he term “optimization” has been used so much, for so many things, that by now it has almost no meaning. Recently, the term “fleet optimization” has been bandied about, with the implication that by installing a lot of computer networking and information management, fleet optimization will be enabled.

While it’s true that fleet optimization may be enabled with networking and information management (IM) infrastructure, relationships and the set of constraints together are called an optimization problem.

This is a somewhat theoretical definition, but it is a very powerful tool. It means that if you are not seeking to minimize or maximize some quantity, then you are not optimizing. This turns out to be important in every optimization problem because of the trade-offs inherent in the set of relationships between variables. The dollar is the conversion factor that points to the sweet spot in the trade-offs.

Regardless of the kind of generation company, all generators want to minimize costs. An extensive set of relationships exists between variables that ultimately resolves all the costs associated with making electricity. An extensive set of constraints also must be satisfied. Fleet optimization is the minimization of cost or maximization of earnings while satisfying all regulatory and business constraints. A fleet may be optimized using mathematical techniques when the relationships between variables and constraints have been defined. A pretty daunting

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**Figure 1 CYCLING LOAD PROFILE ANALYSIS**

**Short-term benefit and mid-term cost**

<table>
<thead>
<tr>
<th>Starts per year</th>
<th>$/year, millions</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
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<tr>
<td>200</td>
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</tr>
<tr>
<td>400</td>
<td>3</td>
</tr>
<tr>
<td>600</td>
<td>5</td>
</tr>
</tbody>
</table>

- **Op margin improvement**
- **Annualized repair cost**

**Mid-term optimum**

<table>
<thead>
<tr>
<th>Starts per year</th>
<th>$/year, millions</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>200</td>
<td>-2</td>
</tr>
<tr>
<td>400</td>
<td>-1.5</td>
</tr>
<tr>
<td>600</td>
<td>-2</td>
</tr>
</tbody>
</table>

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By Tom Snowdon, Emerson Process Management

Fleet Optimization Defined

Optimization is the process of minimizing or maximizing some quantity, given a set of relationships between variables and a set of constraints that must be satisfied. The set of that infrastructure will not be used and useful without a clear understanding and vision of what it means to optimize. The industry is in need of a straightforward definition of fleet optimization and a straightforward perspective on achieving it.
task, but as has been pointed out, every 
journey begins with the first step.

Getting Started

In tackling the fleet optimization 
problem, it is beneficial to begin with a 
bottom-up approach that leverages one 
optimization tool that every fleet already 
utilizes—the energy management 
system (EMS). EMS is at the heart of all 
dispatching systems regardless of whether 
it’s used in a non-merchant utility fleet or 
in a competitive wholesale market.

The EMS uses a rigorous methodology 
that guarantees least-cost dispatch of the 
fleet, given the relationship between cost 
and load for each generating unit and a set 
of constraints describing the minimum 
load, maximum load, emissions limits 
and a host of other constraints applicable 
to each unit. The fleet achieves the 
minimum cost of production when each 
unit has optimized to its minimum cost 
and the fleet as a whole can change its 
output as required to meet demand while 
maintaining a minimized cost dispatch 
solution. This requirement to keep the 
least-energy cost while changing the 
total output of the fleet is the source of 
the inherent value of unit operating 
flexibility. It is the requirement that 
produces value in ancillary services 
markets. The first important realization 
is that the fleet can be optimized only 
when each unit is optimized throughout 
its operating range.

The place to start is with individual 
unit short-term optimization. This 
involves defining all of the relationships 
between variables that have an effect on 
the total cost of production in terms of 
short-term “variable” costs, keeping all 
of the constraints in place.

For most units, the commodities that 
must be purchased and consumed to 
produce electrical energy are:

- Fuel
- NO\textsubscript{x}\textsubscript{2} allowances
- SCR or SNCR reagent 
  (ammonia or another reagent)
- SO\textsubscript{2} allowances
- FGDS reagent (limestone, lime and 
  so on.)

Some units have variable costs 
associated with the purchase of water used 
for cooling water and FGDS slurry water. 
As mercury limit regulations become 
applicable, reagents such as activated 
carbon may become a significant variable 
cost.

Remember that units in states that 
do not have tradable allowances do 
have limits of some sort placed on their 
emissions. An analysis of the incremental 
cost to replace power that cannot be 
generated by a unit that is running up 
against a limit is required to determine 
the virtual value of NO\textsubscript{x} allowances.

An operator or a control system can 
make hundreds of adjustments to try 
to produce the lowest cost electrical 
energy possible. These include damper 
adjustments, fan speed adjustments 
and burner tilts, among others. In 
the language of optimization science, 
these are called manipulated variables.

Changes in the manipulated variables 
result in changes to dependent variables 
such as flue gas oxygen content, steam 
temperatures, heat transfer surface 
cleanliness and so on. Changes in 
dependent variables result in changes to 
other dependent variables down a chain 
of relationships that ultimately result 
in changes to cost of production. Cost 
of production represents the ultimate 
dependent variable and the objective is 
its minimization.

Other disturbance variables such as 
ambient temperature, humidity and 
water in the fuel also produce effects on 
the dependent variables. Those effects 
must be characterized to achieve our 
optimization objective. The combination 
of all the mathematical relationships is 
called the objective function.

Many plant performance engineers 
who tackled unit optimization before 
about 1992 will testify that the multitude 
of functional relationships between 
variables is bewildering. Fortunately, the 
computing power now exists to gather 
all the data necessary to characterize the 
response of dependent variables to changes 
in the manipulated and the disturbance 
variables, develop the objective function 
as a set of mathematical expressions and 
perform the mathematics required to 
achieve total cost minimization.

The programs that collect the data and 
develop the characterizations are known 
as “neural networks” or more generically, 
“characterizers.” The programs that solve 
for the minimum or maximum given 
the characterizations and constraints 
are called “solvers.” Combining the 
functions of these programs produces 
a program called an “optimizer.” The 
latest optimizers include the capability 
to recognize when something about 
the process has changed and develop 
new characterizations that are used to 
“immunize” the optimization problem 
against that change immediately and for 
the future.

Short-term Fleet Optimization

Even using state-of-the-art 
optimization computer programs, 
characterizing a unit and making its 
optimizer bullet-proof is not a trivial 
exercise. However, it is possible and even 
reasonably economical since effective tools 
are now available. Having characterized 
the settings (the manipulated variables) 
required to minimize real-time total 
cost of production for each unit, the 
characterization of cost as a function 
of unit load can be supplied to the fleet 
EMS so that it can optimize the fleet.

The cost of fuel across the load range 
has traditionally been the only commodity 
represented in this characterization. 
With the advent of emissions cap-and-
trade systems and the cost of emissions 
reduction reagents used in SCRs and 
scrubbers, this is no longer adequate. 
The sum of the costs of the commodities 
mentioned above must be included in the 
characterization. The EMS then takes 
care of dispatching each unit at the load 
necessary to minimize the total real-time 
cost of the fleet.

The first challenge in fleet optimization, 
as distinct from unit optimization, 
is to update the EMS with fresh unit 
characterizations whenever appropriate. 
This means that each unit optimizer 
must be able to recognize when something 
about its objective function has changed enough to cause a change 
in the unit characterization used by the 
EMS. Almost any performance change 
of a piece of power plant equipment will 
cause the unit’s objective function to 
change. Also, any change in the price 
of variable-cost commodities causes the 
objective function to change. Because 
these quantities change frequently, the 
EMS must have near real-time updates of 
each unit’s cost characteristics in order to 
achieve an optimized fleet.

Mid-term Fleet Optimization

Having successfully achieved short-
term fleet optimization, we turn our 
attention to optimization in the mid-
term. The goal here is to understand 
how short-term optimization or changes 
in operating procedures might change a
unit’s objective function for the better, or might change some operating constraint in a way that produces a lower-cost result from the EMS. Sometimes these sorts of changes result in a change in the cost of maintaining a unit.

Operating with a cycling load profile, for instance, can result in added boiler maintenance costs and replacement power costs when compared to those resulting from a base-loaded profile. However, at the same time, operating with a cycling profile can save money during off-peak hours. In Figure 1 on page 116 an analysis of the benefit of cycling during off-peak pricing hours versus the added cost of maintenance shows a maximum net benefit of $2.2 million at 220 cycles a year. Mid-term fleet optimization is an exercise in balancing the economic benefit of the operating procedure change or short-term optimization against any resulting added cost of maintenance and replacement power, to minimize the total cost.

Some companies have rejected short-term optimization, fearing that resulting mid-term costs might become too high. Decisions based on knowledge, or at least reason, are preferable to decisions made on fear. Therefore, companies that have rejected short-term optimization on this basis are well advised to re-examine that decision.

The major difficulty with mid-term optimization is that it takes time to measure the rate at which maintenance costs increase as a result of the changed operating procedures or short-term optimization. The key is to start with a well-thought-out hypothetical characterization to use in the objective function. As time progresses, measurements of equipment degradation are taken and used to adjust the hypothetical characterization. This makes it progressively more representative of reality. Such a process is the essence of a continuous improvement program, approached from a perspective that combines business and engineering sciences. It is applicable to any number of operations vs. maintenance trade-off situations including reduction of minimum load, unit load ramp rate and cycling operations.

With a clear understanding of mid-term cost characteristics, the variable cost curves or constraints of each unit in a fleet are adjusted to reflect both short and mid-term costs, ensuring the appropriate dispatch to minimize fleet cost of production over the midterm. This addresses one of the most difficult issues between plant management and dispatch or trading management. Commonly, either the plant gives the dispatcher whatever he wants and then blames “erratic dispatch” for a high forced-outage rate, or the plant constrains dispatch in an effort to minimize mid-term costs, but leaves big money on the table in terms of the ability to minimize fleet-wide aggregate cost of production. Mid-term fleet optimization offers the mechanism through which the lowest total cost set of constraints and operating settings can be approached.

Optimization Through Investment

The next essential component to consider in a continuously improving optimization program is investment in the existing units with the goal of further reducing costs while satisfying all regulatory and business constraints. In other words, finding ways of changing the objective functions of the existing units by investing in new equipment or control software that enables the optimizers to resolve to an even lower total cost of production.

A case can be made for using optimization as a means for determining the number and nature of investment projects that should be implemented on the existing units of a fleet. The optimization problem uses investment in each project as the manipulated variable and maximized earnings as the objective. The problem solution indicates the level of investment necessary to maximize earnings; in essence pinpointing the investment level where further investment becomes dilutive to earnings.

Formal fleet optimization is best accomplished using a rigorous mathematical construct that minimizes the cost of production, maximizes earnings and satisfies all regulatory and business constraints. The form of the mathematical construct is well-established and useful. Its application is best accomplished from a bottom-up perspective starting with short-term unit optimization, moving to short-term and mid-term fleet optimization and finally optimization through investment.

Author: Tom Snowdon is plant performance consultant at Emerson Process Management Power & Water Solutions. For most of his 25-year career he has been involved in plant operation, particularly in the areas of engineering, plant performance and O&M. Before joining Emerson in 2004, he was director of operations planning for a major power generator.