THE APPLICATION OF SYSTEM DYNAMICS (SD) SIMULATION TO VOLATILE SYSTEM MANAGEMENT

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ABSTRACT

One of the most volatile market environments of our time is the energy business. Whether the energy medium is gasoline, electricity, or natural gas, traditional market forces do not seem to exert the same influences as in other markets. Indeed, the behavior of the energy market sometimes seems to defy traditional understanding of the law of supply and demand. Management of, and survival within, such a system requires deep understanding of the system's potential behaviors under many different scenario settings. System Dynamics (SD) is posited as the most appropriate first methodology to apply when a system with highly volatile behavior is under scrutiny. This paper presents the background and some of the lessons learned from projects in which SD simulation was applied to analyze and understand the highly volatile energy market. Two projects are described in which different aspects of the energy market were modeled. A natural gas strategic acquisition simulation provides a tool for examination of market dynamics with a focus on acquisition strategy, while a gasoline business simulation provides insights into the supply side of the energy business. The simulations were used to examine system physics, understand endogenous and exogenous influences, validate performance measures, and to produce a systematic process for energy strategy development. The application of SD to volatile environment management is not new; the scale of these simulations, and some of the techniques used for design and rollout potentially make the projects unique.

1. INTRODUCTION

Presented here are the results of two projects in which SD simulation was applied to the problem of energy acquisition and distribution strategies. While SD simulation is not a new discipline, its application to large scale problems is not yet as common as other simulation methods. In fact, SD simulation is not always the most appropriate technique. In this paper, two projects are described, one fairly small and the other large scale. In both cases, the system under scrutiny is part of the very volatile energy business, one of the most dynamic, complex, and interrelated environments of the present time. The thesis of this paper is that for systems and environments that are characterized by their volatility, complexity, interdependencies, and sometimes unpredictable dynamics, System Dynamics is the most appropriate first step to build an appropriate framework for management and understanding of the system. The SD framework may suggest points within the system that are more appropriately studied with other tools and techniques.

2. WHY SIMULATION ?

The use of simulation was a novel approach in this context, given the legacy tools and methods available to energy planners and analysts. For the natural gas application, a colleague with responsibility for that market, with significant domain expertise and a strong desire to expose planners to new and better ways of conducting their business, decided to attempt an introduction of System Dynamics to his professional community. For the gasoline business application, the use of simulation was less of a new approach than was the complexity of the simulation that was produced.

We had demonstrated the usefulness of simulation as a learning and analysis tool in several other engagements, thus the application of the technology was a natural extension in these markets.

Simulation brings to the analyst/planner the ability that to alter the world quickly, and from that altered state, view many potential alternative futures. This was the primary selling point to use simulation as a general approach to natural gas acquisition strategy/management. The ability to embed a reasonably high fidelity economic model with the more typical supply chain constructs in the gasoline market was also a motivator.

System Dynamics brings the unique capability to easily integrate parameters that are generally non-quantifiable, and thus to test impacts of those parameters over time on a large, interdependent system. Energy market dynamics often respond disproportionately to these non-quantifiable parameters compared to other, traditional market factors. This reduces the efficacy of other analysis techniques and argues for a different approach. For example, the rumor of a hurricane hitting the Gulf Coast of the United States has been sufficient to induce a significant spike in energy prices., The energy acquisition manager may then be forced to spend far more for the necessary gas supplies than had been anticipated. A plan to acquire energy resources with a strategically sound framework that anticipates events like this is critical to reducing this cost.

2.1 WHY SYSTEM DYNAMICS ?

Once simulation was accepted as a viable and desirable alternative to traditional energy planning and analysis methods, introducing the value of SD simulation was straightforward.

The three basic questions of SD were introduced within the context of assessing potential futures: what is flowing in a system, where does it collect, and what causes it to flow. Knowing the answers to these basic questions permitted the development of a simulation. Just the development of the answers added significantly to the knowledge base within the organization because they forced planners to focus on the problem from a different perspective.

Every volatile system environment is a relational environment, with highly interdependent activities throughout the structure. Causal relationships are often understood yet overlooked in the daily grind of energy production and acquisition management. The value of applying SD as the starting point for deeper analysis becomes clear when the relational aspects of the system are clearly demonstrated to analysts. A simple, yet relatively robust, causal loop diagram (CLD) that addresses a portion of the energy market can introduce subject matter experts to the three principal effects that this type of simulation illuminates for its users: systemic feedback loops, systemic delays, and unintended consequences. This usually convinces the experts that SD is the right tool for initial analyses of volatile management environments.

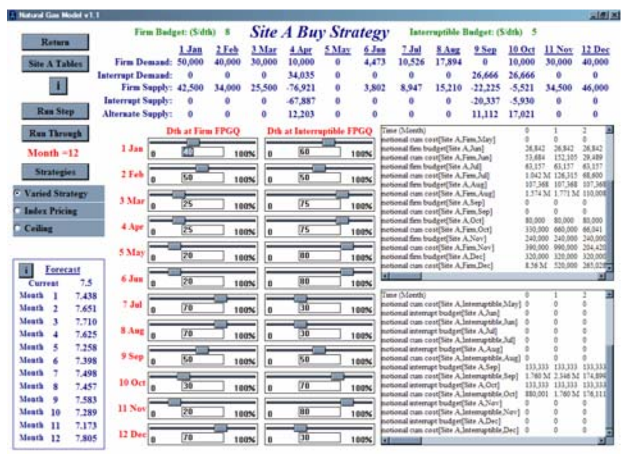
3. THE NATURAL GAS PROJECT

The United States Government is a sizeable user of natural gas. The dynamics of that market are as much influenced by speculation as actual supply and demand. A market space driven by intangibles is, at best, a difficult environment for managers who must acquire large amounts of product at the best possible price. Traditional forecasting tools and methods appeared to be inadequate to assist analysts in devising consistent strategies for product acquisition that would satisfy demand as well as meet taxpayer expectations of lowest possible cost.

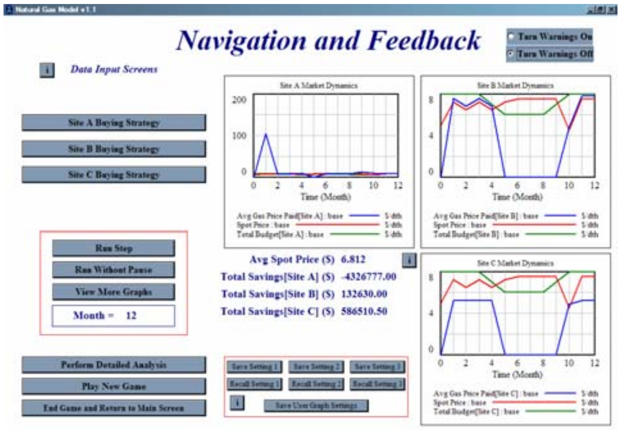
In this project, the design team endeavored to capture the essence of the market dynamics for this commodity to produce a simulation useful to support analyses for product acquisition. The focus was on presenting various market scenarios, and several acquisition options with the resultant predictions of annual cost of procurement and estimated savings against the standard purchase strategy.

3.1 MODEL STRUCTURE

The simulation was designed to represent three distinct sites, each site being either a physically different location, or a single location with three distinct buying strategies. Each of the sites can be described by parameters such as firm and interruptible ceiling prices by month, any alternate fuels that may be desired should the supply of natural gas be interrupted, firm and interruptible gas budget levels, and the desired buying strategy for the site. With this approach, three different strategies for a single site may be simulated simultaneously, permitting rapid analysis of alternatives. The figure shows an example input screen for one of the sites.

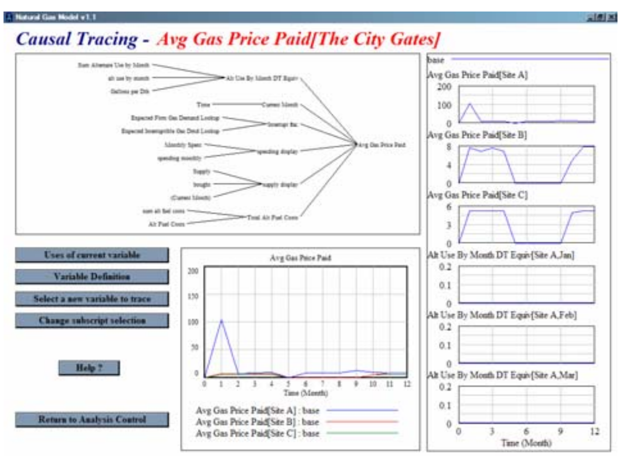


The analysis screen, shown below, allows direct comparison of site physics, either during a model run (using the pause function) or at the conclusion of the simulation.

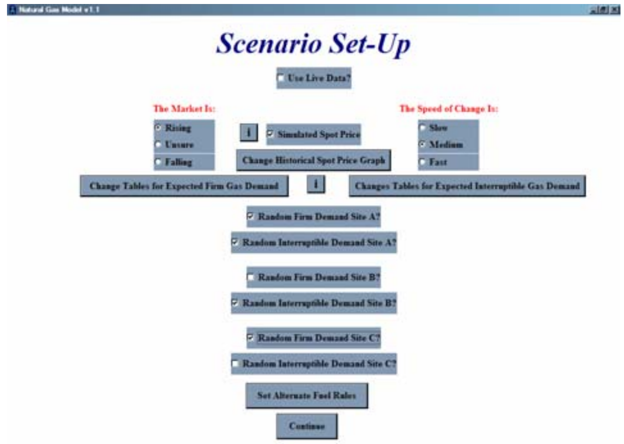


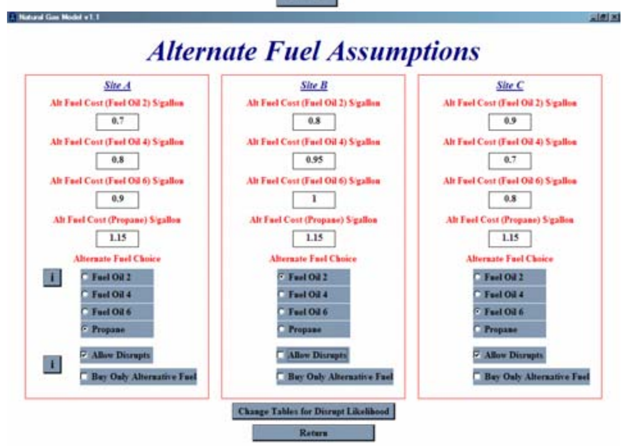
Notice that in this example, the strategy for site A was flawed, resulting in a net projected loss for the year. Sites B and C had strategies that project a net savings across the year. These were three acquisition strategies for the same site, allowing rapid comparison of the relative merits of each. The simulation permits the user to build an acquisition strategy for the year, described month by month. Using a single site with these three views, three completely different strategies for the year may be constructed and played, with immediate comparative feedback, as shown above.

The analysis capabilities provided with the simulation are fairly standard for this type of tool, focusing primarily on behaviors over time. The figure shows a composite display of prices paid at each site over time.



The natural gas model was designed to be an analysis tool for the planner, providing an experimental platform for scenario selection and detailed alternative courses of action analyses. For example, some of the scenario selections available are shown below. Provision has been made to select random events, build interruption profiles for each site, and build an alternate fuel profile, to name a few of the options provided.





System Dynamics has demonstrated its value in this decision support context convincingly because the value proposition centers strongly on rapid analysis of alternatives, the ability to compare multiple scenarios simultaneously, and the ability to compare three distinct sites or three strategies for a given site.

4. THE GASOLINE BUSINESS PROJECT

The gasoline business is indeed complex, interdependent, and central to much of the global economy. Understanding the physics of the business permits decision makers to have the insights necessary to formulate business strategies that meet their long term objectives, while being accountable to the public at large for providing personal energy resources at an affordable cost and consistent rate.

This project revolved around the need for a major United States west coast oil company to fully address the intricacies of the business environment. The business case involved multiple regions, multiple channels of trade, multiple layers of competition, and a set of intricate business rules that were masking some of the true effects in the system.

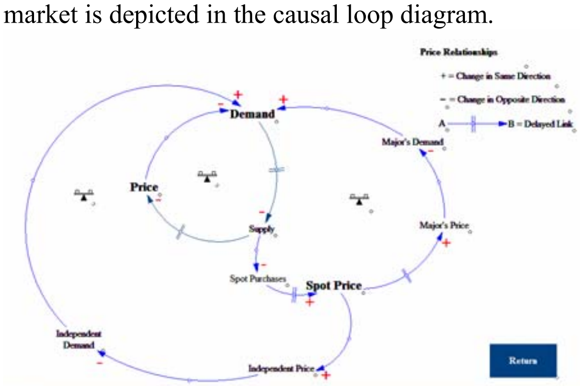
In the geographic area of interest, there were three sources of retail gasoline: major oil companies, independent distributors, and the client, a mid-range producer of petroleum products. The client's pricing strategy at the pump was simple – basically an average of the majors and the independents. This strategy would always place the pump price below the majors and above the independents. The simulation quickly demonstrated the flaw in this strategy.

The company in question had a single refinery in the region under study, and purchased the remainder of their product from the spot market. Since this company was a large supplier of petroleum products in the region, its shift to the spot market would invariably trigger a rise in spot prices, thereby adversely affecting the independents. A typical behavior of independent distributors when the spot price rose was to immediately raise their street price, not to recoup cost but to shift volume. Given our company's pricing strategy, they invariably gained the volume shed by the independents, causing more demand on the spot market, and again causing the spot price to rise. Since the majors had excess refining capacity, they sold fuel to the spot market, effectively capturing both ends of the market.

4.1. MODEL STRUCTURE

The basic simulation is structured to include three regions, three refineries, three levels of competition, and three channels of trade. Known and unplanned interruptions in refining capacity can be simulated. Each competitor's pricing strategies may be independently set, and all elements of the business economics are directly accessible.

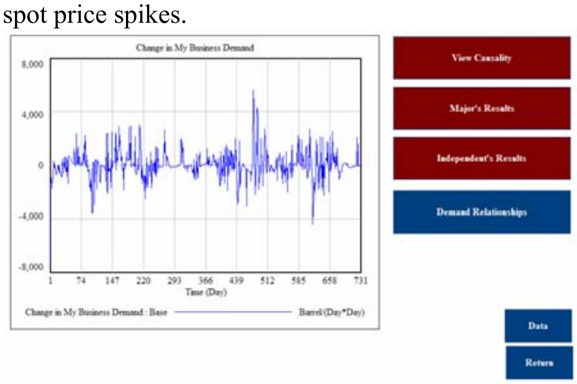
The basic dependence on the spot price in this market is depicted in the causal loop diagram.



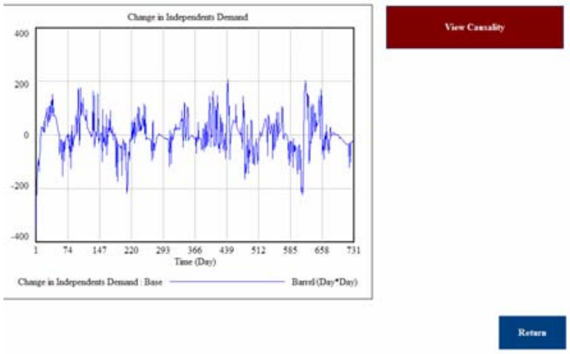
Note the lag in major's pricing in response to the spot market's fluctuations, and the lack of a lag with the independents. An immediate increase of price at the pump by independents as a tactic to shift volume results in an immediate increase in demand at the minor's pumps (not shown in the diagram), which will eventually influence spot price again. The spot market's dynamics are shown in the figure.

A spot price emulation algorithm was developed for the simulation to provide the option of using historic spot price data, or allowing the simulation to generate a spot price profile. The blue line in the graph is the simulated spot price. Note the similarity in behavior compared to the actual spot price. To generate a simulated spot price, the market's reaction to planned and unplanned interruptions, as well as documented market dynamics were incorporated into the algorithm. The simulation permits the use of historical interruption data or will generate interruptions of random length and intensity.

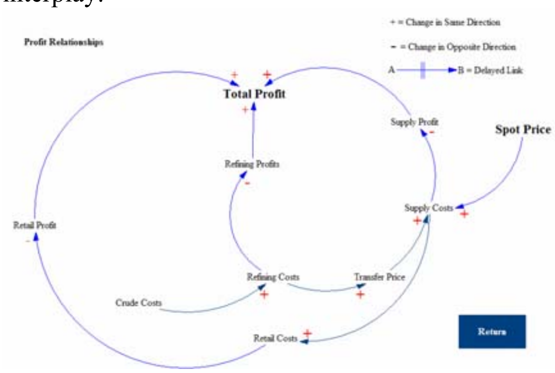
The graphic below shows the simulation's results of demand over time, allowing a direct comparison with the spot price (above), demonstrating the shift in volume caused by the independent's selling strategy. The fictitious company, My Business, is considered to be a minor oil company, and the company of interest described in the introductory description of the project. Note that demand spikes coincide with spot price low values, and the demand drops occur when the spot price spikes.



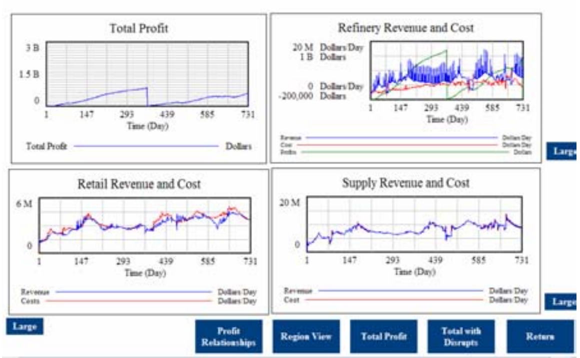
The same display for the independent's demand profile, below, demonstrates this shift.



Profitability is always a concern in any business. The energy business, especially the gasoline business, has an intricate set of market dynamics in play. The basic profitability causal loop diagram shows some of the interplay.



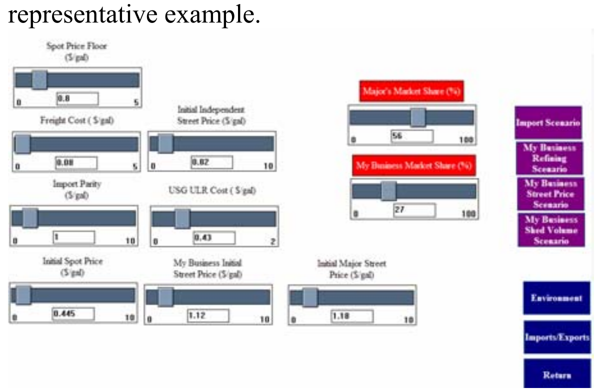
The profitability of the business has been condensed into four metrics, as shown below.



From this display, it is apparent that the initial conditions used to drive this particular model run resulted in a profitable refinery operation, but a somewhat unprofitable retail operation. The retail profit graph is shown below in a larger format.

Note that costs exceed revenues during periods when spot price is elevated. This particular minor dealer has a single refinery in the region. When the refinery is in full production, there is rarely a need to use the spot market to supplement stocks. When that single refinery experiences an interrupt, dependence on spot increases, and spot price will increase accordingly. Comparison of the graph above and the spot price graph demonstrates the linkage.

In use, the simulation can be used to manipulate the many parameters describing the business in order to produce profitability results more in line with business desires, and then analyses can reveal the practicality of the steps taken to achieve the change. The simulation contains many data input screens, with the following as a representative example.



As modifications are made, the user records them. After a suitable solution is reached, the feasibility of the modifications is determined. It is often discovered that the real cost of modification of any complex system is time rather than finances or other resources.

5. LESSONS LEARNED

Projects of the magnitude described here will always generate many lessons. A few of the most notable are listed.

When SD is applied to large scale simulation projects, demonstrated results are often counter-intuitive. This effect demonstrates the need to invest the time at the outset to develop causal loop relationships with the client, and to invest client staff in an understanding of large system physics through their use. This new perspective on organizational physics and interdependence is fundamental to the use of the simulation, but more importantly affords the organization the opportunity to devise and test new methods of management almost immediately.

It is critical to have access to a knowledgeable member of the client organization on a routine and consistent basis throughout design and validation of the simulation. This facilitates developing a reasonable set of assumptions, and lends instant credibility to the simulation among organizational users.

A simulation, especially an SD simulation, has its value in forcing people to learn about their enterprise, not in deriving answers. In fact, if properly constructed, simulations of the type described in this paper should generate far more questions than answers, compelling users to dig deeper into organizational structures, broadening their individual and collective understanding, and generating new behavior at personal and corporate levels.

6. SUMMARY

These projects proved to be an exceptional application of SD methodology in a non-traditional venue. The typical toolset heavily favors regression analyses, optimization techniques, and massive spreadsheets to solve problems. In the approaches described here, we have sought to demonstrate that a credible tool can be devised that will enable decision makers to solve problems, and at the same time provide significant value at a much wider horizon. For example, both projects demonstrated the value of the simulation for training others in how the markets work and the businesses function. Individual and collective behaviors can be influenced through judicious application of tools such as described here. Corporate performance measures can be placed under scrutiny by simulation outcomes, forcing an evaluation of metric validity. The introduction of System Dynamics to the energy simulation environment resulted in learning outcomes consistent with what would be expected from more limited applications of the methodology.

Volatile systems can best be understood through the application of SD simulation, as demonstrated in this paper. Their very volatility, realized through the rapidly changing nature of the industry and its impact on the general public, argue convincingly for a methodology that will provide system-level visibility and understanding in order to gain a long-term view of the impacts of management decisions. Indeed, System Dynamics may not be the final tool for a particular project of this type, but it is arguably the best starting point in gaining an understanding for the proper application of other tools, methodologies, and techniques.

AUTHOR BIOGRAPHY

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