ECONOMIC IMPACT OF CONTROL AND OPTIMIZATION ON INDUSTRIAL UTILITIES

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ABSTRACT

Industrial energy management includes the fuel procurement, production, conservation and efficient use of utilities such as steam, electricity, compressed air and water. Steam is the underpinning utility product and usually has the greatest economic impact. The efficient production and delivery of quality steam directly affects the cost of the other utilities as well as the manufacturing process.

Utilities are rarely looked upon as a source of corporate profit, especially in times of double-digit expansion. They typically represent only 3 to 11% of manufacturing cost and are perceived as an unavoidable cost. However, in an era of heighten global manufacturing competition and world-wide re-allocation of natural resources, utilities are recognized as a variable cost that can be a source of major cost savings opportunities and a strategic contributor to corporate profit.

This paper will discuss an overview of possible control and optimization applications for the steam system of an industrial utility, the approaches for economic justification of those applications, and some examples of successful energy management projects.

INTRODUCTION

The conservation of natural resources is a noble challenge. It is typically voluntary and appeals to the individual's higher Maslowian levels of self-actuation. Unfortunately, corporations are not individuals. They are not chartered to be self-actualized. They are chartered to make a legal profit for the equity holders. Therefore, investments in energy savings equipment or practices must be justified.

There are two basic justifications: mandate and economics. Government mandated requirements need very little justification. Either comply or be punished. Unfortunately, conservation mandated by regulation motivates only minimum compliance criteria with minimum investments and often falls short of motivating optimum, "good corporate citizen," levels of performance.

Economic justification methods, such as Return On Investment (ROI), is the driving force of business. Without an acceptable ROI, decision makers are not interested in saving energy. Investment dollars are scarce. Other competing projects with more attractive ROI's that increase production or expand markets will capture the limited funds. The issue then is how do we quantify the economics of investments in energy saving and how do we compete against the other available investment opportunities?

There are two basic economic justifications: availability and productivity. Availability, much like compliance, is a rather simple justification. If you don't buy the boiler, maintain it, and provide adequate controls to keep it on line, you will not have steam, and you will not maintain adequate production. Because loss of steam would normally stop production, this is the dominant philosophy during periods of production-limited market activity.

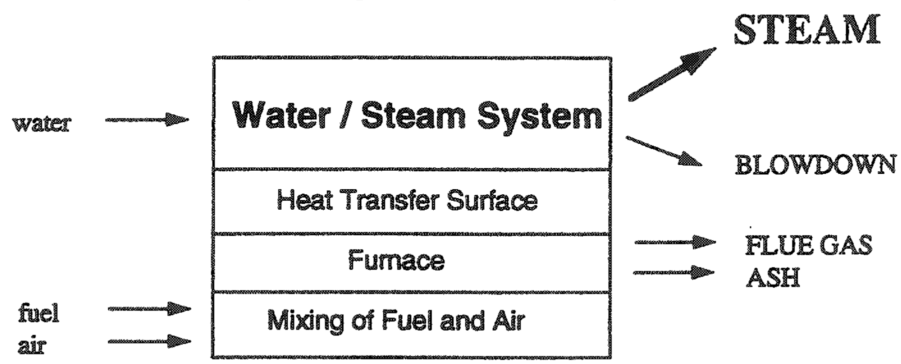
During periods of competition (most of the time) where product cost and quality determines market share and profit, cost-effectiveness becomes a significant driver. Corporate decision makers are constantly looking for means to produce more for less. They are not interested in saving energy per se; they are interested in reducing the cost of energy. Therefore, successful energy saving projects must demonstrate a reduction in the cost of utilities that is greater than the alternative investments opportunities. Since utilities typically make up only about 10% of the cost of manufacturing, the challenge is to find impactive solutions (i.e. high yield or low cost or both) that will beat out more glamorous investment opportunities in the manufacturing process.

With this in mind, let us consider potentially high ROI energy management applications in the steam system: optimal combustion control in the boilers, steam emergency load shed, and economic load allocation.

OPTIMAL COMBUSTION CONTROL OF THE BOILER

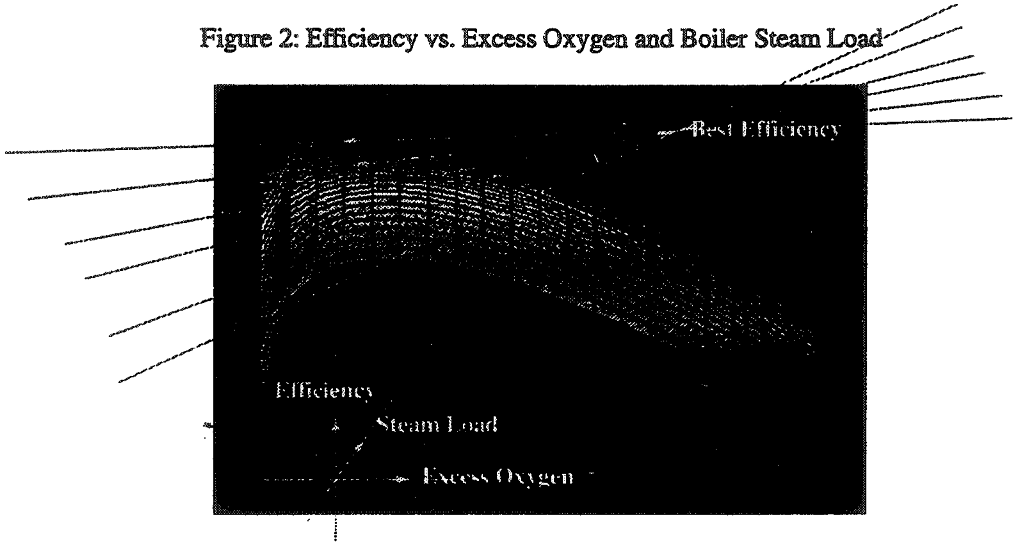
The fundamental physics and chemistry of combustion and boiling water are well documented. Burn fuel in air and generate heat. Transfer heat to water and make steam. See Figure 1.

Figure 1: Representation of Steam System



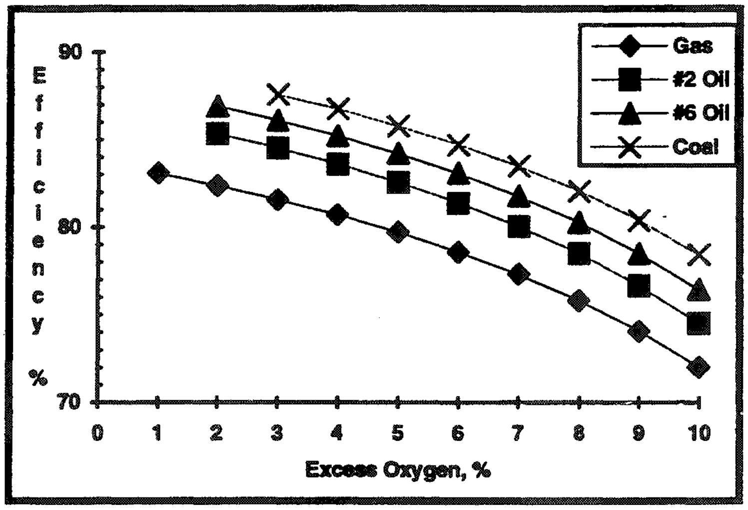
The engineering challenge to make the boiler operate at maximum efficiency is far more subtle. Boiler efficiency is a measure of what percent of the potential energy (BTU's) released by burning fuel end up in the steam. It is primarily a function of two operating criteria: steam demand load and combustion efficiency. For any given load, there is an optimum efficiency that is realized when the efficiency gains from minimizing excess air for combustion are offset by losses due to unburned fuel. See Figure 2.

Figure 2: Efficiency vs. Excess Oxygen and Boiler Steam Load



When a boiler is not operating at peak efficiency, investments can be made to improve the situation. One of the easiest and most cost effective is to modify the control scheme to trim the fuel/air ratio that will minimize excess oxygen. Figure 3 shows Council of Industrial Boiler Owners (CIBO) data that demonstrates the relationship between excess oxygen and boiler efficiency. Notice that it is approximately linear over normal operating ranges. This means that for every percent reduction in the amount of excess oxygen, there is a corresponding increase in efficiency and a one percent improvement in efficiency correlates to roughly a one percent reduction in fuel cost for the same steam production.

Figure 3: Efficiency vs. Excess Oxygen and Fuel Type



Here's a thumb nail guideline to determine if there are meaningful savings available in the boiler.

- First, determine the average excess oxygen in the flue gas at nominal firing rates. Second, determine the average annual fuel bill. Then calculate:

- Potential Savings = Annual Fuel Bill * (Average Excess Oxygen (%) - Target Excess Oxygen (%))

- Where Target Excess Oxygen for gas fired boilers should 2-3%. Oil fired boiler should run at about 3-4% and stoker coal fired, at about 5-6%.

- The mechanism for obtaining the savings is that with a well designed and tuned control system, operations can maintain an O_2 level which is close to optimum over a larger load range without fear of violating an operational limit. Typically without good controls, an operator will raise the excess air or O_2 setpoint to a safe point for all problem conditions and leave it there.

- If the potential savings look attractive, then a study should be conducted to valid the savings, design a solution to obtain the savings and estimate its cost.

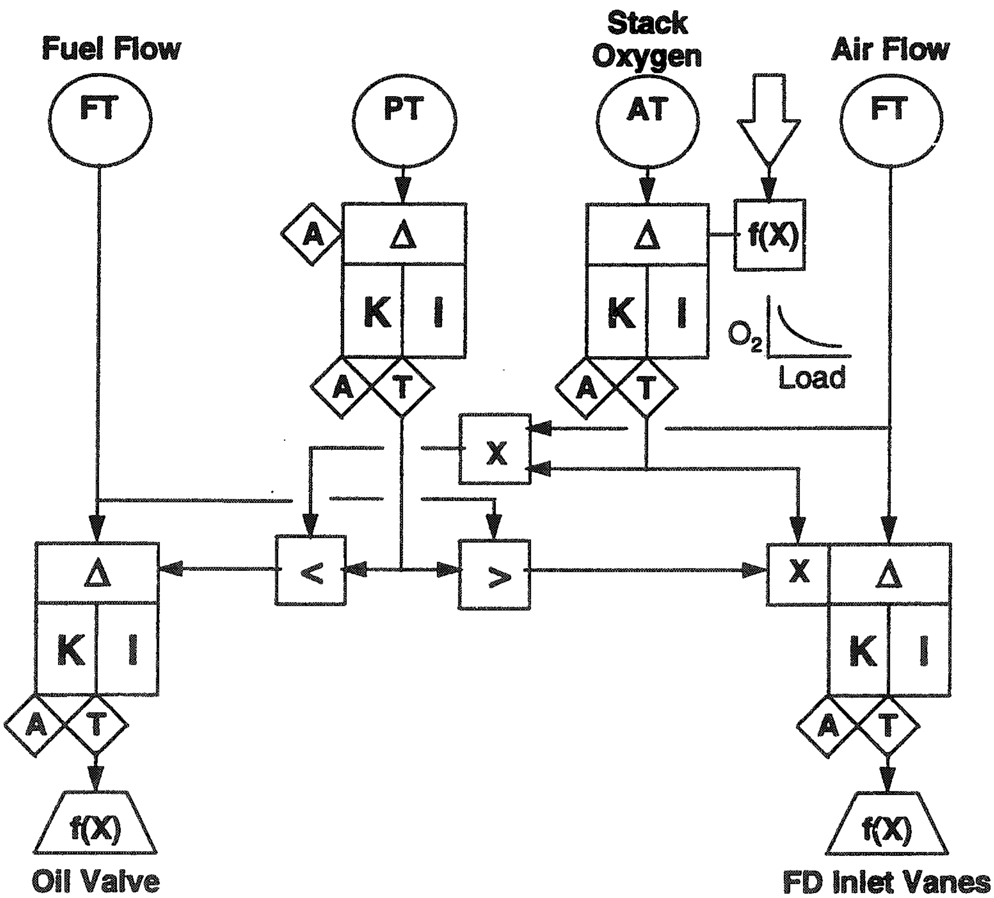
- The solution implementation may be as simple as a revamp of the present control scheme or as extensive as the modernization of the instruments, final control elements, control system, and implementation of the control scheme shown in Figure 4. Once the determination is made what is needed, the ROI can then be calculated based on the potential savings and the estimated cost.

This is the most conservative justification since it doesn't include other potential benefits of a good control system:

1. Responsiveness to steam demands (allowing more consistent quality and quicker changes in production operation).
2. Reduced pollution
3. Minimized thermal stress
4. Reduced operational manpower
5. Increased boiler capacity
6. Increased availability (due to minimizing boiler trips)

Any of these can add significant benefits for the complete financial analysis. If any can be quantified for the particular plant situation, the ROI for such an investment is usually extremely attractive.

Figure 4. Typical Combustion Control with an Optimum Excess Oxygen Setpoint Schedule



Advanced Combustion Optimization

For larger boilers (300 Klb/hr+) - especially coal-fired - it may be justified to replace the O_2 trim schedule with an optimization function, typically an evolutionary optimizer or neural net, in order to dynamically adjust excess air. This approach has been fueled more recently by EPA requirements to minimize NOx or other environmental constraints. In these cases combustion by-products are introduced into the combustion optimization problem and multiple control variables are adjusted such as secondary-tertiary air split, mill biases, fan biases, and air damper biases. Depending on the situation, significant capital expenditures for boiler modifications to meet compliance levels can be avoided, and efficiency gains can still be realized for minimizing excess air. Typically 25-50% reductions in NOx levels can be achieved and/or 0.5-2% gains in efficiency or heat rate.

STEAM EMERGENCY LOAD SHED

This is an application which targets availability issues. The driving force is that if a major steam producer of a steam system is lost unexpectedly (tripped, failed), the remaining boilers may not be able to respond adequately to compensate such that the production processes and the boilers themselves may also be lost. Steam emergency load shed automates (therefore making it rapid and feasible) the normal response of the boiler operator getting on the phone and begging production operators to find ways of reducing steam usage before the entire system fails. This application normally requires an integrated control system which can automatically drop off the appropriate steam consumers to compensate for the loss of steam within seconds. The application should be designed to monitor current steam consumption for sheddable loads, current steam production from major sources (the loss of any being an emergency event) and maintain dynamic priorities based on current needs for each of the predefined load candidates.

The benefits of a steam emergency load shed application is the difference between the cost of a plant shutdown and the plant coming to a partially shutdown state (after designated loads are shed), and, of course, the cost difference of returning to normal production from these two states. Usually the loss in production alone will justify this application if evaluated during a period of production-limited operation.

Table 1 illustrates the layout of a steam emergency load shed application as it might be shown to an operator.

Table 1

steam sources:			Event 1: loss of Boiler 1 @ 139#/hr		Event 2: loss of Boiler 2 @ 113#/hr		Event 3: loss of Unit A @ 55#/hr (steam producer)	
sheddable loads	**priority**	**load**	**mode**	**shed circuit**	**mode**	**shed circuit**	**mode**	**shed circuit**
Load 1	3	**25**	auto	armed	auto	armed	manual	armed
Load 2	2	**15**	auto	armed	auto	armed	auto	disarmed
Load 3	1	**17**	auto	armed	auto	disarmed	auto	disarmed
Load 4	1	**12**	auto	armed	auto	disarmed	auto	disarmed
Load 5	2	**18**	auto	armed	auto	armed	auto	armed
Load 6	3	**33**	auto	armed	auto	armed	auto	disarmed
Load 7	3	**3**	manual	armed	manual	disarmed	auto	disarmed
Load 8	3	**11**	manual	armed	manual	armed	manual	armed
Load 9	3	**6**	auto	armed	auto	armed	auto	disarmed

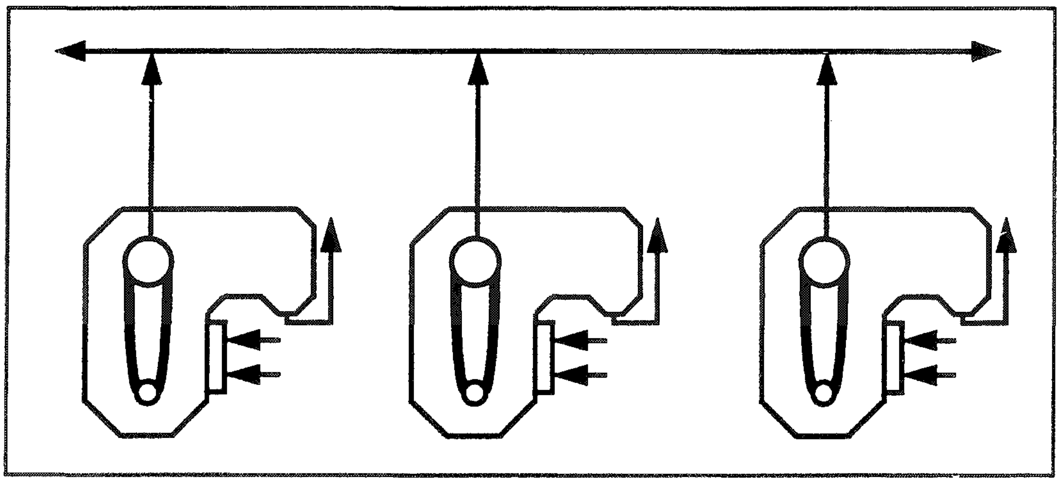
Note that since the balance will never be perfect, the remaining steam producer will have to adjust to some difference, but it should be minimal unless there is insufficient sheddable loads available. Note that more sophisticated schemes can do a best fit determination within some user-set tolerance to optimize the set of currently selected shed circuits.

The biggest challenge to implementing this scheme is not technical or even financial, but getting agreement among operating units to allow for a rapid response to an emergency event by shutting off process equipment that consumes steam remotely from the utilities area. This is often a formidable task which shouldn't be overlooked.

BOILER ECONOMIC LOAD ALLOCATION

Optimizing boiler load allocation can also be a major energy saving opportunity. In a typical utility system, there are multiple boilers feeding steam into a common header as shown in Figure 5. Each boiler has unique operating characteristics that cause their efficiencies to vary with loading, fuel mix, and *time*. When taking an aggregate look at steam production with these individual boiler characteristics in mind, total steam demand can be satisfied with less fuel.

Figure 5. Multiple Boilers feeding a Common Header



Boilers in an industrial utility area are typically loaded evenly. Overall loading is rarely based on minimizing overall cost. Minimizing fuel costs requires an automated control application that will continuously set the boiler loading based on economics as well as current conditions and operational constraints. Economic considerations include changes in fuel cost, changes in steam demand, changes in fuel composition, and changes in boiler efficiency. An application such as this is feasible when there are significant periods of flexibility in the operation so that the best loading isn't obvious (i.e., there are two or more boilers that aren't always loaded to the maximum or minimum, and are allowed to change load automatically).

To determine the optimum loading, the boilers must be characterized, producing an empirical model as input to the optimizing engine.

To illustrate, refer to figures 6, 7, and 8 showing the simplest case: 2 identical boilers with the usual non-identical efficiency curves loaded optimally versus evenly loaded (the usual default operation philosophy). Figure 6 shows one method of characterization determining energy consumed versus steam produced. Figure 7 shows the optimum way of loading the boilers as steam demand increases from minimum to maximum. Figure 8 shows the savings rate at various loading levels; note that actual yearly savings depends on how long the process stays at each steam demand over the year.

Figure 6. Energy consumed versus steam produced

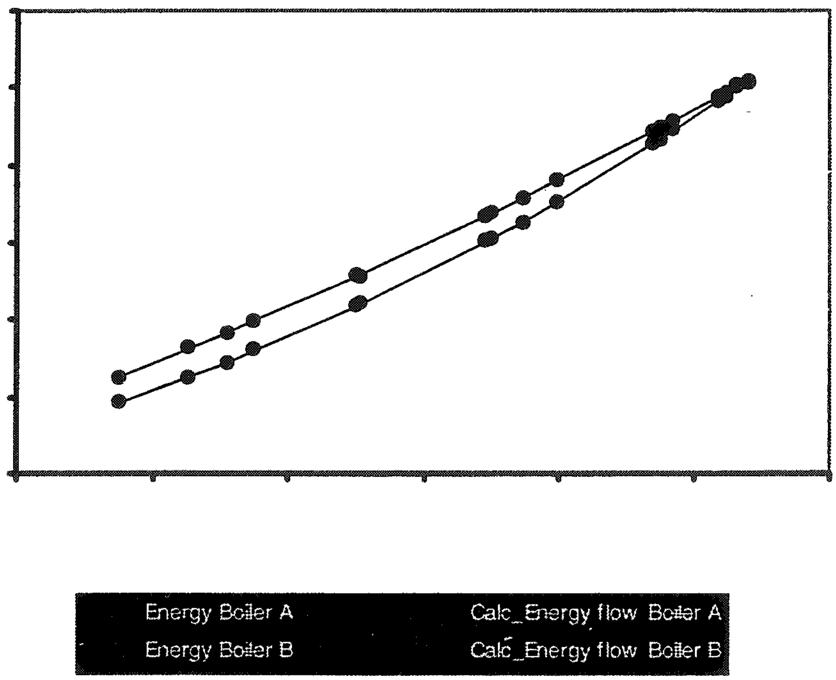


Figure 7: Optimum Load Allocation for 2 boilers

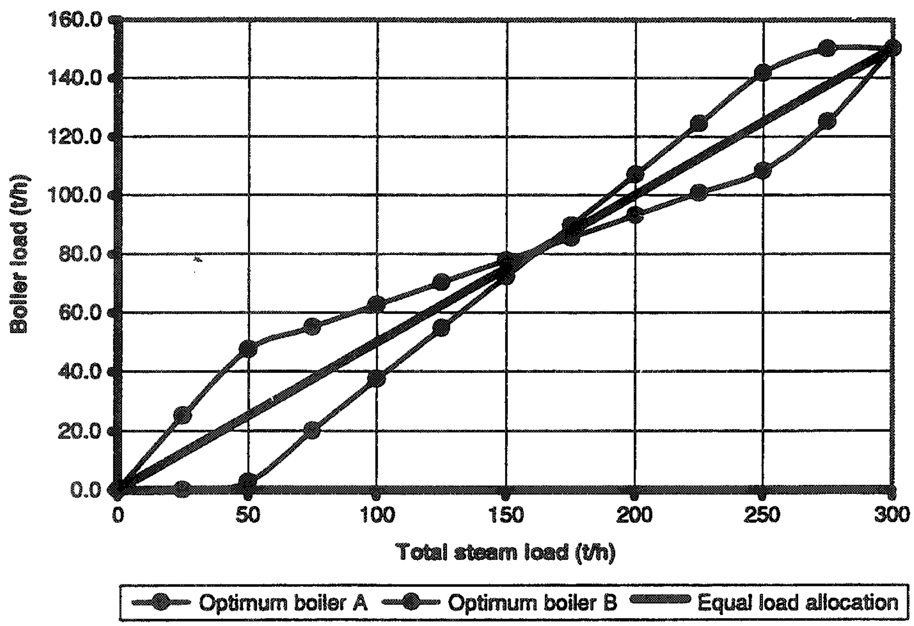
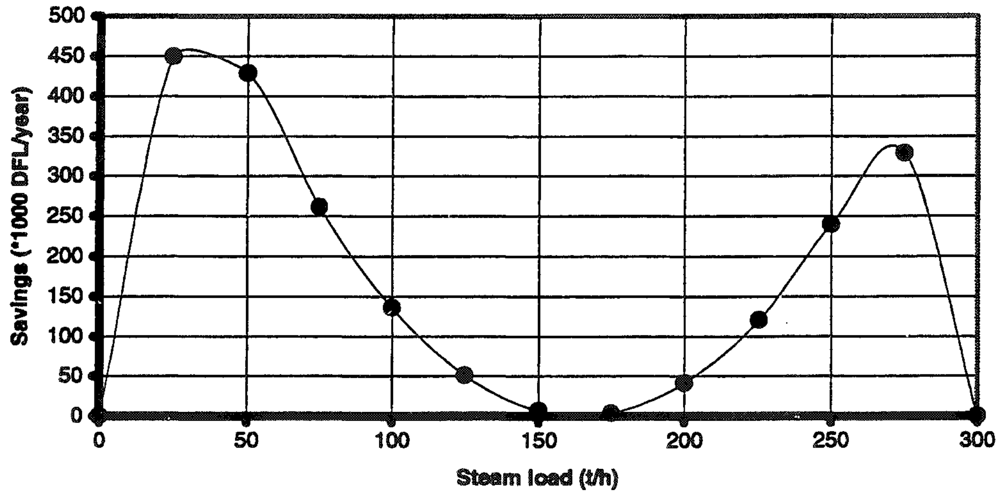


Figure 8: Load allocation savings per year



An automated, on-line, closed-loop application is required in order to keep up with the changes in current operational demands and limits that occur constantly in most industrial sites. This application must monitor the boiler performance, characterize the boiler operation in terms of cost versus steam production, and set the relative loading of the boilers without interfering with the steam header master controller. It must also recognize a boiler mode (i.e., shut down, or manually base loaded) and fuel changes (a change in fuel or a property, including cost), as well as abnormal conditions such as constraint violations, boiler trips, or equipment failure.

Closed-Loop Control Objectives:

The following are objectives of the closed-loop technique:

1. Adjust boiler steam production to minimize overall cost to satisfy plant demand.

2. Minimize disturbance to the header pressure master controller.

3. Minimize disturbances to the boilers being manipulated by the closed-loop optimization.

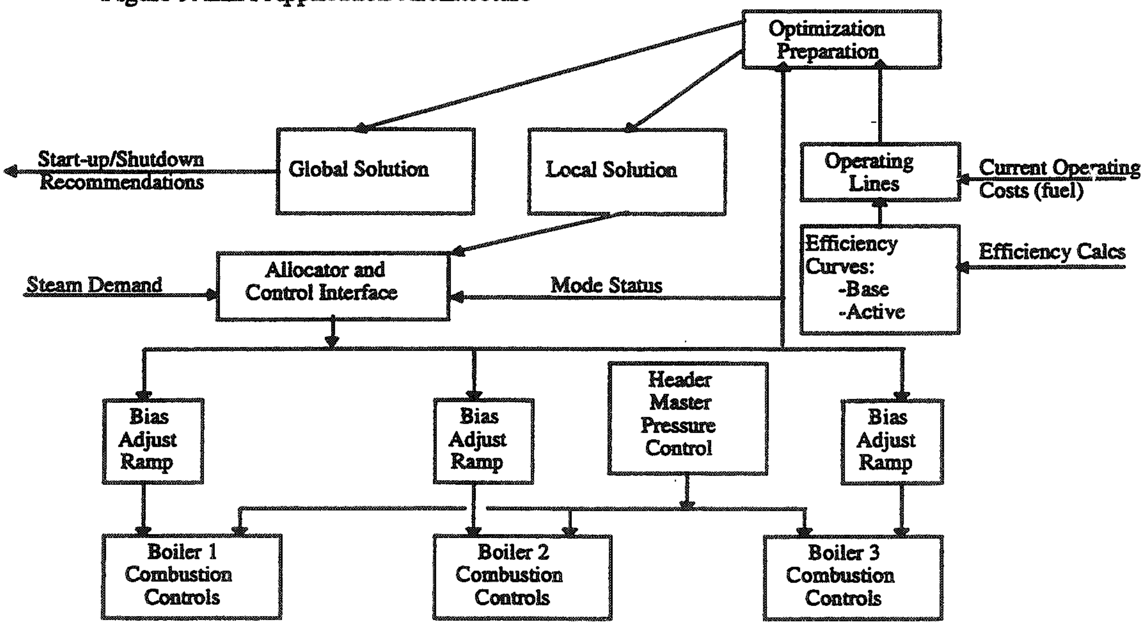
4. Allow no interference to the responsiveness of the header pressure master controller.

Achieving these objectives will ensure that the optimization application will stay on line, adjusting the boilers to obtain as much of the savings as is possible throughout the year.

Economic Load Allocation Application Architecture

The following diagram shows a possible Economic Load Allocation architecture.

Figure 9. ELA Application Architecture



Results

Typical results from a successful ELA application range from 0.5 to 5% reduction in fuel consumption overall for the set of boilers, depending on how well the boilers were watched and controlled without ELA and the complexity of the problem (number of boilers and frequency of load changes). Two methods of evaluation are identified for verifying results:

1) an on-line calculation which compares the predicted incremental cost of steam at the optimum loading for each boiler with the cost of steam with all boilers at neutral bias (0). This is totalized to get hourly, daily, etc. savings.

2) comparison of fuel costs over a period of production before and after economic load allocation implementation, normalized per totalized steam production for that period and extrapolated to get savings over whatever time increment is desired.

Return on investment calculation depends on the cost for fuel, the total steam production for the set of boilers, the number of boilers to be allocated, the number of different fuels to be accommodated and the amount of incremental digital control equipment required to implement the solution. Usually the controls system is in place so that all that is required is a platform for advanced applications (sometimes there is already one of these with spare capacity that can be utilized).

Mini Case Study

Four identical boilers with maximum capacities of 200 KLB/HR in a chemical plant offered savings from boiler ELA up to $87.90 per hour, with an annual savings expected to exceed $200,000. The savings were estimated to provide a 3% reduction of the fuel bill. This generates an ROI of over 100% and less than a

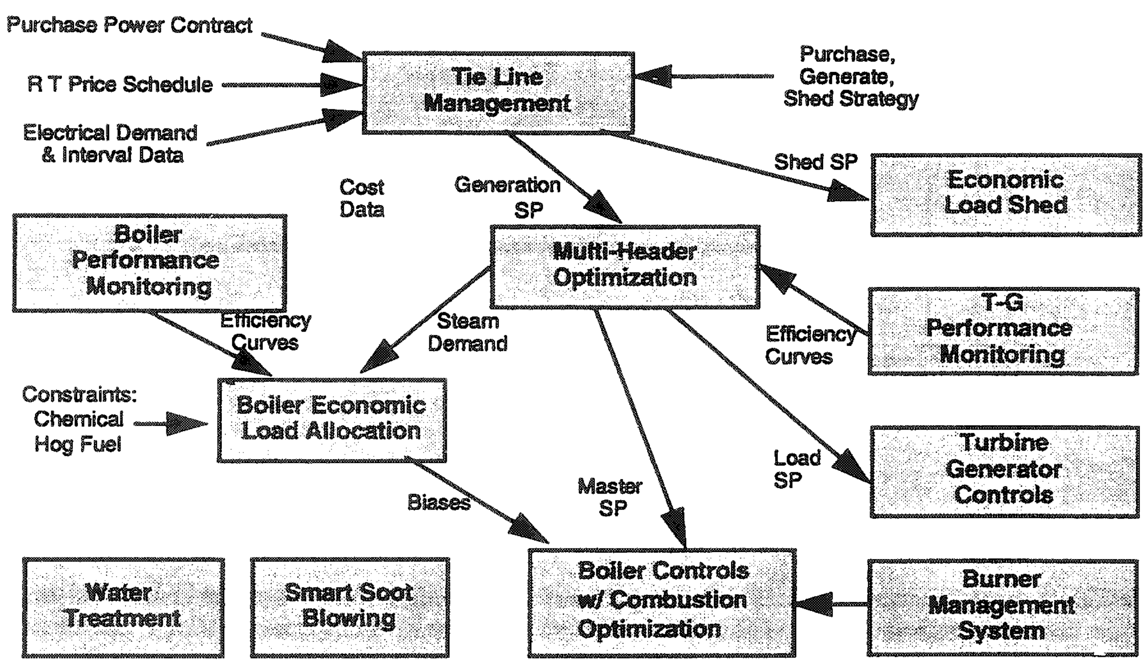
1-year payback. This was incremental to the boiler control system replacement which provided over 6% reduction in the fuel bill and substantially increased steam system stability.

Further savings may be achieved by following the recommendations for shutting down or starting up a boiler. This cannot be automated since operator involvement is required. And there is an economic evaluation which can be made to decide whether to take advantage of the opportunity. The optimization can generate a savings value for shutting down or starting up a boiler; but the operations personnel must take into account how long this current situation will likely exist and balance the potential savings against the cost of doing the startup/shutdown. Risk must also be evaluated by assessing the probability of a high steam demand spike that will exceed the headroom if a boiler is shut down.

AREA OPTIMIZATION

Steam generation should not be evaluated as a independent entity. It is part of an overall utilities system whose total management can produce greater synergistic results. The blocks in Figure 10 represent application functions that work together to take advantage of multiple opportunities for savings. These can be accomplished using a variety of control and optimization techniques including expert systems, fuzzy logic, neural nets, linear or non-linear programming, and model-predictive control. Other site-specific opportunities can also come into play such as shifting production or steam as a by-product so as to maximize internal electrical generation during peak purchase power rates. The justification of each of these blocks depends on the plant's operational and economic situation and is highly variable, but once a digital control system is present doing the regulatory controls, incremental investments to exploit an energy management opportunity can offer very high ROI's.

Figure 10: Industrial Utilities Integrated Control and Optimization



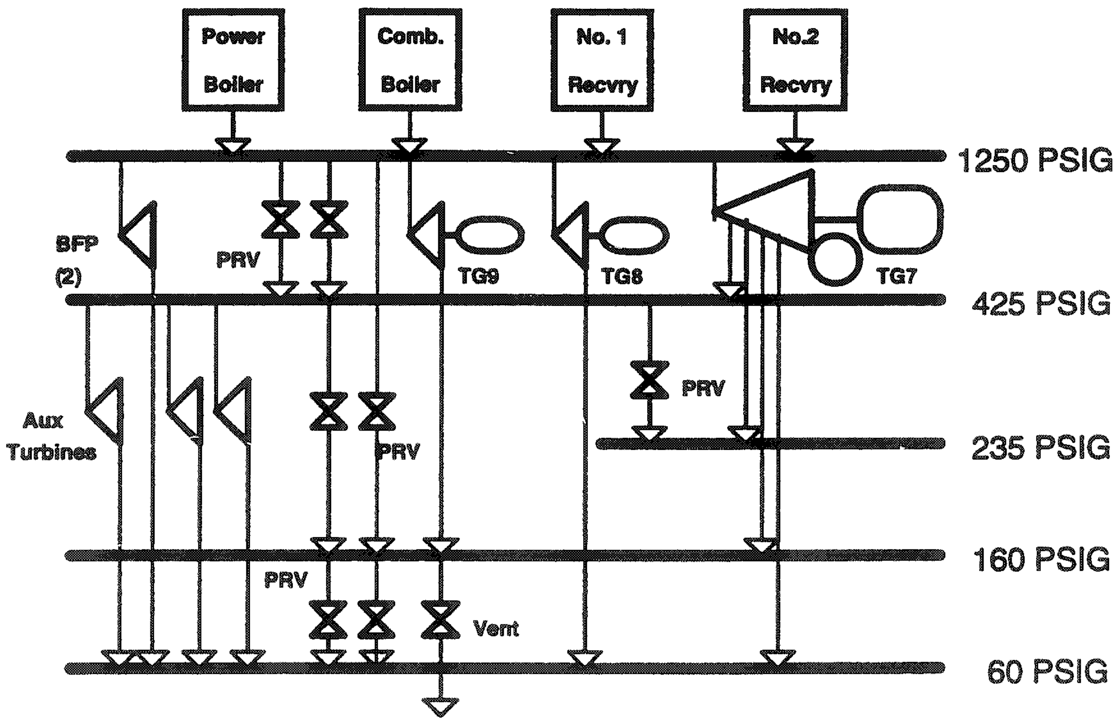
Mini Case Study

The economics of large scale industrial utilities optimization has been demonstrated in many places. Here is one example.

At a large pulp and paper mill in Hodge, Louisiana, owner by Stone Container, a comprehensive utilities management system was installed. See figure 11. The results were documented in 1991 and presented at the Council of Industrial Boiler Owners (CIBO) conference in 1993. The annual savings exceeded $500,000 which resulted in a 1 to 2 year payback period.

The primary sources of the savings were the regulatory boiler control and the tie-line management. Savings from the boiler control and boiler load allocation represented about 2% of the annual fuel cast. Savings from the turbine allocation and tie line management represented about 5% of the annual purchase power cost.

Figure 11: Stone Container, Hodge, La.



CONCLUSION

With increased global competition, all cost components of the manufacturing process must be scrutinized for new savings opportunities. The utilities are one of the most lucrative in terms of ROI, but historically they have been overlooked. However, modern control and optimization techniques can make the production of steam and other utilities a strategic contributor to profitability and competitiveness, and a hedge against rising fuel cost.