Oil Policy Regret Analysis With System Dynamics Models

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Introduction

A simple system dynamics model was used to explore the potential benefits of using regret analysis to develop sensible government energy policies. Regret analysis looks at the relative impact of unexpected futures to design policies that reduce the risk of losses rather than trying to optimize benefits. It is very useful when it is impossible to assess or agree on the probabilities of future events and, especially, those events that can have a large impact on the system behavior.

We focused our attention on understanding the system behavior and the potential benefits that might be derived from this approach, which appears to be previously unreported in the petroleum industry and system dynamics literature. We tested the technique assuming an uncertain future oil price, which was an important driver of our system model behavior based on the conditions we defined in our test problem. This allowed us to easily evaluate the benefits of potential government tax policies. With other assumptions, there could be many more variables that could impact the results. In this case, more sophisticated techniques (e.g., PRIM[1] analysis) will be needed to identify the best policy alternatives.

The primary goal of our research is to use system dynamics and regret analysis to help define sound policies that will encourage exploration and development of new energy sources.

Background

System dynamics and regret analysis have been used extensively[2-5] in the last 10-20 years to develop and evaluate policies in the presence of "deep uncertainty", where the model input data and/or structure is uncertain and probability distributions are unknowable. This is particularly important when surprise events can have a large impact on system behavior and results. Based on this research, it appears that the best policies are those that are robust (work reasonably well even when bad surprises occur) and adaptable (have the capability to accept and adjust to new information).

Most approaches to energy policy in the past have either assumed that the future is either known or will not be full of surprises. The petroleum industry makes extensive use of probability distributions in all facets of decision-making. Our concern is that probability theory breaks down when distributions and limiting values are unknowable. Therefore, we decided to investigate the potential impact on oil field policy of surprise events that cannot be forecasted with any accuracy.

In the following discussion, we will assume that there are two main actors – the State government and an oil producer (called Producer). The State imposes fees (royalties and taxes) on the Producer based on the volumes of energy resources on State lands and the participation of the Producer in producing these resources. These fees are the primary source of revenue for the State and are used to create and maintain the infrastructure (roads, utilities, police and fire protection, schools, etc.) that all citizens (including the Producer as a corporate citizen) use and depend on as members of the society.

We will also assume that the State and Producer are separate entities. In the real world, this is often not the case as the State and Producer are both parts of the government (e.g., Middle-East). However, in North America, most oil producers are independent companies that are completely separate from the State. They are often multi-national corporations with interests in energy production in many worldwide locations. This complication is a serious factor in energy policy because the State is faced with the problem of developing a policy that will attract investment (low fees paid by and possible incentives paid to the Producer) but also generate enough revenue to support the society (fees high enough to cover State expenses). If the society fails to meet the demands of its citizens (private or corporate), political pressures can increase on the State to correct policies that appear to be "too generous" to either the Producer or the society in general.

Sound energy policy should be fair, robust and adaptable, but finding the right balance is difficult at best. For example, how does the government determine the parameter(s) that are important? Typically, multiple interests are involved including near-term profits, longer-term revenues, development of all economically feasible energy resources, and minimizing damage to the environment. While these interests can be at odds with one another, the most politically expedient goals usually drive the policies enacted. Can we do better using different techniques to understand the problem?

From the Producer point-of-view, the objectives of a good energy policy are relatively simple. First and foremost, the Producer wants to maximize near-term profits. However, the Producer can also place some emphasis on the growth of their future energy reserves as a measure of the company's financial health, longer-term viability and attractiveness to outside investors. This may or may not include active participation in alternative energy development as part of a transition away from fossil fuels. Finally, the Producer is interested in reducing costs as an easy way to improve near-term profits. Therefore, reducing State fees would logically appear to be in their near-term best interests. Too often, however, cost cutting also affects exploration, development and operations activities as well. Maintenance activities are reduced and problems are not corrected. A prime example of this includes well explosions (Gulf of Mexico in 2010), pipeline leaks (Alaska North Slope 2006) and pipeline explosions (San Bruno, California 2010).

As a result, the problem of developing sound energy policy is daunting. There are potentially conflicting goals and points-of-view on all sides. Future policies need to address the needs of all parties, including the society. The State needs a reliable source of income to meet the needs of its citizens now and in the future. The Producer needs incentives to take risks and produce energy on State lands. Longer-term, the State and Producer need to work together to transition from non-renewable fossil fuels to more sustainable solutions to meet the energy needs of the society.

This paper represents an attempt to explore the problem and potential strategies that could be used to develop solutions.

The Model

A system dynamics (SD) model was designed to represent a typical oil reservoir of known properties (e.g., depth, estimated reserves) that could typically exist in any oil-producing region. We specifically assumed that the field has been discovered and defined by exploration wells and seismic surveys so that it is ready to be developed. This was a simplification to eliminate some otherwise important model variables (e.g., initial oil reserves, drilling costs, etc.) from our regret analysis.

The main processes at work can be represented in a simple causal loop diagram that explains the relationship between the oil production and cash flows for the Producer and State. This is shown in Figure 1 below. Blue arrows represent positive relationships and red arrows indicate negative relationships between model variables. Higher oil production rates increase positive cash flows for the Producer and State, while higher taxes increase State cash flows but reduce Producer cash flows. This model is intentionally as simple as we can make it to describe the relationships between oil production and economics. It would be straightforward to increase the complexity by adding more feedback loops and this will likely change the system behavior.

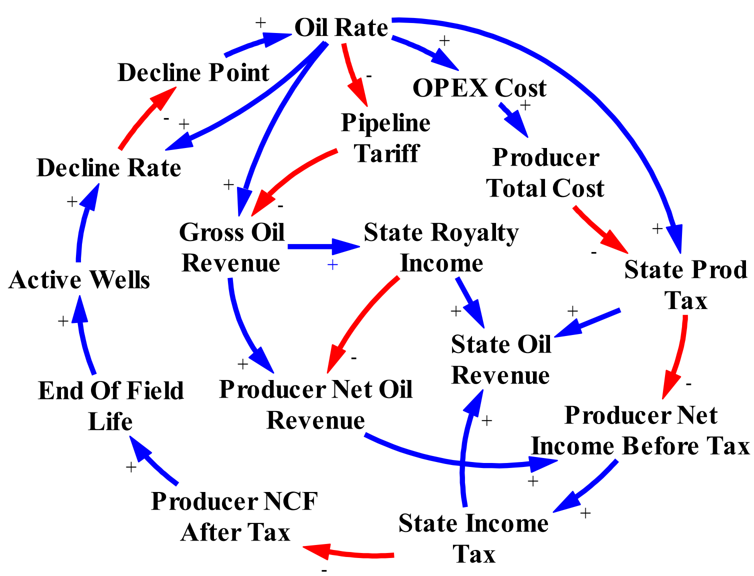

Figure 1 - Model Causal Loop Diagram

The main results from this model are the Producer Net Cash Flow (NCF) After Tax and the State Oil Revenue. The State only receives revenue as long as the Producer has a positive cash flow.

The SD model diagram is shown on Figure 2. Oil production is calculated assuming an exponential decline based on a maximum field production rate and a target field production rate that can be smaller than the maximum if economically justified. The maximum field production rate is also a function of the number of wells drilled. We have assumed that an "optimal" development plan has been determined by the Producer to maximize net present value profit assuming a future oil price. We also assume that there are no limitations due to available pipeline capacity, drilling rigs available, capital available to invest, etc. The field development plan (optimal number of wells, field target production rate) is included in the model as a correlation based on the maximum well oil rate and initial oil reserves values.

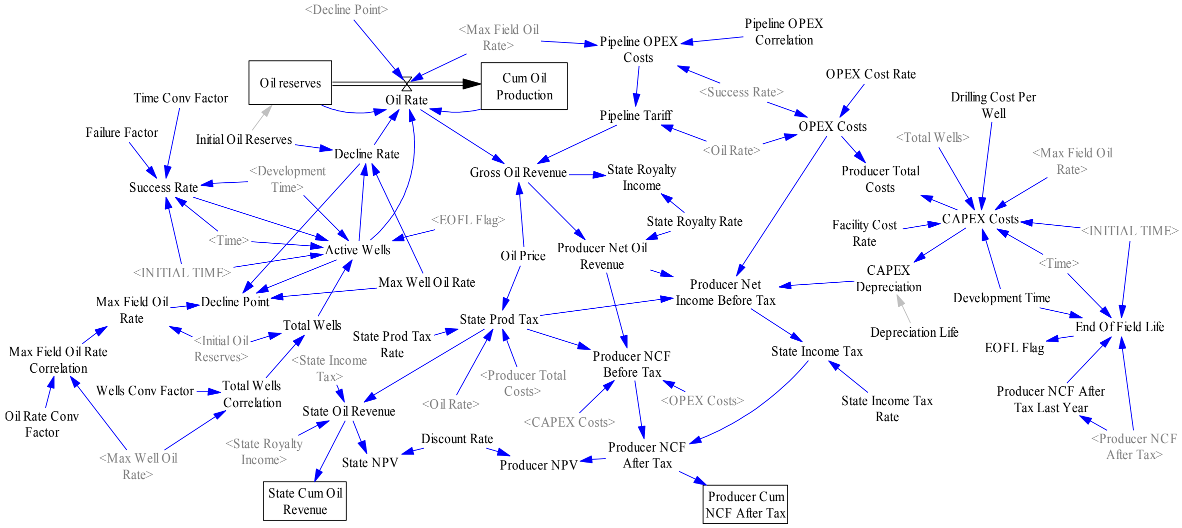

Figure 2 – System Dynamics Model Schematic

Once the production profile is defined, the total field economics are calculated based on the costs of development, operations, transportation costs (Pipeline Tariff) paid to a pipeline, and taxes and royalties paid to the State. Our simplified model assumed a typical North American economic environment. Of particular interest for our current analysis is the production tax, or State Prod Tax, which is a function of the oil production rate, the production tax rate (State Prod Tax Rate), oil price and Producer costs.

Optional input data can account for infrastructure aging by gradually reducing the producing wells with time as well as increasing the operating costs for the field and pipeline. This assumes that the equipment will fail with increasing frequency.

We have also included a simple dashboard that facilitates running the model. However, it is not needed for the testing described in this paper.

The economic performance of our State and Producer actors is tracked during each simulation run. As depicted in Figures 1 and 2, the Producer generates cash flow from the oil production. The State generates revenues from royalties, production taxes and income taxes.

Once the after tax cash flow for the Producer is negative, the field production stops and “end of field life” occurs.

Leakage Calculations

As a validity check on the model economics, we created a system “leakage” calculation, or financial material balance. This is shown on Figure 3. We compared the net model income (Divisible Income Sector) to the sum of net income for all actors (Divisible Income Agent). If the financial calculations are working correctly, these values should be the same and the leakage, or difference between them, should be effectively zero.

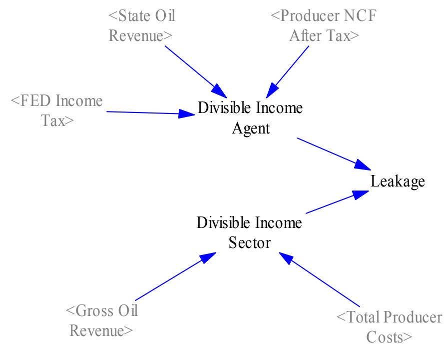

Figure 3 – System Leakage

Parameter Sensitivity Analysis

Before using the model to explore energy policies, we needed to identify the key parameters that affected behavior. We defined "drivers" as those variables that strongly affect the outcome, but are not controlled by the user, because these values are uncertain and may be unknowable. We defined "levers" as those variables that strongly affect behavior, but are controlled by the user.

To identify the main drivers and levers that affect our models performance, we used a very simple single parameter sensitivity analysis technique. We identified the potential range of values for each input parameter. This information was then used to run sensitivity cases where each parameter was varied individually. This was simple to implement for our model, but a more rigorous technique such as those described recently in the SD literature[6] is probably better to identify key parameters.

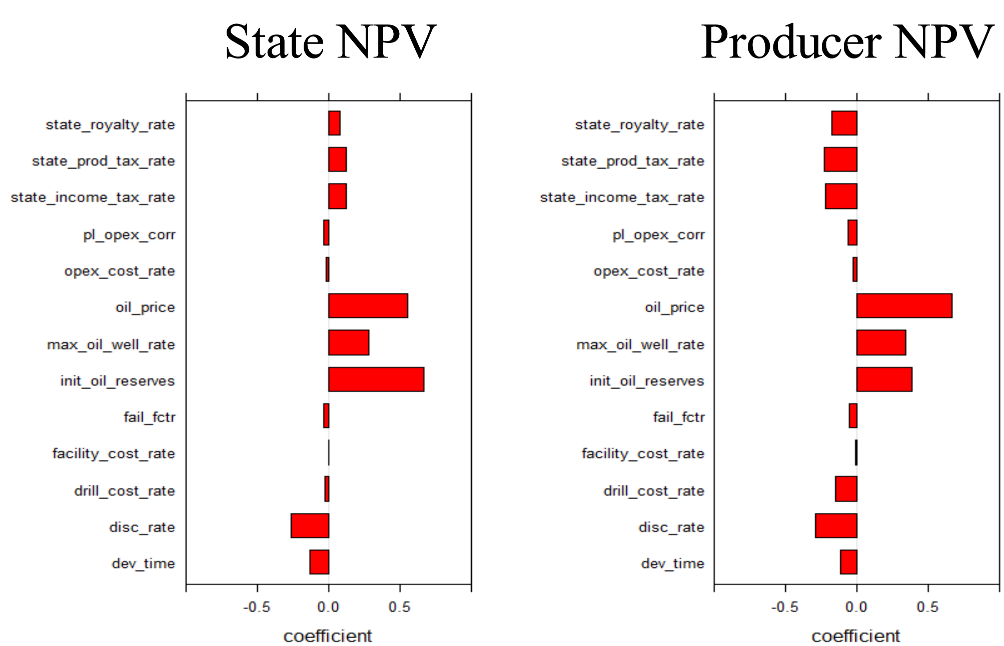

Figure 4 - State NPV and Producer NPV Sensitivity Analysis

The left panel in Figure 4 shows the results from the parameter sensitivity analysis based on impacts to the State net present value profit (NPV). The longer bars indicate more important input parameters. Positive values suggest that the parameter and State NPV are positively correlated. Negative values suggest a negative correlation.

As expected, the three State revenue sources (royalty and tax rates) are the primary levers for State NPV. The size of the initial oil reserves and oil price are the most important drivers for State NPV. Based on our assumptions, we eliminated the Initial Oil Reserves from our analysis because we have assumed that it was known. For this policy analysis exercise, we also assumed that the State Royalty Rate and Income Tax Rate were fixed and, instead, focused solely on the State Prod Tax Rate as our only energy policy lever.

Therefore, from the State's point-of-view, oil policy will be influenced by the production tax rate "lever" and the primary uncertainty in the future will be the oil price "driver".

The right panel in Figure 4 shows the parameter sensitivity analysis from the standpoint of the Producer, based on what impacts Producer NPV. As expected, the Initial Oil Reserves and Oil Price dominate the model results. Therefore, we assumed that the Oil Price was a good choice for driving model futures.

Regret Analysis

Regret analysis is useful for finding strategies that minimize the impact of the "worst-case" scenario. To our knowledge, this technique has not been used in energy policy analysis in the past.

As described before, our simple model consists of one primary lever (State Prod Tax Rate) and one primary driver (Oil Price). The unknown futures are characterized only by different oil prices. A more realistic world would have the future driven by many unexpected, unforeseen events that have significant impacts. To simplify even further, each future in our current example is defined by a constant oil price of different values ranging from 50 to 200 dollars per barrel. A more realistic case might include variations in the oil price with time or as a reaction to world events. For example, oil price could increase dramatically if demand rapidly and consistently exceeded supply. Alternatively, oil price could fall and stay depressed if breakthroughs in alternative energy or a replacement for oil as a raw material made it imperative to reduce prices to compete in the market place.

Can we generate a realistic policy from this analysis? Obviously, our model only shows a highly simplified range of futures. We have focused almost exclusively on how regret analysis might provide insights into system behavior, not on actual results. We were interested in model trends and ignored any complications that might arise if other parameters were included to define futures.

Except in very limited, highly idealistic cases, policy analysis should evaluate the impacts on both existing and future energy production. Our model clearly does not do this yet. Our plan is to include future fields in a later version. One major problem for current energy policy in North America is how to make energy more abundant without just cutting taxes on the Producer. Reducing taxes will obviously provide more profits for oil companies, but they argue that they need this increased profit to justify investments in exploration and development – especially in extreme environments like the Arctic.

However, there is no guarantee that these profits will be used in this way. Are there better strategies that could be developed using regret analysis and system dynamics models?

Based on the assumptions made in our simple model and described in this paper, we ran a series of sensitivity runs in which we varied the Oil Price and State Prod Tax Rate over very wide ranges.

The output from the SD model was post-processed using the R statistical software to determine the maximum State NPV and Producer NPV achieved for each future (i.e., oil price). We then applied the following formula to determine the regret for each oil price future (f) and tax rate scenario (s):

Model Regret(s,f) = Maximum Model NPV(f) – Model NPV(s,f)

From these results, we were able to create a simple policy map.

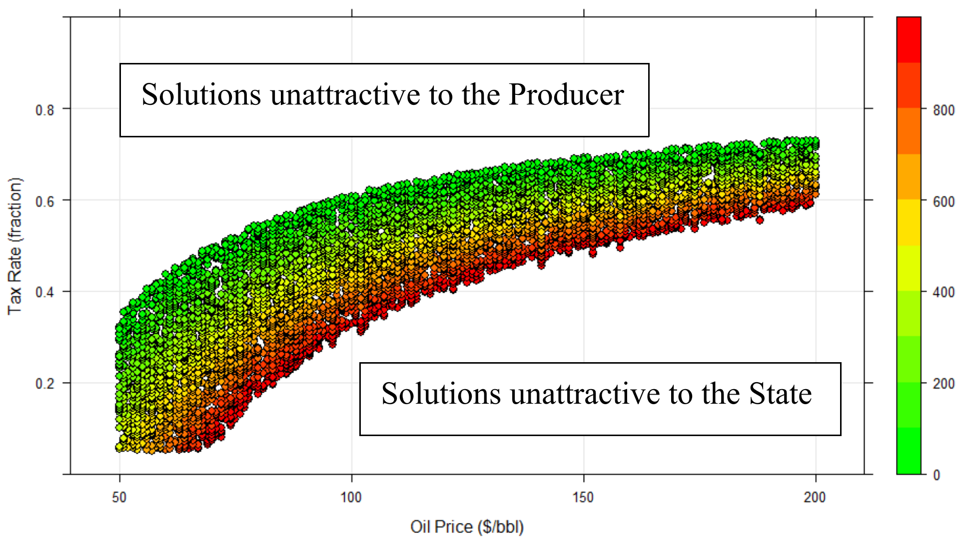

Figure 5 - State Policy Map

Figure 5 shows the regret analysis from the State's point-of-view. Circles plotted reflect the different scenarios run in our system dynamics model with unique State Prod Tax Rates and future Oil Prices.

Using an arbitrary color scale to highlight the regret values, the green portions of the map show the best solutions (minimum regret) for the State. The yellow and red portions show poorer solutions (higher regret). The color scale in Figure 5 extends to a maximum of 1000 mm$ regret. There were other model solutions above and below the results shown that were not plotted. Solutions above those plotted represented scenarios in which the Producer NPV was negative. Solutions below those plotted represented scenarios in which State regret was higher than 1000 mm$.

The general shape of the green and yellow bands suggests that a more robust and adaptable oil policy might include an adjustment in the State Prod Tax Rate to account for changing Oil Price. In this example, there is strong evidence suggesting that the tax rate should decrease as Oil Price decreases and should increase as Oil Price increases.

We would urge caution in reaching that conclusion without looking at the situation from the Producer point-of-view.

The Producer policy map, shown on Figure 6 below, uses the same color scale for regret as described for Figure 5 above. This shows that the best strategy (minimum regret) for the Producer would be to reduce the State Prod Tax Rate as much as possible. As described for the State policy map, increasing taxes beyond a certain point in any future scenario results in the energy development becoming uneconomic so no energy production occurs.

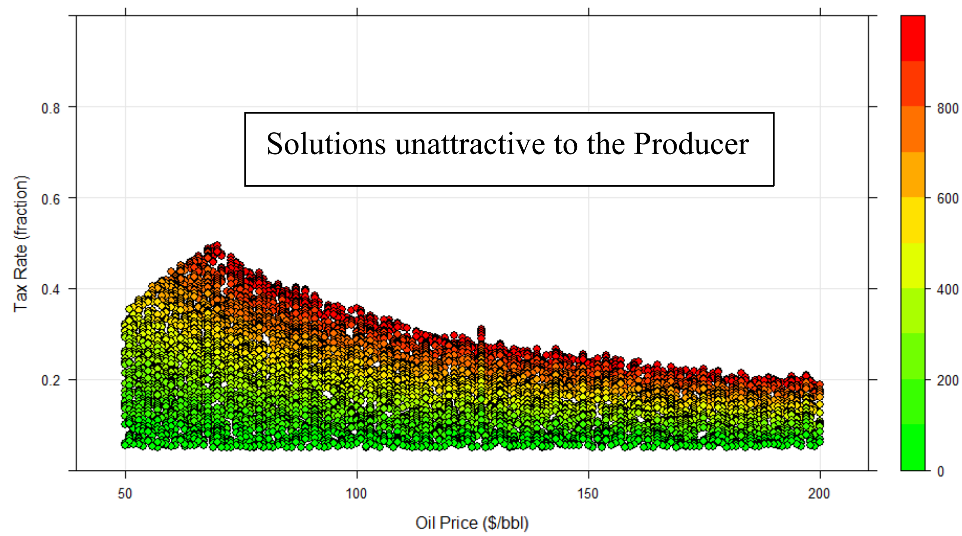

Figure 6 - Producer Policy Map

In our hypothetical model, the State depends entirely on this one field and one Producer, so reducing the taxes can invite disaster for the State. If we compare the "green zones" in Figures 5 and 6, it becomes clear that the State and Producer might reach agreement on the tax rate at low oil prices (both need low tax rates to maintain revenues), but it becomes much more difficult at higher prices. This indicates a potential conflict where a compromise may be difficult to reach. More work is needed to find suitable compromise solutions,

In a more realistic scenario, the State could also have the problem of trying to make additional development attractive to the Producer. This might lead to reduced taxes and even incentives to explore and develop new energy resources.

The Producer will always insist that lower costs are needed because he bears the risk that no commercially viable energy resources will be found. Regardless of reduced fees, the Producer can move his investments and attention to other States (i.e., worldwide opportunities), so the apparent risks to him are much smaller. It is also possible to argue that the State shares the risk that there will be no commercial resource discovered and might diversify its revenue base by investing in alternative sources of energy and revenues if possible. Perhaps a State-Producer partnership might resolve this potential conflict to the benefit of all parties. This will be investigated further in future research.

Economic Yardsticks

Our analysis is based on the idea that NPV is a realistic yardstick for measuring the relative worth of an energy policy. As stated earlier, both the State and Producer can and often have internally conflicting interests that can make it important to consider longer-term issues. While NPV is widely used to aid near-term decision-making, it may not be the correct tool (or only tool) to use for longer-term policy decisions because it effectively discounts the future.

Conclusions

Our simple model shows that an energy policy should be robust and flexible to account for an uncertain and unknowable future. Traditional forecasting techniques can fail in light of deep uncertainties. Regret analysis gives a clearer picture of the risks involved, likely conflicts and possible solutions. Better economic yardsticks are needed to assess the real pros and cons of longer-term energy policies. More sophisticated techniques will be required to identify sound policies when there are numerous drivers and levers in the system.

Future Work

This work will be expanded to include more realistic scenarios. For example, pipeline and well failure surprises could be included. Multiple fields (developed, undeveloped and undiscovered) could be used to investigate the drivers and levers surrounding policies that encourage exploration and development of new resources. Multi-parameter analysis techniques (e.g., PRIM[1] analysis) will be investigated for these more complicated scenarios.

References

1. Friedman, J. and Fisher, N., "Bump Hunting in High-Dimensional Data", Statistics and Computing, Vol. 9, No. 2, 1999.
2. Bankes, S. C., "Exploratory Modeling for Policy Analysis", Operations Research, Vol. 41, No. 3, 1993.
3. Lempert, R. J., Groves, D. G., Popper, S. W., and Bankes, S. C., "A General Analytic Method for Generating Robust Strategies and Narrative Scenarios", Management Science, Vol. 52, No. 4, April 2006.
4. Lempert, R. J., Popper, S. W., and Bankes, S. C., "Shaping the next one hundred years: New methods for quantitative, longer-term policy analysis", RAND MR-1626-RPC, 2003.
5. Lempert, R. J., Popper, S. W., and Bankes, S. C., "Confronting Surprise", Social Science Computing Review, Vol. 20, No. 4, Winter 2002.
6. Hadjis, A., "Bringing economy and robustness in parameter testing: a Taguchi methods-based approach to model validation", System Dynamics Review, Vol. 27, No. 4, October-December 2011.