Alternative Modeling Approaches:

A Case Study in the Oil & Gas Industry

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Abstract

Simulation modeling is one technique that BP relies on to improve the quality of capital investment decisions. To date these simulations have been highly detailed discrete event simulations with the financial computations run in parallel using spreadsheets. In an ongoing project, some of the tools and thinking of system dynamics are being introduced. The goal is to understand how they can complement or substitute the existing tools and analysis techniques and to gauge the reaction of people relative to the existing approach.

For analytic work in support of capital investment decisions the ultimate measure of success is not always clear. Plants and distribution systems that perform as expected in terms of throughput and uptime do validate the results of technical components of the simulation. Making such comparisons in detail is, however, costly and time consuming. In addition, changes in market and business conditions tend to have a very large impact on the economic value of infrastructure and the uncertainty around those is extremely high.

In this study, we will discuss a project in which we introduced a continuously formulated model as a supplement to the discrete event model. For this case we found that the continuously formulated model could be used to address the same issues as the discrete model and could do so efficiently. We also found that the discussion generated by this alternative formulation was more productive and tended to lead the project team in a more interesting direction. While all of these results are tentative, we do believe this is a worthwhile approach to developing models in support of investment decisions.

Overview of Paper

In this paper we will first give background on BP's investment activity and the manner in which models are used to help guide that. We will touch on the component models, project organization, and workflow typically used to attack the problem and then outline the reasons we thought system dynamics might help. Following this we will discuss the traditional solution and then what we did to approach the problem in parallel. We will then compare the reactions of the project teams to the two approaches and draw some conclusions. The actual models used for the project and their results are proprietary. We have, however, included a version of the continuous model that has been modified to contain no proprietary data in the program CD.

Background

BP is a vertically integrated oil and gas company with operations spanning the globe. Its business is organized into upstream, downstream, and chemicals sectors. The upstream sector is responsible for exploration, development, and production of raw oil & gas products. The downstream sector refines the raw upstream products into petroleum products such as gasoline and lubricants and sells them to the public. The chemicals sector is engaged in the production of feedstock for a variety of industrial manufacturing processes.

In order to accomplish these activities, each sector routinely invests in the design and construction of new production facilities. Due to the commodity nature of oil & gas, there is intense competition among industry participants to efficiently build technologically advanced, safe facilities while balancing capital investment, operating costs, and availability. As stated in the annual report, during 2001 BP invested a total of $13 billion in new facilities, 70% of which was spent in the upstream sector. The magnitude of these upstream capital investments demands that appropriate tools and techniques be used to continuously improve the quality of decisions and resulting shareholder value.

BPs current approach to improving the quality of facility capital investment decisions involves the preparation of one or more discrete event models to evaluate availability and size facilities along with spreadsheet models to evaluate the economic consequences. These models are normally built during the early phases of a project, well before construction begins, to finalize the facility design. The WITNESS discrete-event simulation environment and Excel spreadsheet software are used to construct these models. The WITNESS models are built to calculate facility availability based on a variety of equipment assumptions such as Mean Time Between Failure (MTBF), Mean Time To Repair (MTTR), availability of spare equipment, frequency and duration of scheduled maintenance and resource availability. Custom input and output Excel spreadsheets insulate the user from the underlying complexity of the WITNESS model and automate many analysis tasks. The separate economic model is typically created using Excel spreadsheets and uses as inputs the results of the availability modeling activity.

The completion of these models requires a multidisciplinary team with skills in engineering, commercial analysis and technical modeling support. Most modeling team members come from the business unit recommending the investment, which will also operate the resulting facilities and be held accountable for the operational and financial performance of the facilities. BP also has a group that supports modeling across business units called the Upstream Technology Group, Integrated Business Modeling Team (UTG – IBM) of which one of the authors is a member. The team members work together, often with contract consulting support, to develop the models to support the investment analysis. For the technical models flexibility and model processing time are two very important characteristics since the process of selecting the final design is highly iterative, involving the identification and evaluation of multiple cases.

A typical development effort starts with a discussion between an engineer and an internal modeling support person. After a review of past projects, a starting template is found that most closely matches the current project. A process flow diagram and reliability block diagram are then developed and used as input for the discrete event simulation model. The development of the discrete event simulation model is typically done by a contractor with the results and assumptions refined based on discussions with the BP personnel. Once the engineers are comfortable with the model results the commercial analysts use them as a basis for developing cost models. The technical models give an indication of expected throughput and operating expense which, combined with investment costs and assumptions on market conditions, allow the construction of a financial model. There is then some iteration with the financial and technical models making changes and rerunning them both for the purposes of plant design and understanding uncertainty. This iterative process can span multiple days and involve several meetings between stakeholders to complete.

Problem Statement

Given this background, we wanted to introduce elements of the system dynamics method and also make use of the Vensim® software to see what kind of difference this would make. This was done in the context of real projects which are still ongoing as of the writing of this paper. The approach we used was not to replace the methods and models in use, but to build additional model in parallel with the standard development stream and present these to the project teams. We were looking for answers to, or at least insights into, the questions:

1. What is the best way to use system dynamics methods to improve the quality of capital investment decisions?
2. What are the benefits associated with a causal view?
3. What are the advantages of having a single model that integrates both facility availability and economic consequences?
4. Does an integrated model approach allow for faster turnaround in terms of simulation speeds and understanding of results?
5. Can the alternative models replicate the results produced by the discrete event WITNESS models?

6. What do the project members like and dislike about the alternative models relative to the standard models?
7. How do the alternative models differ from a more standard system dynamics model?
8. How do the alternative models differ from the WITNESS discrete event models?
9. How can the alternative models position the project team to investigate different problems that they could not address using the WITNESS models and spreadsheets?

To address these questions we are using this parallel development approach on two projects. The first project is a plant to produce Liquefied Natural Gas (LNG), and the second is a transportation system (storage tanks, boats, and docks) to move LNG from a plant to the destination distribution facilities. In this paper we will focus on the first of these as that is the one for which we were able to do a substantial amount of work and interact thoroughly with the project team. Longer term, we hope to link the models from the two projects into a single model to understand the value of bringing these projects together.

LNG Production Problem

BP is continually researching the development of new LNG plants to service markets around the globe. The major questions that need to be answered are: how big to make the plant, what should be the balance between plant equipment reliability, redundancy and capital cost and what are the bottom line implications?

In order to address these questions a project team was formed following the process described under Background. The project began without any emphasis on the alternative modeling approach. During the development of the discrete event model the authors developed the alternative model behind the scenes. There was no attempt to engage participants in the system dynamics process or change the early problem clarification process. The value of such early intervention is not being investigated here, though it is certainly an interesting research problem.

The WITNESS Discrete Event Model

The WITNESS model uses an excel interface to both enter inputs and display results. A portion of the model itself is shown in Figure 1. It is a very detail oriented model that includes each major piece of equipment. For each piece of equipment there are from one to three failure modes and each of these has an associated mean time to failure, mean time to repair, and effect of plant throughput. The failure times are assumed to have a negative exponential distribution, the repair times a log normal distribution, and the effect on plant throughput a constant.

The WITNESS model is run with for 20 years with 100 replications. This is done to get average values for throughput and repair activity and is a standard thing to do with models having a great deal of randomness. Although the 20 years is a reasonable time to think of a plant running without a major refit, there is no attempt to capture the lifecycle of the plant or startup and learning effects. The statistics that come out of the simulation are steady state statistics.

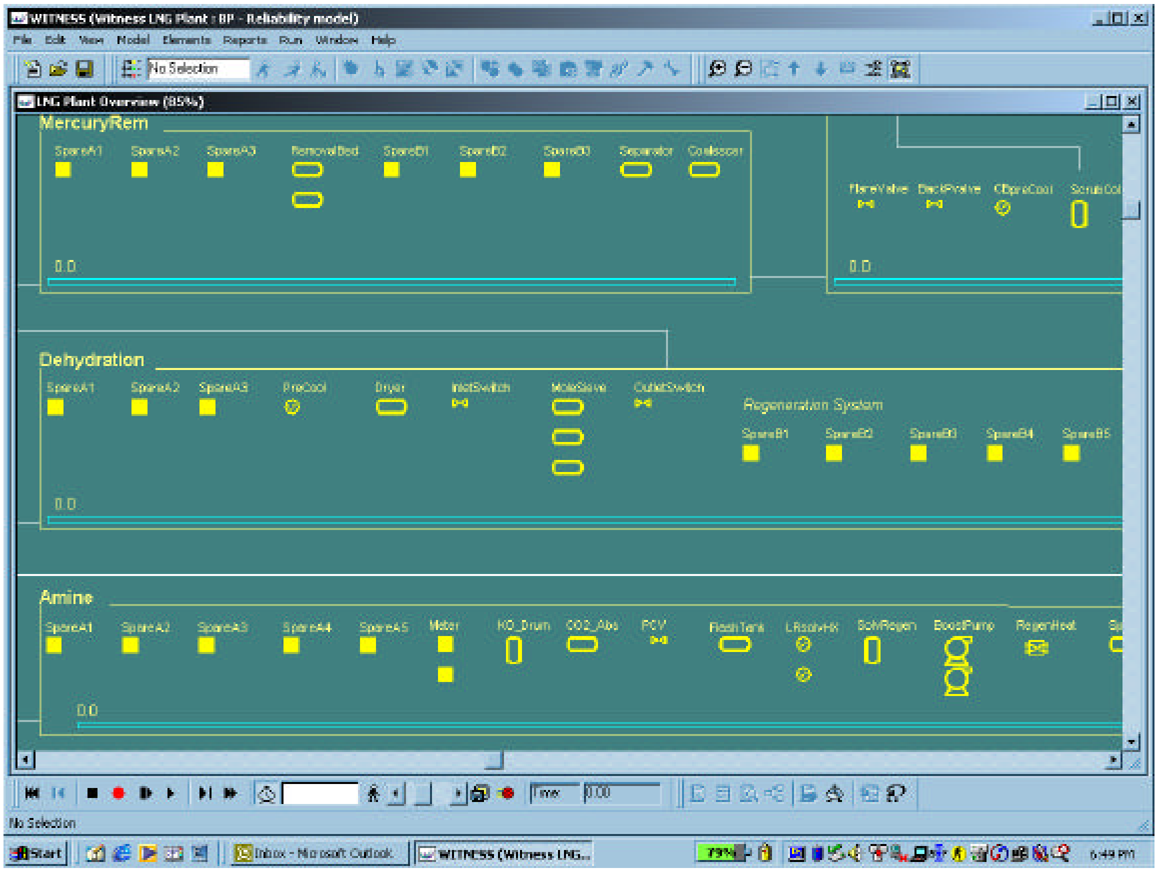

Figure 1. A partial view of the WITNESS discrete event model.

The Vensim Discrete Event Model

We built a Vensim model that used the same conceptual modeling framework as the WITNESS model. An overview of that model is shown in Figure 2 (the model itself is available on the proceedings CD[1]). This model is also highly detailed, but the detail is relegated to the model subscripts rather than the diagram. For example, the variable `Equipment is Functional` represents 263 different equipment/failure mode combinations.

At first glance, this looks like a fairly typical causal loop diagram. However, on closer inspection it is clear that many of the variables such as `Equipment is Functional` can only take on two values. Although there is feedback in this model, there is not any structure that can generate surprising dynamics.

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[1] Please note that we had to make some adjustments to the Vensim model to be included with the paper. Most importantly, the different failure and repair times have been changed because this information is considered proprietary.

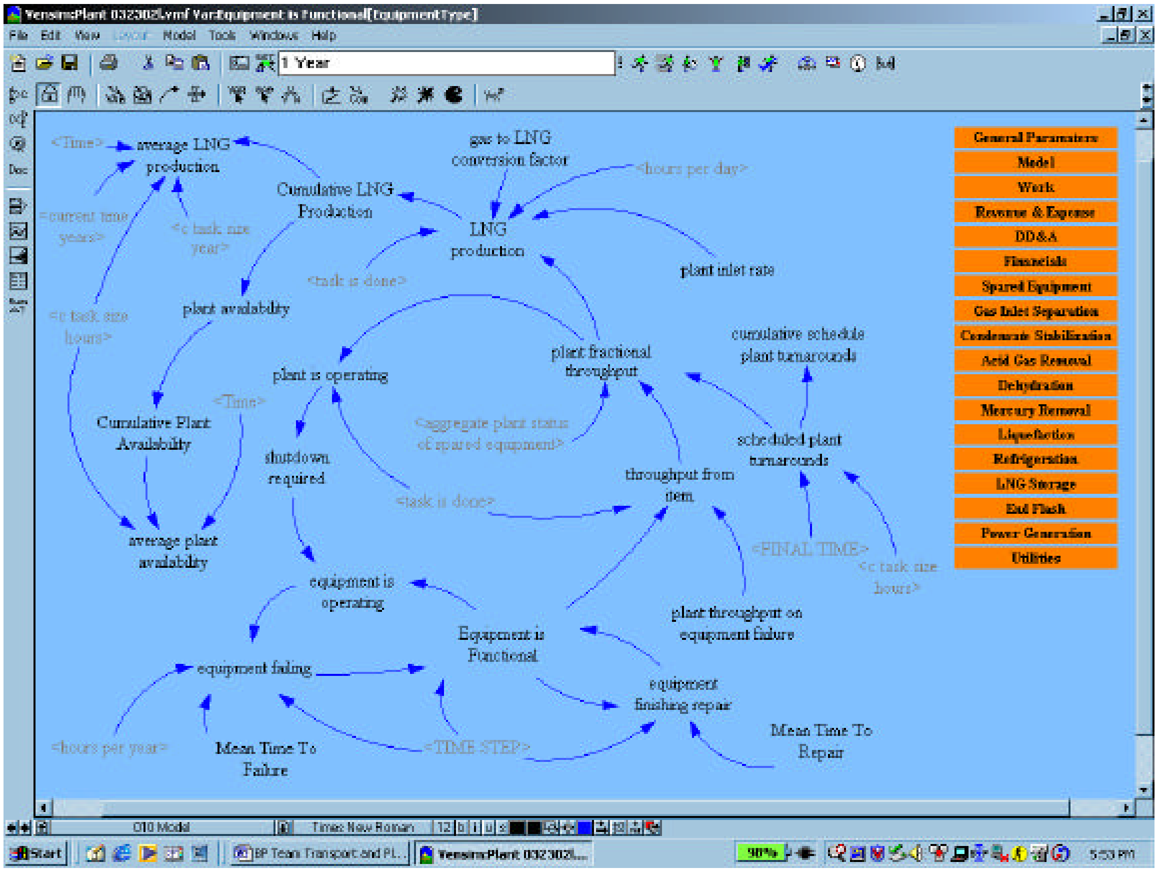

Figure 2. A overview of the Vensim model.

The Vensim model is different from the WITNESS model in that we use a constant Time Step of 1 hour, rather than stepping through time to the next event. We also use a random realization of failures with a Poisson distribution, instead of distributing the failure times with a negative exponential distribution. These two representations can be shown to be the equivalent, though our use of the Poisson distribution on repair completions is different from the log normal distribution on repair times in the WITNESS model. There is also one element of the WITNESS model (the Plant cold box) that uses a custom distribution that was not implemented in the Vensim model.

Nonetheless the two models give results within 2% and respond in the same way to changes in key assumptions on reliability.

The Vensim model also has built in some rudimentary financial and operational computations as shown in Figure 3. These are similar to those used in the financial models done in Excel, though they are not yet complete. This makes the financial results available alongside the technical results without having to run things through another model. Because the current model has incomplete financial modeling we have not presented this to the project team as yet.

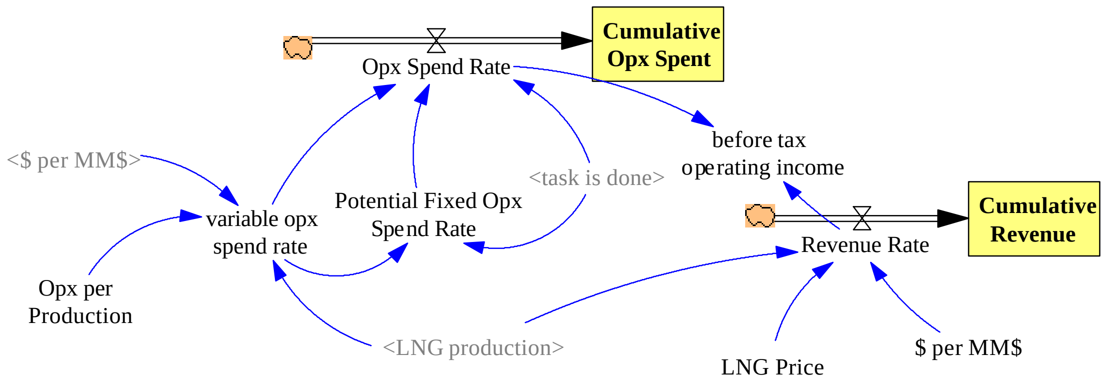

Figure 3. Example financial computations.

Model Comparison

As we have noted, the two models produce substantially the same results. It is interesting, as well as delightful from our perspective, that while the WITNESS model takes about 20 hours to complete 100 simulations of 20 years each the Vensim model can do the same thing in about 1 hour. This result is important because it does have implications on how the model can be used to investigate problems.

In any situation where the project stakeholders are not directly involved in developing the model it is important that they have techniques for building confidence in its correctness. With the WITNESS model the intended mechanism for doing this was to recreate and animate the Reliability Block Diagram used as a basis for developing the model. This diagram names the different pieces of equipment and the animation simply involves showing which piece of equipment is currently broken along with the current plant status. In practice, there were just too many elements in the model to be able to watch this, map to the plant life time scale and form any judgment about the correctness of the model. In the end the WITNESS model was treated as a black box with changes made to inputs checked against the resulting performance changes.

The Vensim model is presented in a different format. We did not reproduce the Reliability Block Diagram, though some of the project members though that we should. Confidence in the Vensim model was built based on our ability to explain the model logic and demonstrate how it was done, along with the fact that it did the same thing the WITNESS model did. Due to the very technical nature of this model it was not the case that the model could easily be made to tell a story. We had to rely on our ability to describe how things worked. When compared with the WITNESS model this was murky compared to muddy – an improvement but only modestly. It is possible that the incorporation of Reality Check® logic into the model could be used to improve confidence and this is something we are looking into.

While most of the confidence building through parameter changes was done using the WITNESS model, it is true that the faster simulation time for the Vensim model would have made this easier. Ironically, the experienced WITNESS modeler working on the project was concerned that the Vensim model was not giving correct results because it ran too fast. This concern faded after this individual reflected on some of the things that might be causing the WITNESS model to run slowly. It was, however, observed by several team members that individuals experienced with WITNESS models might be uncomfortable changing to a Vensim model. Nonetheless, additional research on using Vensim to address availability problems was recommended for selected projects.

Model Attractiveness

The ability to show causality and explain logic in the Vensim model, while modest for the availability computations, was outstanding for the financial computations. Not only were the relationships clearer than the spreadsheet cell references people were used to, the fact that they were directly tied back to the availability model was considered outstanding. The team quickly moved to the idea of integrating not only the economic models but also transport and other models. Because of this extensibility Vensim was perceived as an appropriate tool for exploring new areas.

The Vensim model was also perceived as a good tool for educating others about the impact of various plant equipment configurations and specific equipment selection. Ultimately this would lead to stakeholder buy-in and confidence in the plant design. The Vensim model would also be useful for helping operations and maintenance personnel learn the logic of the plant.

Conclusions and Extensions

While this is ongoing work and it seems likely that much of the learning remains ahead of us, there are some relatively solid conclusions based on what we have done so far.

First it is both possible and fruitful to develop models typically done as discrete event models using a continuous approach. Both approaches have the same theoretical foundation and both yield substantially the same results. While the continuous approach is not uniformly better than the discrete approach it does have some advantages. For this case, based on the implementations, speed was one advantage. More importantly, however, is the added ability to extend the model with more continuous additions.

Second, the continuous model seems to engage people in discussion in a direction that is more general. Rather than digging into details of failure modes and the implications of specific combinations of failures there was a tendency to move toward discussion of the business implications of different design decisions. The discussions were also more fully engaging for more team members.

It is, of course, important to do a good job on the availability and throughput modeling. Our original development in this area combined a flow oriented approach to plant operation with the failure mode modeling described in this paper. We did not pursue this because we felt it was important to develop a model that could replicate the WITNESS model results. Nonetheless, this combination of the stochastic failure modes with the deterministic process flows would yield an improved ability to experiment with plant design. This is something that can be most easily pursued in a continuous modeling environment.

Finally, a few closing comments on the relationship of the model developed to more traditional system dynamics models. The Vensim model might be best cartooned as a very simple, limited feedback, system dynamics model agglomerated onto a complex discrete event machine. It is a brute force marriage of two paradigms that actually works. Not that many system dynamics models are run hourly for 20 years, but they can be. While elegant ways to incorporate alternative modeling approaches into system dynamics models do seem desirable, there is a lot that can be done with the tools at hand.

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