architecture and extract the knowledge required to solve the profit optimization challenge. NeuCo and Black & Veatch have been working together since 2001 to develop integrated performance, maintenance and financial plant optimization modules that leverage a single online plant model. These modules are built on NeuCo's ProcessLink platform, which uses first principles, neural network, heuristics, and other optimization methods. The ProcessLink environment also features action-centric portals which aggregate the key performance indices, actions and advice on a single, customizable dashboard.

Costing Theory

A method was needed that provided a rational basis for assigning costs throughout the power plant. The basic concept was to build up product costs similar to methods used in a manufacturing plant or an assembly line. For example, the cost of coal to the bunker includes the cost of delivery, weighing, sampling, stockpiling, conveying, and crushing. This same principle can be applied to the power block. Costs are additive through the plant until ultimately electricity is produced. All costs can be considered including maintenance and operating expenses. We have elected to omit sunk capital costs, but the same principles developed herein would apply if one elected to include those costs.

On the surface, a dollar spent on steam turbine maintenance has the same impact on the cost of electricity as a dollar spent on boiler maintenance. However, what is important here is the benefit gained from the work performed or action taken. Let us assume that the benefit from the projects can both be measured in terms of improved efficiency or btus saved. In that case, the project closest to the final product stream should be selected. To understand this more clearly look again at the idea of an assembly line. If you are going to reject a component based on

quality, you are better off rejecting it early in the assembly line instead of waiting until other assembly costs are added to it. This same notion applies here.

The methods of exergy costing were selected for our purposes and the concepts developed in exergy texts are consistent with the ideas we have outlined above. Exergy, also referred to as available energy, is merely a measure of the potential usefulness to do work.

Control Volume Analysis

Let us consider the coal pulverizer as a component or a control volume to demonstrate the costing method. A control volume has energy streams entering and exiting, but the important identification for our analysis is the output working substance or product stream. In the case of the pulverizer, the product is the pulverized heated coal along with the primary air stream. All other entering or exiting non-product streams are considered fuel streams. These include the inlet primary air, inlet crushed coal, motor power in, and pyrites rejected.

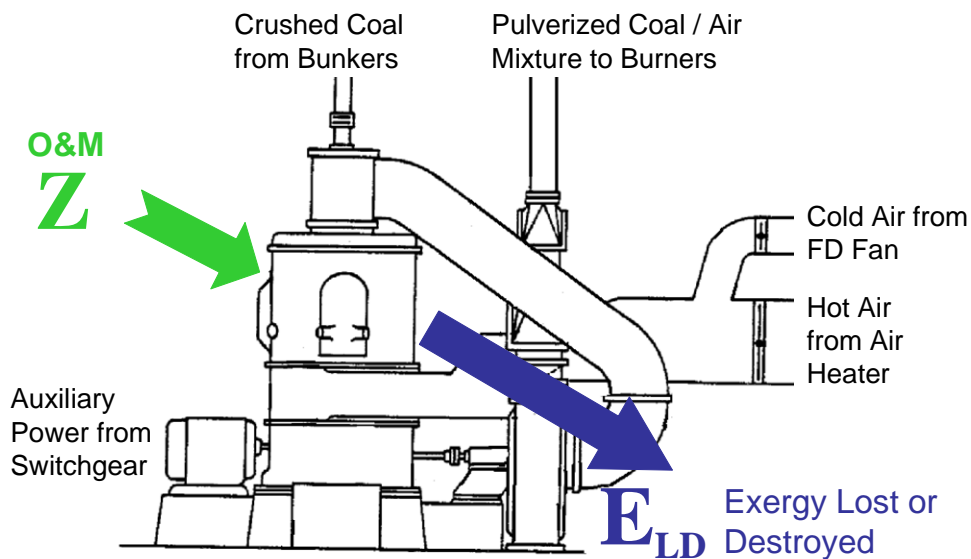


Figure 2: Pulverizer Control Volume

Applying 2nd law thermodynamic principles on a rate basis, the exergy rate ($\dot{E}_{P,k}$) in the product is equal to the sum of the fuel exergy rate ($\dot{E}_{F,k}$) plus the exergy rate lost or destroyed ($\dot{E}_{LD,k}$) in the process. The more efficient the process or the component, the lower the exergy lost or destroyed. The exergetic efficiency of a component is defined by the following relation $\epsilon_k = \dot{E}_{P,k} / \Sigma \dot{E}_{F,k} = 1 - (\dot{E}_{LD,k} / \Sigma \dot{E}_{F,k})$. Another relationship we utilize is the conservation of dollars. The product cost rate ($\dot{C}_{P,k}$) is equal to the sum of the fuel cost rates ($\dot{C}_{F,k}$) plus the cost rates of any remaining costs (\dot{Z}_k) such as operating and maintenance cost rates. The other cost category could also include amortized capital costs, however we have chosen to ignore sunk costs for now.

Combining these two concepts, we can consider the idea of cost per unit of available energy (c) equal to the cost rate (\dot{C}) divided by the exergy rate (\dot{E}). Of course the product and fuel unit costs are calculated based on their cost rates and exergy rates. The O&M unit costs should be

based on the sum of the fuel exergy. The cost rate of available energy combined lost or destroyed is based on its exergy and costed at the product unit cost¹ ($c_{P,k}$).

The component cost rate (\dot{I}_k) can be derived as the cost rate of exergy lost or destroyed ($\dot{C}_{LD,k}$) plus the remaining cost rate (\dot{Z}_k). It is the cost that the component adds to the fuel(s) and is the cost that should be minimized. Plainly put, the O&M costs are traded off against component efficiency to minimize the net cost. So how does one calculate the cost of electricity? The unit cost of electricity is equal to the sum of a raw fuels component (fuels not coming from a previous component) plus the sum of all component costs. This formulation allows the stacking of pricing adding all raw (or boundary) fuel inputs with all component costs to obtain the cost coming out of the final component. Components can be combined into larger control volumes such as sub-plants to produce the same result.

Our analysis divides the plant into four subplants: Fuel Preparation & Air, Boiler, Emissions, and Steam Cycle (see Appendix A). Auxiliaries are also considered, but they are allocated to subplants or even components if possible based on definable terms (e.g. a breaker would be assigned to a piece of equipment, the overall switchgear values would be allocated to equipment on a percentage basis). The subplants are divided further into system control volumes. This breakdown continues down to the component level. All control volumes should be defined by physical and performance boundaries with definable fuels in and out if possible. It is the job of the control volume to deliver its fuel to the next system, therefore, delivery piping and ductwork lies with the delivering system. The basic vision is to associate all applicable costs with a piece of equipment.

Prioritizing Efficiency Improvements

Investment should be considered to highest ranked component by component cost rate. Pay attention to components with high relative cost difference (the relative increase in the average unit cost between fuel and product). Use the thermoeconomic factor of a component (the ratio of O&M cost rate to the component cost rate) to identify the major cost source. A low value suggests that cost savings in the entire system might be achieved by improving the component efficiency (reducing the exergy destruction) even if the investment for this component will increase. A high value suggests that investment should be minimized at the expense of efficiency.

Using the component efficiency with the component cost per unit of fuel the following relationship can be derived: $i_k = c_{P,k} (1 - \epsilon_k) + z_k$. This formulation is key to managing tradeoffs between efficiency and investment. While these factors may be used to help identify the major cost source, as well as areas for improved efficiency or investment, another measure is needed to determine if investment is prudent. Expressed as a ratio, the availability benefit cost (ABC) ratio is defined as $\Delta(c_{P,k} (\epsilon_k - 1)) / \Delta z_k$. The ABC ratio provides a standard method of prioritizing work. Ratios less than 1.0 are not justified as this raises the component cost. The higher the ratio, the

¹ Costing energy lost or destroyed at the unit cost of fuel underestimates the value of this loss. Costing it at the product unit cost may overestimate the value. However, if we are operating in a profitable market environment where price is higher than $c_{P,k=final}$, perhaps price is a better driver of investment. With that considered, costing at the product unit cost is a good general guideline to adopt.

higher the priority. Similarly, looking at this not in terms of a ratio, but in terms of relative availability benefit ($\Delta(c_{P,k}(\epsilon_k-1)) - \Delta Z_k$).

Cost Savings Doesn't Necessarily Mean Maximum Profitability

As powerful as the concept of exergy is, it focuses exclusively on the cost side of power generation. As we pursued our quest for plant optimization, we realized that we could get insight into how to maximize profitability by using exergy analysis together with forecasts of LMP and emissions credit prices to determine how best to invest our maintenance dollars.

To that end, OMU invested in NeuCo, Inc.'s integrated performance, maintenance and profit optimization systems, to enable the plant to perform comprehensive, real-time cost and revenue analyses and determine opportunities for improving profitability. The suite of products brings together process, fuels, and maintenance data so plant personnel can better understand the impacts of their actions and decisions, and prioritize their work activities (including project evaluation and scheduling) based on profitability impacts (combining efficiency, capacity and reliability.) It leverages first principles models, heuristics rules and neural network optimization to achieve optimized actions and, ultimately, maximum profitability.

Paths to Profitability

Profit (Π) can be simply expressed as $\Pi = (p - c) \hat{W} t$. In addition to the costs, expressed as c (raw fuel, component costs, and O&M), we can now consider the effects of price (p), load (\hat{W}), and time (t). To increase profits, one must reduce costs or increase revenue. In a clearing price market, we should assume that the price for any particular time is fixed. Therefore, in the power generation industry, we should consider, broadly speaking, the following ways to reduce costs and increase revenue. The cost reduction possibilities are:

- Spend less on consumables – inputs and emissions (e.g. coal and allowances)
- Reduce O&M costs
- Increase efficiency

The only ways to increase revenue is to run at higher capacities and to be more available – more specifically to be available at those times when the market price for power is greater than the cost of generating the power.

Figure 3, shows these two paths to profitability, reducing costs and increasing revenue, as well as the steps and sub-branches of each path. While optimization can be performed on several individual systems, the key to profit optimization is managing tradeoffs between these systems so that profit itself is optimized, not just NOx emissions or maintenance costs.

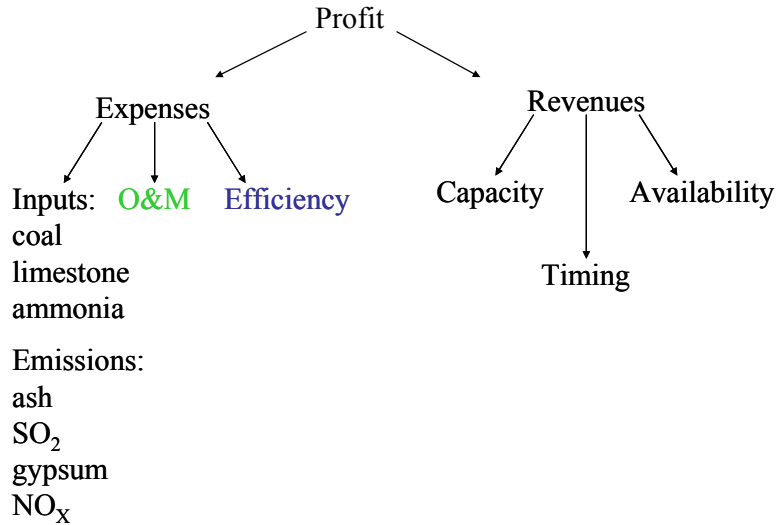


Figure 3: Paths to Profitability

In the optimization trees that follow, we try to provide some illustrative detail and depict some of the give and take of decision making, such as the “spend smarter on maintenance” path. Actions taken now to increase profitability can be intending an immediate effect or can be taken to increase total profitability over some timeframe – even if that involves suboptimal profits at various points in time within the interval. Within the “spend smarter on maintenance” category, the two ways that profitability can be increased are to make repair versus replace decisions that have the lowest overall cost and secondly to ensure that each maintenance action is done at the optimal time; this means:

- not performing work on equipment until the work will result in either decreased costs or increased revenues,
- but performing work on equipment before the work results in either increased costs or decreased revenues

Optimizing Profits at OMU’s Elmer Smith Station

The remainder of the paper will focus on explaining how each of NeuCo’s optimization products that we’ve invested in makes Elmer Smith Station more profitable. We have installed three of NeuCo’s products and are currently in the process of installing two more. The products that are installed are CombustionOpt, PerformanceOpt, and MaintenanceOpt. The products that are currently being installed are SootOpt and ProfitOpt.

CombustionOpt

Figure 4 shows how CombustionOpt contributes to improved profitability. The ovals indicate where CombustionOpt is making its contributions. CombustionOpt helps increase profitability by reducing costs – specifically by avoiding penalties for NOx emissions and by spending less on fuel by using it more efficiently.

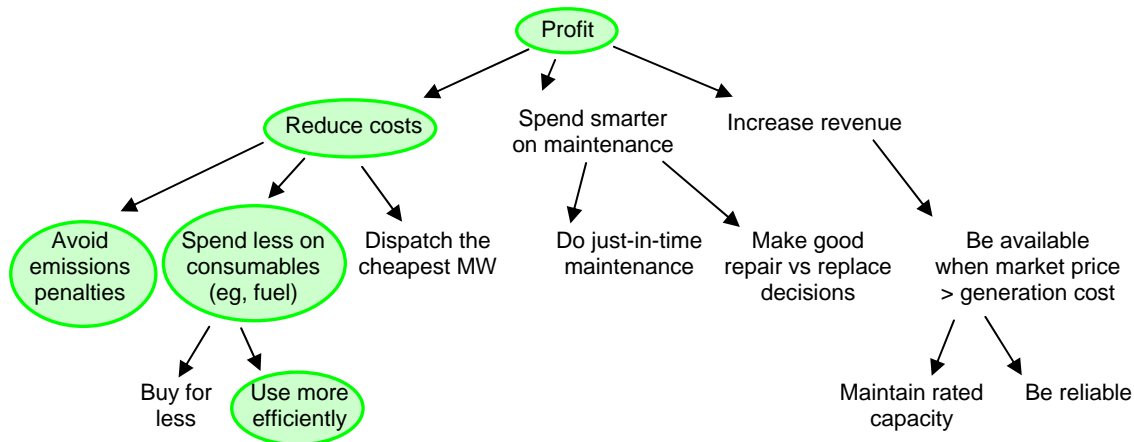


Figure 4: What CombustionOpt Does for Profitability

CombustionOpt operates in closed-loop. Based on its neural net model, it determines every few minutes how a number of actuators should be biased in order to maximize cost reduction. The actuators it biases include OFA dampers, secondary air dampers, primary air dampers, burners in service, and mills in service. In order to make its decision of how to bias the actuators, it takes into account factors such as load, fuel-air ratios, temperature distributions, and the current biasing of those actuators. CombustionOpt’s decisions are constrained by a variety of objectives (eg, keep CO below 100 ppm) in addition to its objectives to minimize NOx penalties and minimize the cost of fuel. It sometimes needs to trade-off NOx emissions with boiler efficiency; it determines the relative cost savings that would result from different proportions of NOx reduction and improved boiler efficiency by calculating those savings based on the current value of NOx credits and the price of the fuel being burned.

PerformanceOpt

Figure 5 shows how PerformanceOpt contributes to improved profitability. It does this both by reducing costs and by giving insight into how revenue can be increased. It reduces costs by identifying problems that are resulting in the inefficient use of fuel. It helps increase revenue by identifying problems that are reducing capacity; note that it does not provide any assistance in ensuring that maximum capacity will be available when power is most in demand.

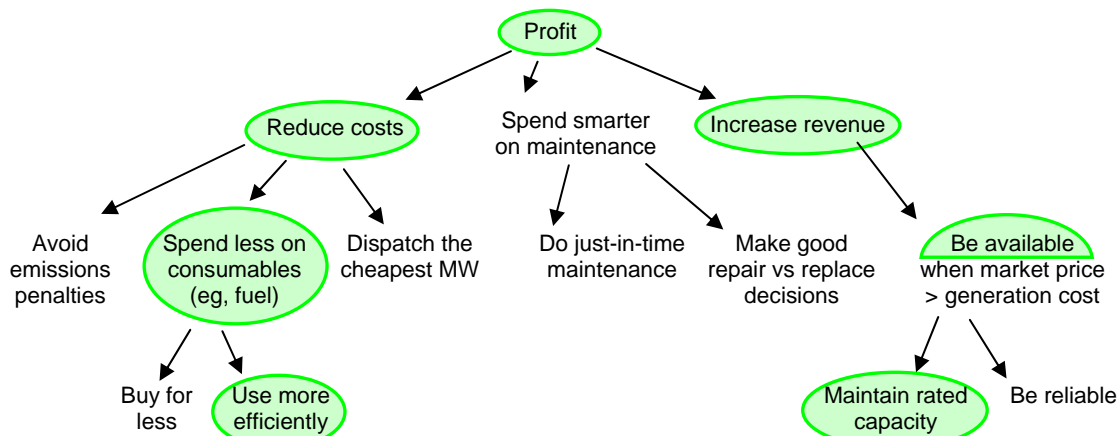


Figure 5: What PerformanceOpt Does for Profitability

PerformanceOpt currently operates in open-loop; instead of taking action itself, it makes specific recommendations to operators about what they can do to improve efficiency and capacity. It also identifies problems that will require maintenance actions to fix. Based on its 1st principles model, it determines every minute whether there are any problems on the Unit that are introducing fuel inefficiencies or reductions in capacity. Whenever it finds such a problem, it calculates its cost (ie, the cost of the additional fuel that's being burned), and it calculates the number of MWs that the Unit capacity is being reduced by. If the problem is one that can be remedied by the operator, PerformanceOpt recommends a specific action. With respect to the remaining problems it finds – those that require maintenance actions – although PerformanceOpt provides substantial assistance, it also requires substantial effort on the part of Elmer Smith Station personnel. In order to make use of the information provided by PerformanceOpt, station personnel must do the following:

- Diagnose the root cause of each problem PerformanceOpt identifies. This will spot any false positives that PerformanceOpt has identified as a result of faulty instrumentation; it will also determine whether a de-rate or outage is required in order to fix the problem.
- Determine whether there are any equipment reliability risks associated with the problems that PerformanceOpt identifies.
- Estimate the amount of additional revenue that will be generated if the problems that PerformanceOpt has identified are fixed as soon as possible and, for those problems that will require a de-rate to fix, the amount of revenue that will be lost while the problems are being fixed.
- Decide whether the problem should be fixed by repairing what is broken or replacing it.

MaintenanceOpt

Figure 6 shows how MaintenanceOpt contributes to improved profitability. Using information about problems that PerformanceOpt, CombustionOpt, and SootOpt have identified, MaintenanceOpt helps increase profitability by reducing costs and by giving insight into how revenue can be increased. It reduces costs by identifying the root causes of inefficiency problems. It helps increase revenue by identifying the root causes of problems that are reducing capacity and also by identifying equipment that poses a reliability risk.

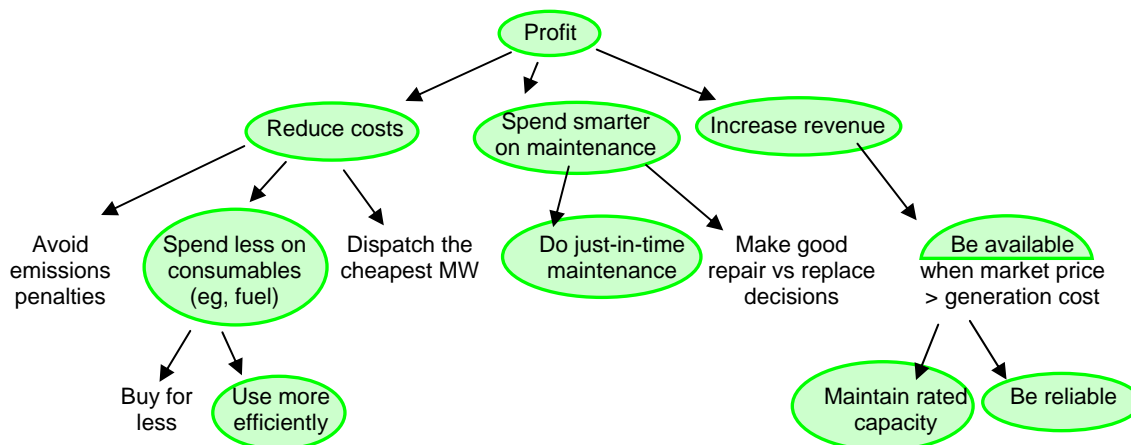


Figure 6: What MaintenanceOpt Does for Profitability

MaintenanceOpt operates in open-loop; it helps diagnose the root causes of problems the other Optimizers have found and then makes specific recommendations about what needs to be done to fix those problems. MaintenanceOpt complements PerformanceOpt by reducing the amount of work that station personnel need to do once they have been alerted to the existence of efficiency and capacity problems: it provides a lot of help in diagnosing the root cause of the problems, and MaintenanceOpt identifies reliability risks that may further reduce capacity in the future. But MaintenanceOpt, like PerformanceOpt, does not provide assistance with the following two tasks:

- Estimate the amount of additional revenue that will be generated if the problems that PerformanceOpt has identified are fixed as soon as possible and, for those problems that will require a de-rate to fix, the amount of revenue that will be lost while the problems are being fixed.
- Decide whether the problem should be fixed by repairing what is broken or replacing it.

SootOpt

Figure 7 shows how SootOpt contributes to improved profitability. It helps increase profitability by reducing costs – specifically by avoiding penalties for NOx emissions and by spending less on fuel both by using it more efficiently and by buying it for less (since its management of slagging allows us to use low quality coal).

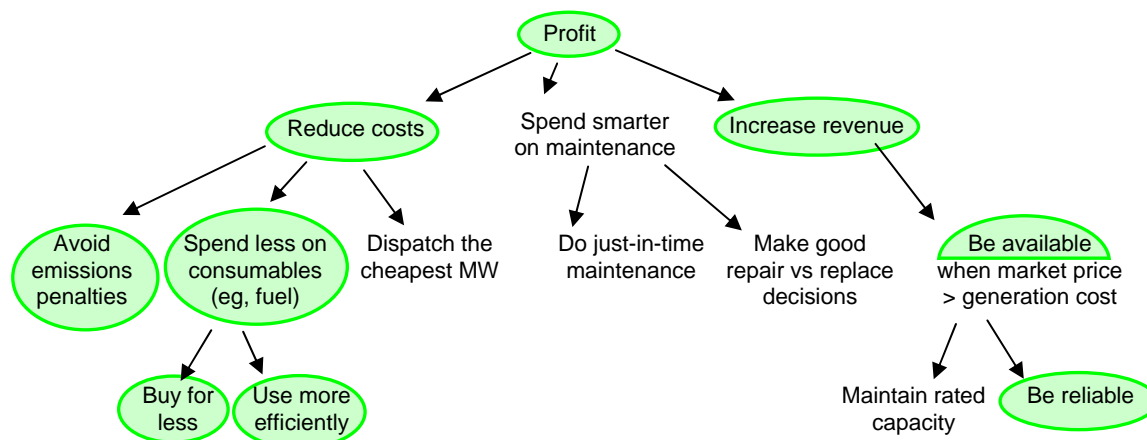


Figure 7: What SootOpt Does for Profitability

SootOpt operates in closed-loop. It is a hybrid system that uses both a knowledge base of rules and a neural net model to determine what to do; it determines how clean each boiler zone should be, what boiler zone needs to be cleaned next, and when the cleaning should begin. In order to make its sootblowing decisions, it takes into account factors such as load, heat transfer efficiency, FEGT, pendant weights, and the when each zone was last blown. SootOpt's decisions are constrained by a variety of objectives (eg, minimize slagging) in addition to its objectives to minimize NOx penalties and minimize the cost of fuel. Like CombustionOpt, it sometimes needs to trade-off NOx emissions and boiler efficiency; it too determines the relative cost savings that would result from different proportions of NOx reduction and improved boiler efficiency by calculating those savings based on the current value of NOx credits and the price of the fuel being burned.

ProfitOpt

Figure 8 shows how ProfitOpt contributes to improved profitability. It helps increase profitability by reducing costs and by giving insight into how revenue can be increased. It reduces costs by ensuring that the next MW generated comes from the Unit that can generate the lowest cost MW. It helps increase revenue by proposing maintenance schedules that will maximize capacity during those periods when the market price of power is expected to be highest.

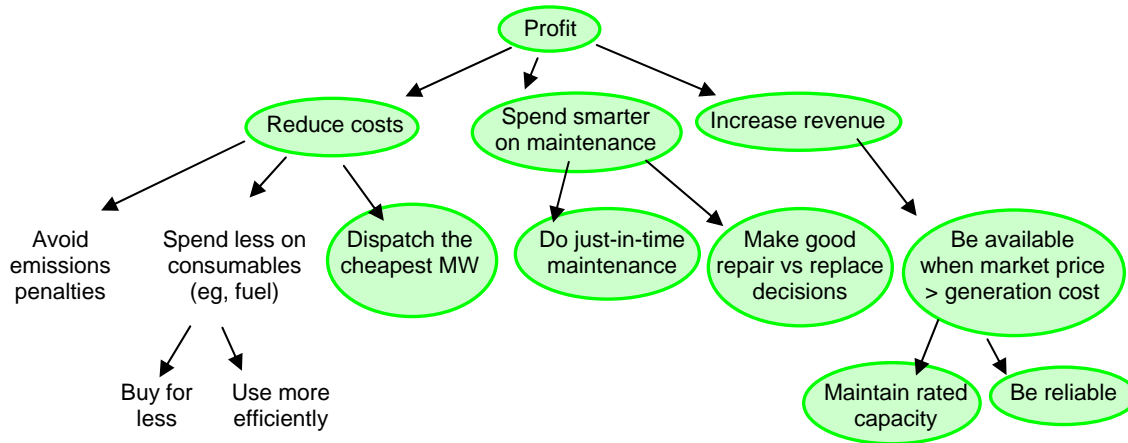


Figure 8: What ProfitOpt Does for Profitability

ProfitOpt operates in open-loop; it provides several different kinds of support:

- Whenever it receives a request to increase the number of megawatts being generated by Elmer Smith Station, it analyzes the cost of doing so and then generates the additional power from the Unit that can generate it most cheaply.
- It predicts the price of power over the coming days and weeks using weather data, and information about the time of year and the day of the week.
- It performs periodic control volume analyses to identify opportunities for spending smarter on maintenance.
- It provides support for meaningful repair versus replace analysis.

Conclusion

By using the suite of products provided by NeuCo, we have been able to achieve our goal of integrating all of the data – cost data, process data, and maintenance data – in our plant. And because NeuCo’s approach is action-centric, we’re not simply confronted by different types of data with no obvious interconnections. Rather, the products provides a view into how well we are doing with respect to profitability, where we need to focus, and how much improvement we can expect depending on which problems we tackle.

References:

A. Bejan, G. Tsatsaronis and M. Moran, *Thermal Design and Optimization*, John Wiley & Sons, 1996.

Appendix A

Subplant	Control Volume	Major Equipment or Subsystems
Fuel Prep & Air	FD Fan System Booster Fan System Air Preheater Coil System Air Heater System Bunker & Feeder System Fuel Oil System Coal Handling System	FD Fan 11 & 12 Booster Fan 1 Air Preheater Water Coil 11 & 12 Air Preheater Steam Coil 11 & 12 Air Heater 11 & 12
Boiler	Boiler Cyclone Burners & Igniters Boiler Chemistry System Sootblowing Air System	Economizer Furnace / Waterwalls Drum Primary Superheater Secondary Superheater Reheater Primary Air System Secondary Air System Boiler Blowdown System Overfire Air System Cyclone 11, 12 & 13 Igniters
Steam Cycle	Circulating Water System Condenser System Condensate / LP FWH System Feedwater / HP FWH System Turbine System Generator System	Circulating Water Pump 11 & 12 Condensate Pump 11 & 12 Vacuum Priming System Boiler Feedpump 11 & 12 LP Feedwater Heater 11 & 12 Dearator HP Feedwater Heater 14 & 15 SH / RH Attemperator System Low Pressure Turbine Intermediate Pressure Turbine High Pressure Turbine Lube Oil System Gland System Generator Cooling System Excitation System
Emissions	SCR System Precipitator System Ash Handling System Scrubber System	Fly Ash Conveying System Slag System
Auxiliary Systems	Auxiliary Cooling Water Electrical System Distributed Control System Seal Air System Seal Water System	