AN INNOVATIVE OPTIMIZATION-BASED SERVICES & SOLUTIONS OFFERING IDENTIFIES THE LOWEST COST SOLUTION TO ACHIEVE EMISSION LEVEL COMPLIANCE

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Abstract

The Houston-Galveston Area (HGA) is classified as a "serious" ozone non-attainment area. Each company operating in the area must achieve specific NO_x emission level limitations, staged between 2003 and 2008. Various treatment technologies are available for the different types and sizes of emission point sources. Air Products & Chemicals, Inc. (APCI) has developed a unique Services & Solutions Business offering, built on a patent-pending business method, which establishes a web-based emissions network that links companies' emission-reduction plans to determine the lowest cost of compliance under the Mass Emission Cap & Trade (MECT) program. The web-based management system integrates data from the Texas Commission on Environmental Quality (TCEQ) and the customers' forecasted point source emission levels to provide input to an Emissions Optimizer (EO). The EO develops a solution using state-of-the-art mathematical-programming-based optimization techniques. A large-scale Mixed-Integer Linear Programming (MILP) problem is solved using the *NO_x Model Manager* application, customized for APCI by Advanced Process Combinatorics (APC) using APC's proprietary *VirtECS* solver technology, to determine the lowest compliance cost for the region. A subsequent Nonlinear Programming (NLP) problem is solved using the *NO_x Trading Model*, developed by APCI using the *Generalized Algebraic Modeling System* (*GAMS*), to determine the corresponding credit trades. Optimization results are returned to the database for each customer's individual review.

Keywords

Emissions Optimizer, NO_x, Emission Compliance Monitoring, Cap & Trade, Environmental Management Information System, Mixed-Integer Linear Programming, MILP, Nonlinear Programming, NLP, Houston-Galveston Area, HGA, Texas Commission on Environmental Quality, TCEQ

Introduction

The Houston-Galveston Area (HGA) is classified as a "serious" ozone non-attainment area. Over 2750 point sources are subject to treatment to reduce NO_x emission levels (ton/year) by 80%. Based on current point source activity levels (MMBTU/hr) and emission factors (lb NOx/MMBTU), each company must achieve specific NO_x emission level limitations ("allowances"), staged between 2003 and 2008. Various treatment technologies

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are available for the different types and sizes of units. These technologies have different emission-reduction capabilities (lb NO_x/MMBTU) and investment costs ($-hr/MMBTU). In many cases, two technologies can be combined.

Air Products & Chemicals, Inc. (APCI) has developed a unique Services & Solutions Business offering, built on a patent-pending business method, which establishes a web-based emissions network that links companies' emission-reduction plans. APCI entered into an alliance agreement with VisionMonitor Software LLC, who used their Compliance Intelligence suite of products to develop the Environmental Compliance Competitive Advantage (ECCA) solution. The ECCA solution enables organizations to track, monitor, and predict their compliance with various regulatory standards and reporting requirements across the enterprise.

Additionally, the ECCA solution integrates data from the Texas Commission on Environmental Quality (TCEQ) and the customers' forecasted point source emission levels to provide input to an Emissions Optimizer (EO), as highlighted in D'Aquino (2003). The EO determines the lowest cost of compliance with the Texas State Implementation Plan under the Mass Emission Cap & Trade (MECT) program, as described by Huston *et al.* (2002). The EO develops a solution using state-of-the-art mathematical programming-based optimization techniques.

The EO consists of two components: (1) a large-scale, Mixed-Integer Linear Programming (MILP) problem to determine the lowest cost of compliance, and (2) a large-scale, Nonlinear Programming (NLP) problem, to determine the trades between companies corresponding to the investment selections determined by the MILP. These two components will be discussed in the next section.

Air Products has applied for a patent to protect this business model. The model is configured to handle any type of emission data in any non-attainment geography.

Air Products' Emission Optimizer

Mixed-Integer Linear Programming Component

The selection of the lowest cost of compliance for the entire HGA involves discrete decisions. These are, for each point source, when to install what remediation technology or combination of technologies over a six-year time horizon. These discrete decisions are represented by integer (0/1) variables. The lowest-cost solution to this question can be found by formulating an MILP problem. A high-level abstraction of the MILP problem is:

Minimize *Total Discounted Investment Cost*
Subject to:
Emission Level Constraints
Customers' Point Source Emission Forecasts
Technology Emission Level Reduction Capabilities
Customer Fixed Technology Decisions

Large-scale MILPs are considered intractable, because the number of potential solutions to an MILP problem grows exponentially with the number of integer variables. While there is no known algorithm that can solve general MILP problems in polynomial time, previous projects with Advanced Process Combinatorics, Inc. (APC), a venture spin-off company from Purdue University, had shown that, through careful problem formulation, decomposition techniques could be applied to exploit problem structure, and algorithms could be engineered to solve the specific class of problem under consideration. Subramanian, Pekny, and Reklaitis (2000) and Pekny (2002) provide a detailed discussion.

APCI's EO was developed in collaboration with APC using APC's *VirtECS Design* tool. The model parameter input database and basic structure of the NO_x problem were developed at APCI. APC then created a customized *NOx Model Manager* and tailored the problem formulation and solution algorithm to perform the optimization in an acceptable amount of time using their proprietary *VirtECS* solver technology.

The *NOx Model Manager* determines the lowest cost of compliance with the Texas State Implementation Plan. First, the EO performs an enterprise-wide optimization, where all companies act independently. This is followed by a region-wide optimization, where all participating companies act cooperatively. The optimization determines at each time period which companies should over-control their point sources to what extent to generate and sell credits, and which companies should under-control their point sources to what extent and buy credits.

Nonlinear Programming Component

Trading is implicit in the MILP framework. The EO performs a subsequent NLP optimization based on the MILP results to determine the tons per year (TPY) and dollar trades corresponding to the Cap & Trade program. APCI developed this *NOx Trading Model* using the *Generalized Algebraic Modeling System* (*GAMS*), described by Brooke *et al.* (1998).

The difference in capital investment between the two MILP solutions forms the economic basis for determining the marginal values of the buyers and sellers ($/TPY). The difference in the marginal values provides the driving force for trades. The net savings between the region- and enterprise-wide MILP solutions is partitioned between the sellers and buyers through the trades. The NLP trading model essentially maximizes the area between the buyer and seller trading curves, which corresponds to the net capital savings. The sellers receive more revenue than their additional investment required to generate credits, and buyers pay less through credit purchases than their alternative to invest in additional control technology.

The difference in margins for each trade represents the "negotiating range" for the individual trades, so there are many potential solutions to this problem. Many of these would be impractical from a commercial standpoint, because their interpretation is for a seller to trade at the break-even cost for the additional investment or a buyer to trade at the break-even point for the alternative investment. Therefore additional constraints are added to drive the solution towards a sharing of the savings within the individual trades. A high-level abstraction of the NLP problem is:

Minimize *Disparity in Shared Savings*
Subject to:
Total TPY Bought = Sum TPY Traded by Sellers
Total TPY Sold = Sum TPY Traded by Buyers
Dollars Bought = Sum Dollars Traded by Sellers
Dollars Sold = Sum Dollars Traded by Buyers
Dollars Sold ≥ Seller's Additional Investment
Dollars Bought ≤ Buyer's Alternative Investment
Buyers' Trade Margin ≥ Seller's Trade Margin
Total Savings Distributed Through Trades
Definition of Shared Savings

Results

These models have been solved for the entirety of the point sources belonging to all the companies in the HGA. Activity level and emission factors were taken at the base-values from the TCEQ database. Marketing reports and internal studies were used to generate appropriate treatment technology options, emission-reduction capabilities, and costs for each point source.

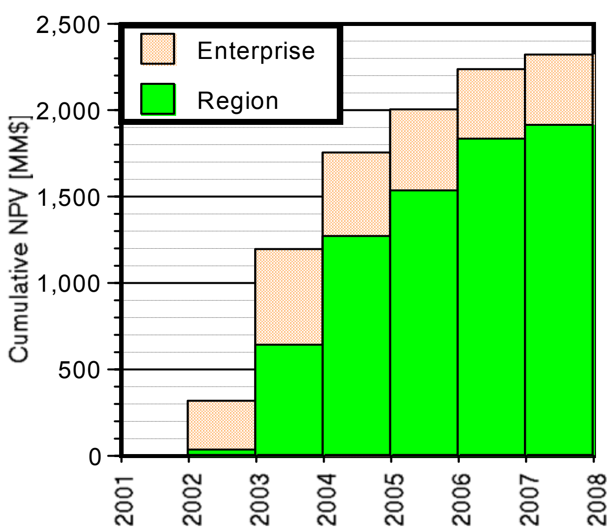

Figure 1. Cost Savings

Figure 1 illustrates the 15.7% cost savings between a region-wide optimization with Cap & Trade compared to an enterprise-wide optimization. Figure 2 illustrates an example of a trading curve between buyers and sellers.

The ECCA solution returns the enterprise-wide EO solution directly to the customer through the web-based supporting software. APCI's sales team follows up with a benefits opportunity analysis to those companies that can achieve a significant cost savings through trading.

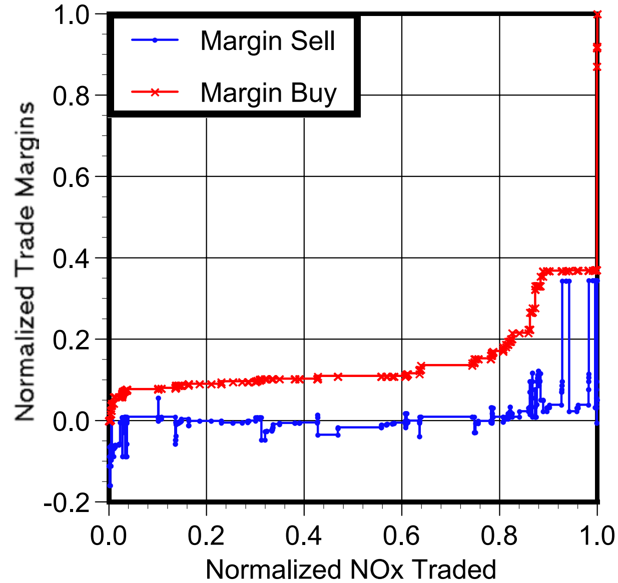

Figure 2. Normalized Trading Curve

Customer Input Data and Interface

The customer inputs a monthly forecast of activity level and fuel source for each point source. The allowances are based on the data from the TCEQ database.

The customer then provides one or more (or no) control technology options under consideration as well as any control technology selections that have already been decided, along with the timing of those decisions. Each control technology requires a cost and emission-reduction capability. Two technology options may be combined, where the performance of one is dependent on the selection of the other. For example, the performance of a Selective Catalytic Reduction (SCR) unit will be different if it is connected directly to the point source or if it is downstream of a Low NO_x Burner (LNB).

Unique features have been added to the EO model to match specific company requirements and regional regulations. Companies can identify equipment that must be reduced (even if non-optimal) due to other reasons such as consent decrees or plant efficiency projects. They can specify whether or not to roll over extra allowances at the end of each year. Depending on the local regulations, companies can use Emission Reduction Credits and Discrete Emission Reduction Credits (ERCs and DERCs) to add to their allowance limits. These additional allowances can be continuously added to the solution. Finally, they can restrict the installation of technology until a plant outage occurs. This is done on a unit-by-unit basis to allow the greatest degree of flexibility.

Figure 3 illustrates one of the customer screens.

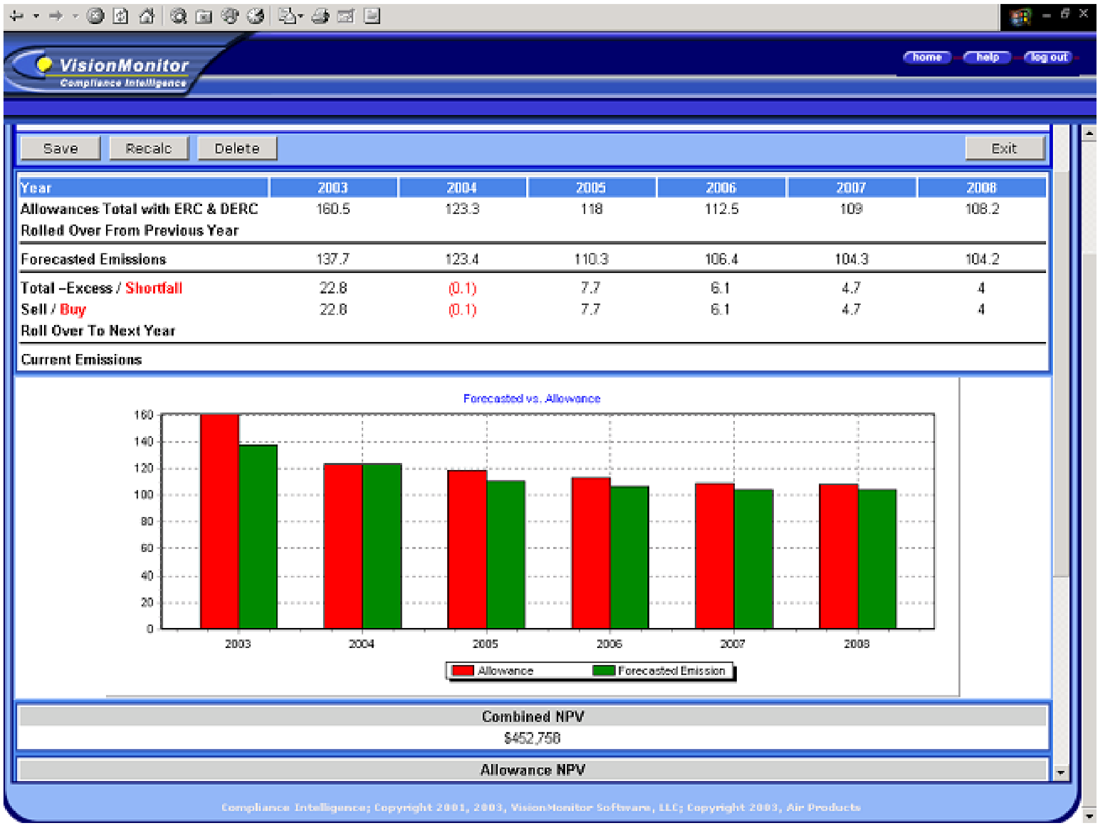

Figure 3. Example of a Customer Display Screen

Conclusions

APCI's ECCA solution is a unique environmental compliance monitoring and optimization product designed to deliver value-added services to our customers. The EO is a key differentiating component of this Services & Solutions Business offering. The EO couples APCI's in-house modeling and optimization expertise with APC's proprietary *VirtECS* solver technology.

The EO provides a successful example of how technical advances made by academic researchers can be transformed into viable commercial products. By cultivating a long-term industrial-academic relationship, changing business needs can be used to identify new opportunities to advantageously apply optimization technology to determine solutions to critical problems.

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