International Journal of Business Analytics
Volume 9 • Issue 1

Applications of System Dynamics and Big Data to Oil and Gas Production Dynamics in the Permian Basin

James R. Burns, Texas Tech University, USA

Pinyarat Sirisomboonsuk, The University of Texas Permian Basin, USA*

https://orcid.org/0000-0002-5226-6877

ABSTRACT

In this paper, the authors create, justify, and document a system dynamics model of the oil and gas production within the Permian Basin of Texas. Then the researchers show how to fit the model to historical time series data (big data). The authors use the model to better understand the process structure, the production dynamics, and to explore the deleterious consequences of limited pipeline capacity in the Permian Basin. The model is also employed to better understand how to increase revenues derived from the basin. From this model, numerous suggestions are made as to how to improve the overall revenue and profitability coming from the Permian Basin. The model's ultimate purposes and its associated big data are to foster a basic appreciation of the causality inherent in the 'system' and how basic model parameters affect and influence measures of model performance.

KEYWORDS

Bottlenecks, Oil and Gas, Permian Basin, Pipelines, System Dynamics

INTRODUCTION

The Permian Basin of Texas is the largest petroleum-producing basin in the United States. As of September 2018, the Permian Basin has produced a cumulative 33 billion barrels of oil and 118 trillion cubic feet of gas (U.S. Energy Information Administration, 2018). For some days, over four million barrels of oil a day have been pumped from the basin and that makes it the largest producing oil field in the world (Caldwell, 2019), exceeding that of the Ghawar in Saudi Arabia. At least one analyst suggests that the region might be producing upwards to eight million barrels of oil a day in less than four years (Domm, 2019).

The Permian Basin has been a major hub of oil and gas production for the United States for nearly 100 years (Enverus, 2021). Robinson (1988) wrote extensively about the hydrocarbon plays in the Permian Basin more than thirty years ago. Its production of hydrocarbons helps fuel various industries

DOI: 10.4018/ijban.314223

*Corresponding Author

and provide key resources that aid in economic growth. The applications of oil production are not limited only to car, diesel, and plane fuel but also to other industries such as clothing, cosmetics, and plastic. Similarly, natural gas--a cheaper, cleaner hydrocarbon--is used for electricity generation, for space heating, water heating, cooking, lighting fixtures, and various other applications (Gaswirth et al., 2016). The supply and demand for oil and gas play a vital role in market fossil fuel energy prices and, hence, production. As market prices increase, the hydrocarbons' operators or producers will increase their production to maximize their profits (Alquist & Kilian, 2010). Dynamically, this increase in supply has a negative effect on market price. Likewise, when prices decline, producers in the Permian Basin will decrease their production. Again, this has a stabilizing effect on market price. The cyclic nature of the industry incentivizes the producers to exploit high prices as much as possible.

Over the year 2020, the spot-market price of oil has been very volatile, varying by as much as negative $36/barrel to as much as $63/barrel for West Texas Intermediate (Y-Charts, 2021). The highest volatility ever seen in the spot market price of West Texas Intermediate occurred in the first half of 2020 because of a decline in demand due to COVID-19 and a spike in supply due to OPEC and partnering countries not adhering to production cuts (Barnett & Barron, 2020). Indeed, a contributing factor to production levels is the overall global political and economic climate. Turbulence in the oil and gas producing states or regions could mean potential disruption in global supply, which in turn, will motivate American operators to increase their production to accommodate global demand (Mohaddes & Raissi, 2019).

With horizontal drilling, the Permian Basin is producing a lot of gas that it can't profitably sell. The horizontal drilling necessarily causes a lot of gas to be forthcoming out of the formation it is produced from (MacRitchie & Zobba, 2019). There appears to be no easy way to prevent this inadvertent production of gas from horizontal wells. When pipeline capacity is lacking, there is nothing that can be done profitably with the gas. The price to move gas to market is four to five times higher via rail or truck as compared to pipeline. A constant array of 750 tanker trucks loading and departing every two minutes, 24 hours a day, seven days a week is equivalent to the capacity of even a modest pipeline. The railroad equivalent of this single pipeline would be a train of 225 28,000 gallon tank railcars every day (Pipeline and Hazardous Materials Safety Administration, 2018). At today's spot market prices for gas, it is not economical to ship natural gas by rail or truck.

The major effect of such factors is that as production levels increase, the producing region must cope with an increasing flow of hydrocarbons. This not only adds strain on the current infrastructure system but also creates a bottleneck effect that limits and even prevents producers from getting their oil and gas to the refining facilities. This research will focus on the bottleneck effect pipelines have on production and their implications for oil and gas price differentials. It must be noted that gas must be transported to refining facilities to be purified of any impurities and to produce the end product that can fuel households and other industries. Failing to transport the gas to such facilities forces the operators to accept selling their gas at a price that is well below the market price. Others have simply resorted to flaring (burning) the gas, although there are limitations on the amount of gas that can be flared. Such contractors viewed their gas as essentially worth nothing and the best solution was to burn it off. This not only has a tremendous deleterious environmental impact but also an economic one as the operators and the American economy are not benefitting from the product. Consequently, this paper will use the various methods of System Dynamics and Business Dynamics (Forrester, 1961a; Sterman, 2000) to identify possible constraints and to explore possible future behaviors. Then, the paper explores various proposed solutions to evaluate how the constraints can be exploited. The paper develops possible solutions to this urgent and important problem of gas burn-off.

Relevant Factual Information

According to the Oilfield Knowledge Center at Baker Hughes (2021), the most updated rig count as of February 5, 2021 is 392 rigs active in the United States, down 398 rigs from the same date a year ago (Coogan, 2020). Roughly 130 are currently in the Permian portion of Texas and in the state of New Mexico. These 392 drilling rigs manage to drill roughly 560 wells on average per month. According to Patel and Geary (2020), the average rig can drill about 1.5 wells per month. An interesting aspect is that the rig count has been decreasing steadily for the past year or so. This decrease is not entirely affected by the fluctuating oil and gas prices. COVID-19 has taken its toll. And as technology has evolved and multi-well pad drilling (drilling several wellbores from the same pad) has become available, drilling rigs have become much more efficient and hence, operators do not require as many drilling rigs anymore.

Additionally, the logistics problems faced by many operators make it more challenging for them to transport their products to refineries. This has discouraged and significantly damaged many small operators that cannot afford the hefty costs of transportation by truck or rail. Industry trends currently show a steering away from natural gas production in the near future primarily due to the inability to profit from the produced natural gas. There is, in fact, a glut of natural gas world-wide so prices are depressed (Conklin, 2020).

Furthermore, the majority of the wells being drilled are horizontal and target oil-producing formations. It must be noted that, although horizontal wells may be more expensive to drill and complete, they still offer the most promising returns on the investment. The probability of actually getting a productive well, as opposed to a ‘dry hole,’ is much higher when using horizontal drilling technology. The issue with drilling horizontal oil wells is in the fact that such wells tend to produce considerable amounts of gas along with the oil, much more so than did the older vertical wells drilled decades ago. If the gas is not injected back into the well for productivity enhancement reasons or simply sent to the refinery, then it is usually flared and, it goes to waste. Depending on the well, gas injection may not be necessary or effective and is costly to implement (Johns & Dindoruk, 2013).

Despite the flaring and logistics constraints, gas is still being produced at a higher rate (around five thousand cubic feet/day month over month) and it is expected to go on an upward trend. This is greatly caused by the accompanying gas production from oil-phase horizontal wells. The effect of this trend is very significant on the gas price differentials. The increasing amount of gas production puts tremendous strain on the current midstream infrastructure.

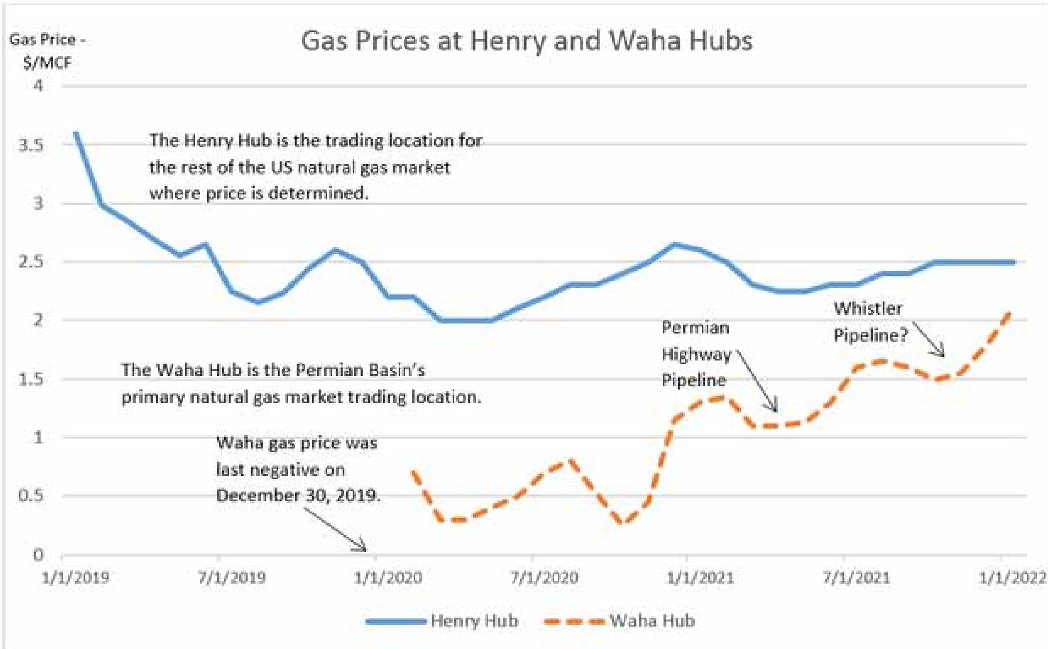
Moreover, pipelines are filling up at an unprecedented rate and, the current transportation methods involving rail and truck are no longer sufficient to get the gas to the refining facilities. This bottleneck effect has caused the price differential between the Waha and Henry hubs to be greater than the actual market value per Million Cubic Feet (MCF) during several months of 2019 and 2020. The Henry hub in Louisiana is where natural gas prices for the entire US are established; the Waha hub is where gas prices for gas coming from the Permian Basin are established. Hence, the operators resorted to flaring, an easier alternative that can have environmental concerns yet saves the gas producers the trouble of paying to get rid of their produced gas.

The natural gas price turned negative throughout several months of the fiscal year of 2019. Figure 1 delineates the effects of the logistics constraints on the Permian Basin’s Waha Hub (West Texas) in comparison to the Henry Hub (Louisiana) and provides a representation of the anticipated future performance of gas prices from January 2020 to January 2022. It is apparent that within the next two-to-five years, the price of gas at the Waha Hub will approximately equal the price of gas at the Henry Hub as more pipeline capacity comes online. Thus, the increased pipeline capacity carries with it two benefits—much lower transportation costs and higher gas prices. Clearly, this leads to profitability for refining and retailing of natural gas.

Pipelines as the Solution

By a factor of two-to-four, the most economically efficient means of transportation for the produced natural gas and oil is through pipelines. Thus, to solve this bottleneck effect, several new pipelines have been or are currently being built to accommodate the increase in production levels. The Gulf Coast Express, a pipeline built by Kinder Morgan and completed in 2019, transports two billion cubic feet per day, somewhat alleviating the transportation constraints in the Permian Basin (Kinder Morgan,

Figure 1. Natural Gas Prices at the Henry and Waha Hubs. (Data source from U.S. Energy Information Administration (2018) and DiSavino (2019))



2019). Although Kinder Morgan's project was very healthy to the natural gas market, the pipeline was quickly filled up. In fact, the Permian, on average, currently produces 18 Billion Cubic Feet/Day (BCFD) (U.S. Energy Information Administration, 2021). This number is expected to increase by at least 10 BCFD between 2020 and 2030. On the other hand, RBN Energy LLC argues that the Permian will witness an annual increase of 2 BCFD (Kopalek, 2019). Consequently, a new pipeline should be completed every year as pipelines have a typical capacity of 2 BCFD.

New pipelines are coming online every quarter for the Permian market including, the Permian Highway Pipeline and the Whistler Pipeline. Both of which should dramatically aid in the transportation of natural gas. Charif Souki, Chairman of U.S. LNG Company Tellurian Inc. stated, "We need at least four more pipes in addition to the three that are already going forward to meet growing output in the Permian and help reduce flaring" (DiSavino, 2019). It is also worth mentioning that as newer methods of transportation become available, the gas price differentials will be expected to decrease proportionally. This would discourage the operators from flaring unwanted gas and will offer them new means to generate additional revenue. The anticipated pipelines (intended primarily for movement of natural gas) that are recently available or are expected to go online in the near future include:

- The Permian Highway Pipeline (2.1 BCFD, completed December 2020)
- The Whistler Pipeline (2.0 BCFD, scheduled to operate in the second half of 2021)
- The Permian 2 Katy Pipeline (1.7 BCFD to 2.3 BCF D, not yet operational)
- The Pecos Trail Pipeline (1.9 BCFD, operational in 2019))
- The Permian Global Access Pipeline (2.0 BCFD, withdrawn, to start in 2023)
- The Bluebonnet Market Express Pipeline (2.0 BCFD, shelved)
- The Permian Pass Pipeline (2.0 BCFD, on hold)

By the end of 2020, there was enough pipeline capacity to accommodate all of the 16-20 BCFD of natural gas that the Permian Basin was capable of producing at that time (Tobben, 2020; Passwaters, 2021). This additional pipeline capacity is needed to slow the flaring of gas and to get these hydrocarbons to market where they can be sold for a profit. In that sense, the Permian Basin production bottleneck has been pipeline capacity and the lack thereof to move all of the produced oil and gas to the points where it can be refined and used. However, such appears not to be the case, currently. What is being observed is cyclicality—at times the pipeline capacity is insufficient; at other times there is overcapacity.

With regard to oil, the authors are interested in understanding another similar problem that the Permian Basin is facing in that more oil is being produced, and operators are having logistics capacity problems moving this oil to market so they can produce more (Enverus, 2021; U.S. Energy Information Administration, 2018). Again, the bottleneck has been the transportation infrastructure. With the completion of the Wink-to-Webster oil pipeline, the total oil pipeline capacity will increase to approximately 7.8 million b/d (barrels/day) by mid 2022 (Passwaters, 2021). By far the least expensive and safest way to transport oil and gas domestically is by pipeline (Green & Jackson, 2014). Internationally, the cheapest and safest way to transport oil and gas is by pipeline when there is one; otherwise, by tanker. Occasionally, it happens that new discoveries of oil or gas do not have easy access to pipelines. During such occasions, rail and truck demand will grow but then decline as the infrastructure pipeline capacity catches up. Suffice it to say that rail and especially truck methods of transportation are significantly more expensive (two to four times more expensive) and slower methods of transport as compared to the pipeline. Finally, the researchers are interested in the volume of escaping methane gas from dormant gas wells.

RESEARCH QUESTIONS

In this research, our interests were driven by the following pervasive questions. First, what are the causal (structural) and behavioral fundamentals in the Permian Basin oil and gas industry, particularly as they relate to pipelines? Second, what are the structural (causal) considerations impacting the installation of more pipelines? Third, what are the revenue consequences of a lack of sufficient pipeline capacity? Fourth, what are the implications for new well completions? Must operators find a way to stop producing the gas even though it necessarily comes forth with the oil when drilling horizontal wells? Fifth, besides adding pipeline capacity, what are some other strategies for making the Permian Basin oil and gas industry more profitable and more environmentally accommodative that are evident from the model structure? Finally, from a practical, pragmatic perspective we want to assess the suitability of system dynamics and the Vensim tool in particular as a business analytics tool.

From a superficial holistic view of the Permian Basin, it appears that the desired pipeline capacity is oscillating—going from too little capacity to too much capacity. This analysis endeavors to look under the surface to understand what the structural and dynamical issues and consequences are concerning oscillating pipeline capacity when supply and demand are growing. The system dynamics model to be discussed next and the use of business analytics are the tools of discovery.

In what follows, we review the extant literature on the subject, we describe the methodologies and models we used in this research, and we characterize the results. Then we perform analyses and provide further discussion of the results, including answers to each research question. Finally, we end the paper with conclusions and implications.

LITERATURE REVIEW

The use of various simulation and optimization models in the energy industry is wide-spread. For example, optimization models have been used in the transportation sector to find minimum cost/time/pollution routes for delivery and pickup trucks (Dutta et al., 2019; Munsamy et al., 2020).

Daneshzand et al. (2018) developed a system dynamics model of natural gas supply and demand for Iran in which they explored various pricing strategies and their effects on the supply of natural gas. Their research did not consider the close connection between oil and gas coming from horizontal wells. Moroney and Berg (1999) demonstrated that models that combine the physical reserves of oil with certain economic and regulatory variables provide better forecasts of future production than models based on either reserves or economic variables alone. Sun and Wang (2018) proposed an energy consumption structure measurement model that uses a fixed-sum input method subject to an energy shortage constraint. Empirical results show that energy configuration of China's provinces is inefficient.

Van Doren et al. (2011) found that models used for model-based (long-term) operations such as monitoring, control and optimization of oil and gas reservoirs are often first principles models. They are the result of partial differential equations being discretized, leading to nonlinear models that are large-scale in terms of number of states and parameters. Estimating a large number of parameters from measurement data leads to problems of identifiability and consequently to inaccurate identification results. Many similar models like this are prevalent in the oil and gas industry. However, our interest is not in reservoir dynamics. We understand the issues involved with fitting distributed parameter models to data. However, our interest is understanding the dynamics of behavior and structure of the Permian Basin oil and gas industry. So papers like the one by Van Doren et al. (2011) are irrelevant to the objective of our research.

Holdaway (2014) has written a book on how to harness oil/gas big data with analytics and optimize exploration and production with data-driven models. The material in this present paper demonstrates yet another method for business analytics, one involving big data and system dynamics models. System Dynamics (Sterman, 2000; Forrester, 1961a, 1961b, 1971) is the methodology of choice when it comes to understanding the interconnections between behavior and structure of any system.

In testimony before the Texas House of Representatives Transportation Committee, Collins (2018) showed that drilling and developing oil/gas wells is a very material intensive operation. A single well involves 500 tons of steel pipe, a string of sand-carrying railcars 14 football fields long (365 truckloads), and enough water to fill more than 35 Olympic-size swimming pools. That same well produces 500,000 barrels of crude over its lifetime generating the need for 2,700 truck trips just to move the oil. All of this wears out roads and makes them dangerous. Oil and gas-producing counties are often undercompensated for damage to roads. Greater use of pipelines for moving water, gathering crude/gas and delivering it to trunk pipeline injection points is a welcome development. Collins (2018) suggested a number of options to encourage the transportation of liquids and gases from the wellhead to the trunk pipeline.

Kim (2019) proposed considering all components in the supply chain leading from the Permian Basin wellhead to the ultimate customer in terms of possible bottlenecks. He suggested a number of bottleneck possibilities, not just the trunk pipelines themselves, but the pipeline infrastructure leading from the wellheads to the trunk pipelines, the refining capacity, and distribution infrastructure leading from the refiners to the retailers.

Peach and Starbuck (2011) examined the relationship between energy production and economic growth in New Mexico using cross section data for the state's 33 counties in Census years 1960, 1970, 1980, 1990 and 2000. The ultimate issue was whether New Mexico's counties are subject to the resource curse, a phenomenon discussed and documented in the literature. Most empirical studies of the resource curse hypothesis used state or national level data. In contrast, this analysis used county level data with a focus on oil and gas extraction only. Their (Peach and Starbuck, 2011) models suggested that oil and gas extraction in New Mexico counties has had a small but positive effect on income, employment and population. Similar results were obtained when the model was applied to 925 counties in 13 energy producing states for the year 2000.

Wang (2020) presented the first basin-wide study that examines both the employment effect and the income effect of the Permian Basin development. Wang (2020) considered not only the local impact but also the spatial spillover effect and the industry-level spillover effect. To correct for the estimation bias due to the potential simultaneity between drilling decisions and economic activities, an instrumental variables (IV) regression model was employed. Wang (2020) found that both the employment effect and the income effect of shale development in the basin are highly significant. Wang (2020) also showed that there are significant spatial spillover effects and spillover effects onto the indirect industries.

Townsend-small and Hoschouer (2021) found that some wells in the Permian Basin are a major source of methane emissions and produced water. They investigated and measured 37 shut in wells and found 2/3 not to be a problem but the remaining seven wells product significant methane gas. Some shut-in wells could be a substantial source of CH_4 emissions if this category is not subject to leak detection and repair regulations. It was not apparent, from their perspective, whether diminished demand for gas would reduce the methane gas emissions. In fact, just the opposite would occur as diminished demand for gas would result in more abandoned and shut-in wells resulting in more dormant wells potentially producing methane gas inadvertently.

Additionally, methods/models for finding constraints/impediments (Dettmer, 1997; Goldratt, 1990a, 1990b; Goldratt & Cox, 1992; Goldratt & Fox, 1986; McMullen, 1998) are frequently applied to this type of problem when there is an obvious capacity bottleneck. Further, Klein and DeBruine (1995), Kendall (1998), and Scheinkopf (1999) all made important contributions using Goldratt's Theory of Constraints (1990b). Modi et al. (2019) utilized Goldratt's Theory of Constraints (TOC) to introduce revolutionary concepts into supply chain management. Al-Fasfus et al. (2020) continued to explore the effects of TOC implementations on company attitudes. However, because the intent of this paper is to understand and manage the behavioral (dynamical) consequences of the problem, these techniques are only briefly touched upon here. The techniques developed by Goldratt (1990a, 1990b) and fully explained by Dettmer (1997) are not concerned with behavioral dynamics and structure but rather with an understanding of what constraints/bottlenecks/impediments are and how these can be exploited and elevated.

Gaswirth et al. (2016), Roussey (2019), U.S. Energy Information Administration (2018) and many others continue to assess the total amount of reserves in the Permian Basin. At todays' rate of usage these reserves are thought to be sufficient to last at least another 50 years (Enverus, 2021).

Burns and Janamanchi (2006) utilized system dynamics and Vensim to study project and change management. They were able to improve upon conventional project dynamics models with significant additions to model robustness. Many other researchers, most notably Lee and Pena-Mora (2007), Love et al. (2002), Lyneis and Ford (2007), Rahmandad and Hu (2010), have used system dynamics to study the mechanics of various processes, projects and systems.

Bieker et al. (2007) provided a survey of key literature in the field of real-time production optimization of oil and gas production. They described the information flow used for optimization of the system. The elements in this description include data acquisition, data storage, processing facility model updating, well model updating, reservoir model updating, production planning, reservoir planning, and strategic planning. The Bieker et al. (2007) material is somewhat relevant to this research from the standpoint of being an optimization model of oil and gas production.

Searches performed in the scholarly literature revealed no system dynamics models of oil and gas fields like the Permian Basin. The authors conducted extensive searches and could not find a single system dynamics model of oil and gas well production in the Permian Basin. Naill (1992) published an article on a system dynamics model of national energy policy that was developed in the 1970s. One focus of this national energy policy model had to do with transitioning from wood to coal to dependence on oil and gas and finally to nuclear power as the primary source of energy for the US. That transition from oil and gas to nuclear power was believed to occur in the 1990s as most of the planet's usable oil and gas was thought to be consumed by the end of the 20^{th} century. (There is far more recoverable oil and gas on this planet than anyone thought possible during the 1970s.) But the Naill (1992) model and its conclusions are far-removed from the focus and interest of this research.

METHODOLOGY AND MODEL

In what follows, the authors choose to use the various methods of System Dynamics and Business Dynamics (Forrester, 1961a, 1961b, 1971; Sterman, 2000) as our research methodology to better understand the structure and behavior of pipeline capacity dynamics in the Permian. The researchers also explain how these models can be fitted to time-series data so as to improve the accuracy of the models, enabling them to make short-term forecasts. One purpose of this explanation is to demonstrate the excellent contribution that system dynamics models make to business analytics. For system dynamics models the independent variable is time. Based on the model structure, system dynamics models generate plots showing how major variables in the model behave and change over time. These models are themselves quite capable of generating big data time series. System Dynamics has been around for 60 years and was originally invented and created by Forrester (1961a).

Model Development

Basic model constructs are developed using the methodology described in *Business Dynamics-Systems Thinking and Modeling for a Complex World* by Sterman (2000). The System Dynamics Model is developed using Vensim Professional Software of Ventana Systems (2016). The objective is to understand the underlying dynamics so that managers can make considered decisions, fully aware of the likely impact these decisions will have on the behavior of the dynamic system. While the model was created to better understand pipeline capacity dynamics, it does so in the context of maximizing revenues and profits for the Permian Basin oil-and-gas industry.

Vensim was specifically designed to accommodate system dynamics simulation models. The time horizon is assumed to be 100 months—8.33 years. This model is not to be confused with the myriad of simulation software tools in the oil and gas industry that create 2D and 3D visualizations of seismic data and/or model reservoir dynamics. The model takes a holistic view of the oil and gas industry for the Permian Basin only, looking at the resulting behaviors over time. Vensim is particularly adept at taking an explicit model structure and translating that into an array of model behaviors as revealed in behavior-over-time charts.

Model Description

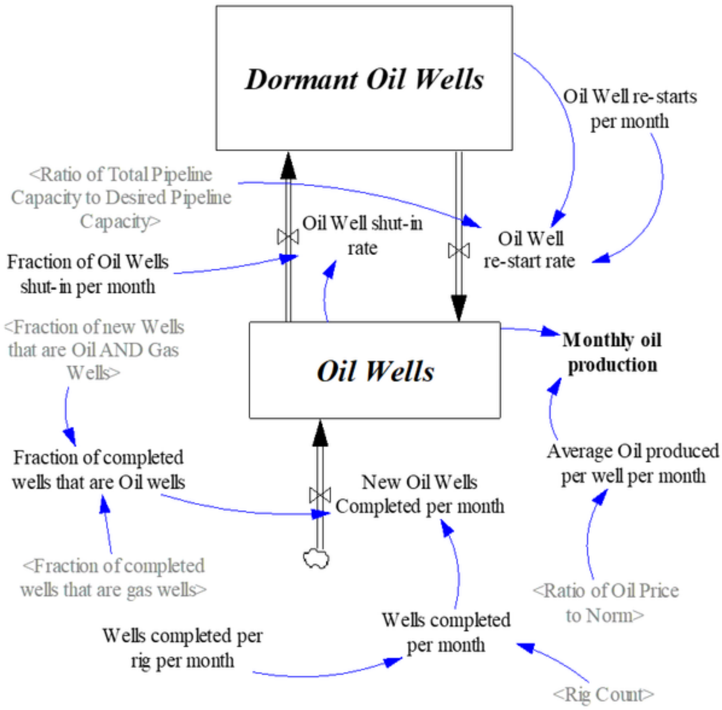
The seven sectors comprising the simulation model include: 1) an oil well sector, 2) a natural gas well sector, 3) an oil-and-gas well sector, 4) a rig count sector, 5) a pricing-and-demand sector, 6) a pipeline capacity sector, and 7) a revenue sector. All of these interactions between model variables have their effects reflected in the revenue sector. The structure of each of these sectors is shown in Figures 2 through 8 below.

In Figure 2, the authors present a structure for the production of oil exclusive of natural gas. The two 'box' variables are places where content can accumulate and deplete. The three 'rate' variables control flows into and out of the box variables. What is flowing and being accumulated or depleted is 'oil wells' (their number). This structure allows oil wells that are unproductive to be placed in a dormant stage where they can be refurbished and brought back to a point of productivity. New oil wells are being completed, while some old oil wells are taken to a state of dormancy. Meanwhile, some dormant wells are being re-serviced and made productive again. The dormant oil-well re-start rate is proportional to the "Ratio of Total Pipeline Capacity to Desired Pipeline Capacity." If actual pipeline capacity is significantly below desired pipeline capacity, the re-start rate is slowed.

DUC (Drilled but UnCompleted) wells are assumed to be among the dormant wells in this structure. In the Permian Basin there are over 4 million DUC wells (oil wells, gas wells, oil-and-gas wells) that could be brought on line should the need arise.

In Figure 2, the Average Oil produced per well per month is influenced by the price of oil as reflected in the "Ratio of Oil Price to Norm." The parameter settings in this model are derived from data for the Permian Basin.

Figure 2. Structure of the Oil Well Sector



This oil well sector (Figure 2) starts with the number of completed wells per month ('Wells completed per month'—near the bottom), a certain fraction of which are declared/determined to be 'Oil Wells.' That fraction is determined by the parameter shown to be 'Percentage of completed wells that are oil wells.' What follows next is the structure for the gas wells sector.

Similar structures appear in Figures 3 and 4 where the Gas Well sector and the Oil-and-Gas well sectors are depicted. DUC wells are included in the dormant wells category in each of these sectors as well.

In Figure 3, the researchers present a structure for the Natural Gas Well sector at the Permian Basin. As new gas wells are completed, they are accumulated into the box (state) variable labeled 'Gas Wells.' Over time, gas wells, like oil wells, tend to become unproductive. When that happens, the model transfers these wells to a category of gas wells called 'Dormant Gas Wells.' Dormant gas wells do not produce any useful hydrocarbons until they are serviced. The dormant gas-well re-start rate is proportional to the 'Ratio of Total Pipeline Capacity to Desired Pipeline Capacity.' If actual pipeline capacity is significantly out of touch with desired pipeline capacity, the re-start rate is slowed. Once serviced (re-started), the Dormant Gas Wells are returned to the state of active 'Gas Wells.'

At the bottom-right of Figure 3, the Average Gas produced per well per month is influenced by the price of gas as reflected in the "Ratio of Gas Price to Norm." Like the oil well sector, this natural gas well sector (Figure 3) starts with the number of completed wells per month, a certain fraction of which are declared to be 'Gas Wells.' That fraction is determined by the parameter shown to be 'Percentage of completed wells that are gas wells.' In Figure 3, the authors also depict another deleterious consequence of the absence of pipelines to transport the gas. Because the price of natural gas is so low and the non-pipeline transportation cost is so high, there are thousands (perhaps millions) of abandoned and orphaned (dormant) gas wells that are leaking methane gas into the atmosphere (Groom, 2020).

Figure 3. Structure of the Natural Gas Well Sector

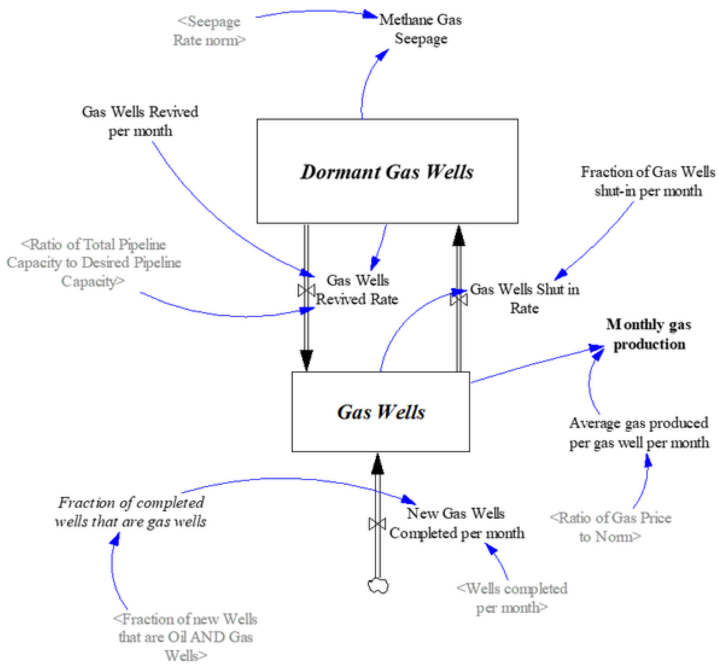
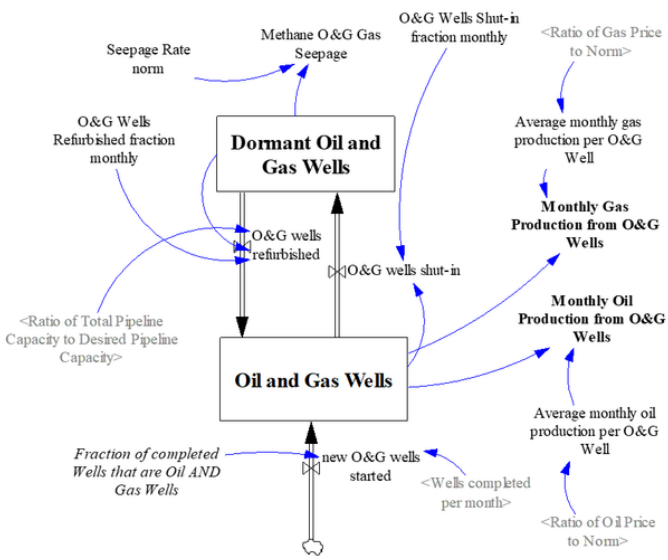


Figure 4. Structure of the Oil-and-Gas Well Sector



In Figure 4, the authors present a structure for the wells that produce both oil and gas in the Permian Basin. As a result of the horizontal drilling, most of the wells being completed today produce both oil and gas. As new oil-and-gas wells are created, they are accumulated into the state variable labeled 'Oil and Gas Wells.' Over time, these oil and gas wells, like oil wells, tend to become unproductive.

When that happens, these wells are transferred to a category of Oil and Gas wells called 'Dormant Oil and Gas Wells.' Dormant oil-and-gas wells do not produce any usable hydrocarbons until they are serviced (refurbished). Once serviced, they are returned to the state of active 'Oil and Gas Wells.' Dormant Oil and Gas Wells have the same problem observed in Figure 3. Namely, there is methane gas seepage from these dormant wells. This is also depicted in Figure 4.

Like the oil well sector and gas well sector, this oil-and-gas well sector (Figure 4) starts with the number of completed wells per month, a certain fraction of which are determined to be 'Oil and Gas Wells.' That fraction is determined by the parameter shown to be 'Fraction of new Wells that are Oil and Gas Wells.'

The Rig Count View shown in Figure 5 endeavors to replicate the actual rig counts that have been observed on a monthly basis. New drilling rigs can be put into production (added to the rig count). Old, less productive rigs can be taken out of production (removed from the rig count). In this model, the researchers assume the rig count will continue to decrease over the time horizon of the model (8.33 years—100 months). Whether more or less rigs are added or removed is dependent upon the ratio of Total Pipeline Capacity to Desired Pipeline Capacity.

In Figure 6, the authors use the data in Figure 1 to drive Waha Hub Price for Natural Gas, delayed by six months. It becomes apparent that the price of both oil and natural gas is dependent upon a host of factors such as the supply of oil and gas internationally, the demand internationally, the strength of the economy, government subsidies, price supports and tax incentives.

In Figure 7, the structure of the pipeline sector is driven by Total Pipeline Capacity which is in a delayed relationship with Desired Pipeline Capacity. The length of that delay is the Pipeline Construction Delay (months). The Construction Delay also includes related delays such as a perception delay associated with how long it takes to realize that there is a pipeline shortage. This combination of delays is the determinate of the length of the pipeline business cycle (Liehr et al., 2001).

In Figure 8, the box variable 'Accumulated Revenues' accumulates the monthly revenues derived from sales of Oil, Gas, and Oil and Gas coming from the sectors depicted in Figures 2, 3 and 4. The industry objective is assumed to be one of maximizing accumulated revenue over the 100-month period. Exhibited in Figure 8 is how the "Ratio of Total Pipeline Capacity to Desired Pipeline Capacity will have an attenuating effect upon the revenues generated in each of the sectors. As discussed in the

Figure 5. Rig Count View

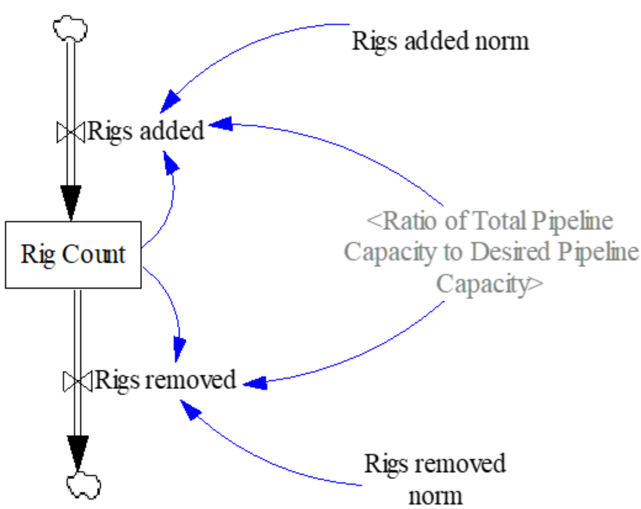


Figure 6. Oil and Gas Pricing Sector

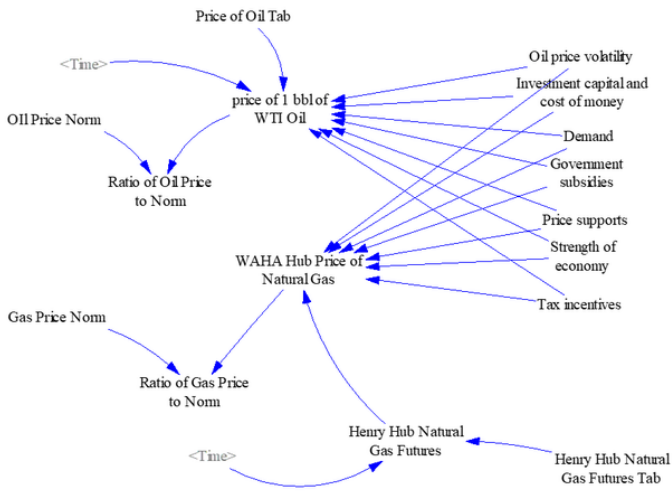
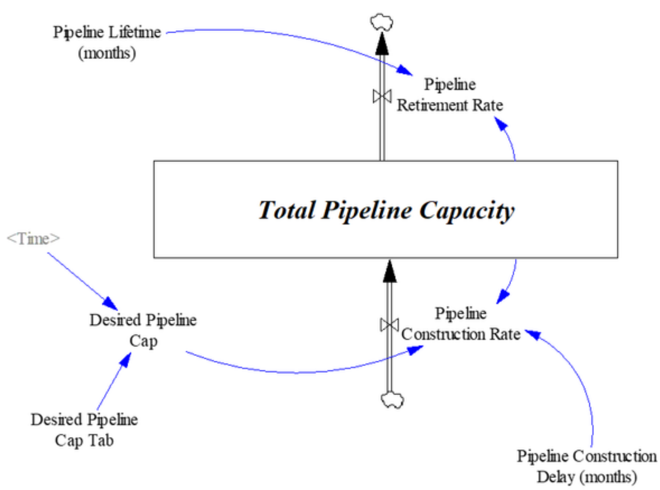


Figure 7. Total Pipeline Capacity

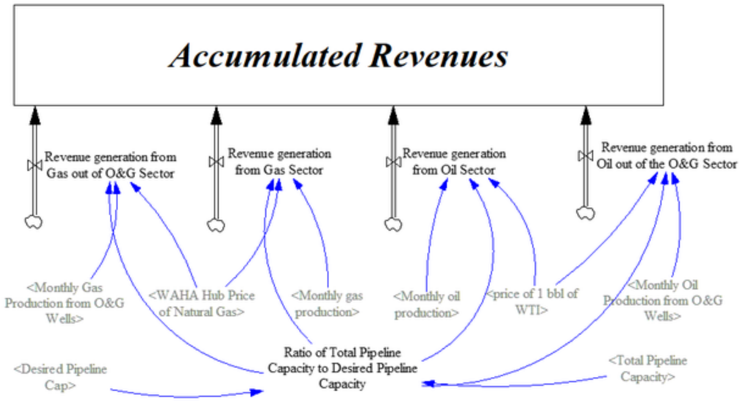


introduction, limited pipeline capacity lowers the price operators receive for natural gas and limits the amount of both oil and gas that can be shipped to refiners.

Why Vensim? Does Vensim Have Business Analytics Capabilities That Are Relevant to This Research?

Our final research question was to assess Vensim's appropriateness as a business analytics tool in the context of the dynamic model of Permian oil-and-gas industry that we constructed. Our choice of Vensim here is based on several considerations. First, Vensim is a powerful tool for relating our understanding of the causality inherent in the real system to its behavior over time. Second, Vensim's simulation parametric optimization feature allows for any dynamic model developed in Vensim to be fitted to data. This feature also allows Vensim to choose parameter values so as to optimize an

Figure 8. Accumulated Revenues Sector



objective function. The analyst does not need to experiment with thousands of combinations of different parameter values. Vensim's calibration makes this procedure automatic. In what follows, we also use this capability to find optimized values for specific model parameters. Vensim employs an efficient Powell hill-climbing algorithm to adjust model parameters so as to optimize an objective function. We also use Vensim to fit the model to historical data. These applications of Vensim involving both data and a model of the system have led us to the conclusion that Vensim makes an important and unique contribution to the arsenal of business analytics tools available to the data scientist.

Vensim's business analytics tools accommodate big data and enable managers to understand and control the dynamic system they are managing. The Vensim tool set allows the data analyst to combine his/her understanding of the structure of the system with the real-world behavior implicit within the historical time-series data measured in the outputs of the system. The result is an improved understanding of both the structure of the system and the behavior of the system and an increased capability to accurately prescribe the possible futures coming from the system.

RESULTS

The resulting behaviors are shown below in Figures 9 through 12. Rather than showing specific times and amounts, these plots show trends/behaviors over a 100-month time horizon. The interest here is patterns of behavior over time, not whether the actual numbers are exactly correct. The purpose of these models is to get an understanding of the dynamics, not to forecast actual counts, numbers or volumes. Such an understanding has managerial implications in terms of the decisions that management takes.

Figures 9 and 10 reveal a significant increase in the number of Oil-and-Gas wells coming from deliberately completing all wells as Oil-and-Gas wells. In Figure 9 the fraction completions for Oil-and-Gas, Oil, and Gas wells was 0.33, 0.33, 0.33. These were the parameter values used for:

Fraction of completed wells that are Oil-and-Gas Wells
Fraction of completed wells that are Oil Wells, and
Fraction of completed wells that are Gas Wells.

These parameter values must sum to 1 because if a well is to be completed, it can only be completed as one of these three categories. In Figure 10, those fractions were changed to 1, 0, 0, respectively. The number of Oil-and-Gas wells completed in the first scenario (Figure 9) was 15,874. The number of Oil-and-Gas wells completed in the second scenario (Figure 10) was 33,264—roughly double. In

Figure 9. Behavior-over-time chart assuming all well types (Oil-and-Gas, Oil, Gas) are evenly completed with completion fractions of 0.33, 0.33, 0.33

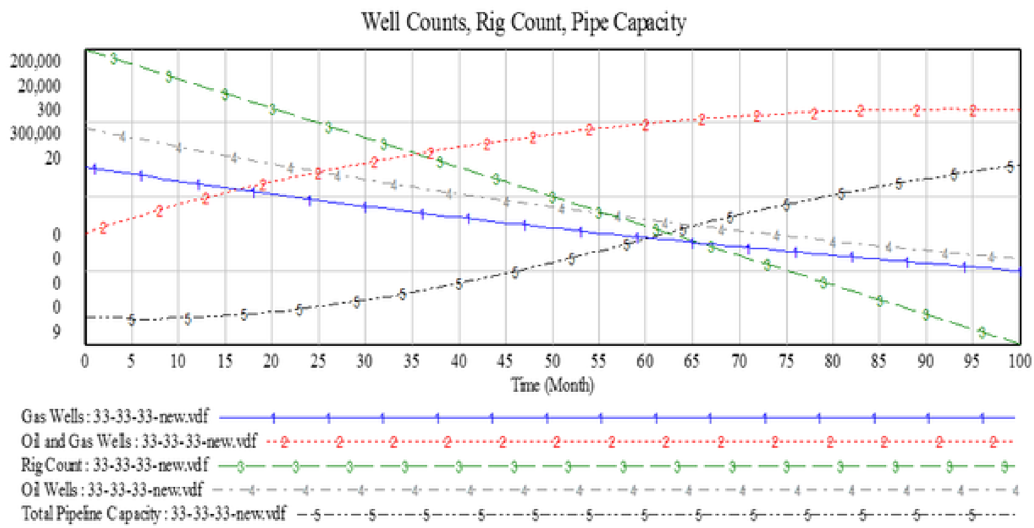
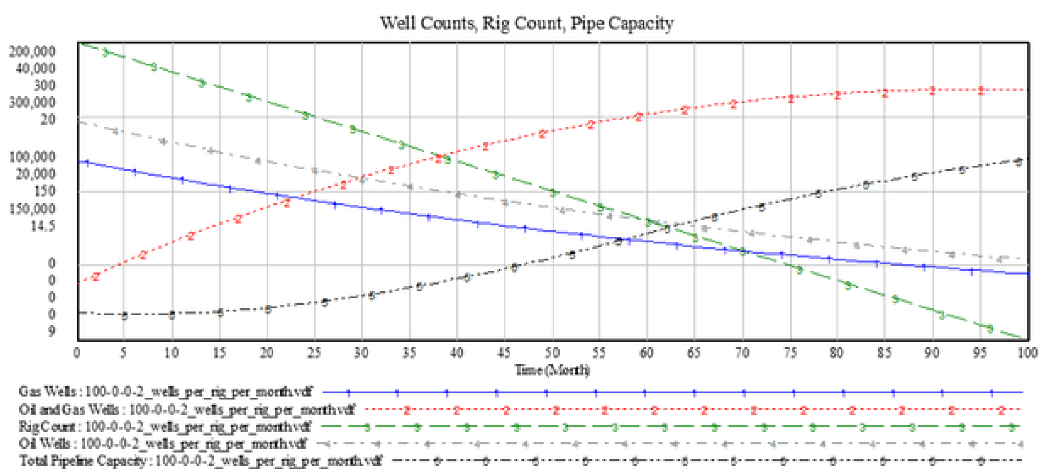


Figure 10. Behavior-over-time chart assuming well types (Oil-and-Gas, Oil, Gas) are completed with completion fractions of 1, 0, 0



both Figures 9 and 10, the authors observed the Total Pipeline Capacity to increase from 10 to 16. In both Figures 9 and 10 the researchers observed a declining rig count, declining at the same rate (in both figures).

Figures 11 and 12 reveal that accumulated revenues for the 100-month period nearly doubled from 78 billion to 132 billion. This was the result of changing the Fraction of completed Oil-and-Gas wells from 0.33 to 1. In both Figures 11 and 12, the number of active oil wells and active gas wells continues to decline while the number of active Oil-and-Gas wells continues to increase early in the 100-month period and then hold steady through the second half of the 100 months.

Figure 11. Behavior-over-Time Chart Showing Accumulated Revenues for Completion Fractions of 0.33, 0.33, 0.33

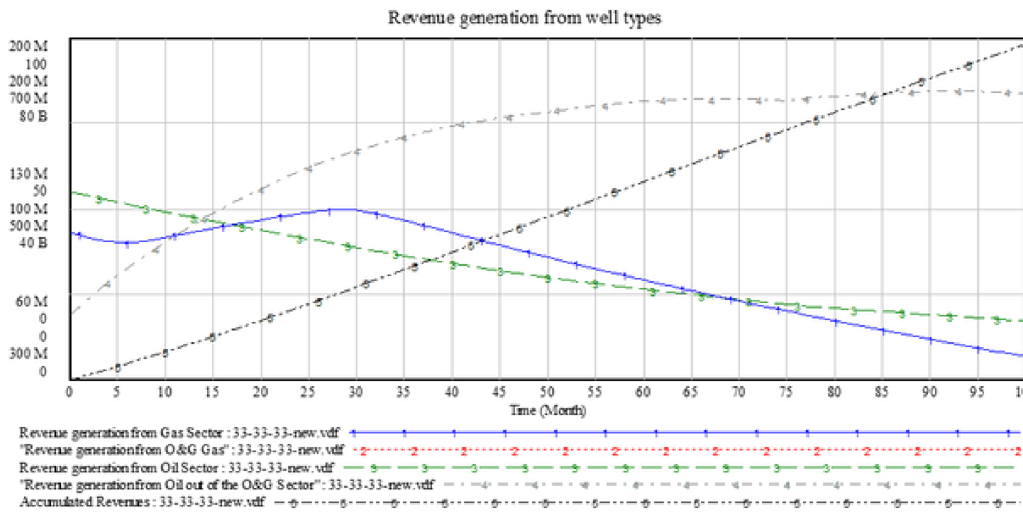
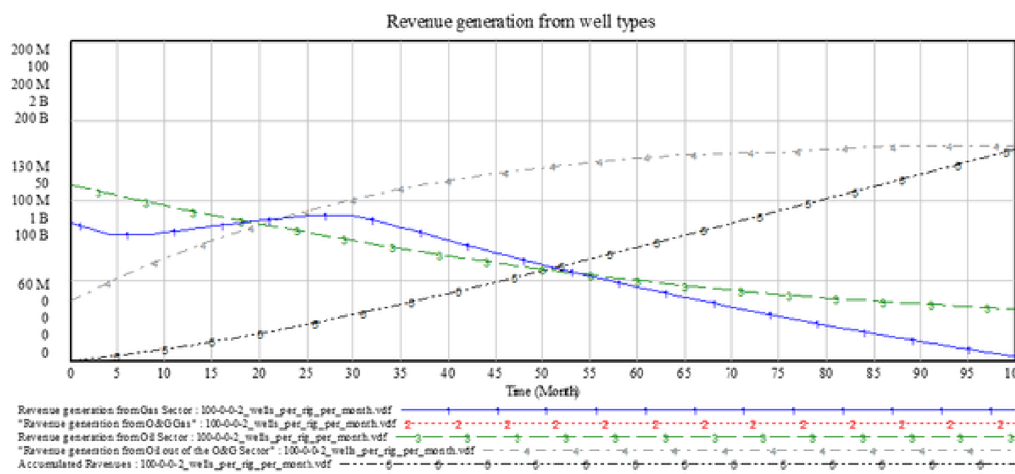


Figure 12. Behavior-over-Time Chart Showing Accumulated Revenues for Completion Fractions of 1, 0, 0



ANALYSIS AND DISCUSSION

From the simulation modeling and scenario analyses, the researchers conclude that the pipeline introductions are helping to make oil and gas production in the Permian Basin more profitable. Such introductions cause prices for the basin's natural gas to go up and approach those of the Henry Hub in Louisiana where the price of all remaining gas produced in the US is established. The new pipes also significantly decrease the cost of transporting the gas to refineries compared to trucks and rail. All of this substantially lessens the amount of gas that gets flared in the area.

Thus, increased pipeline capacity enables gas to be profitably transported to refiners and markets, and reduces the dreadful practice of flaring. It also reduces the amount of methane gas that is seeping into the atmosphere from dormant and abandoned wells because the number of such abandoned gas wells is fewer as more pipelines increase the dormant well re-start rates (Figures 2 and 3). Re-starts will fix any dormant well's seeping problem.

Our study also discovered that pipelines are by far the least expensive and safest means of transporting oil. Further, more pipeline capacity will allow the Permian Basin to produce and sell more oil. Since oil is the main raw product coming forth from the Permian Basin, increased pipeline capacity can also help to make this product more profitable. The literature suggested that transport rates of oil to refineries could be much faster and less costly due to increased pipeline capacity (Enverus, 2021; U.S. Energy Information Administration, 2018).

The Accumulated Revenues (Figure 8) objective exhibits a high degree of sensitivity to the following three parameters:

Fraction of completed wells that are Oil Wells
Fraction of completed wells that are Gas Wells
Fraction of new wells that are Oil-and-Gas Wells

These parameters must sum to one because these are the only kinds of wells that get completed. The implication is that if more wells are completed as Oil-and-Gas Wells, less wells of the other two categories get completed. The sensitivity and parametric optimization studies show that if more wells are completed as Oil-and-Gas wells and less wells are completed as mere Gas Wells, that the resulting increases in Accumulated Revenues are substantial over the 100-month period. In fact, at optimality and in the absence of any real-world constraints, the optimized result is all wells be completed as Oil-and-Gas wells, producing both. The cost of drilling the well and getting its oil and gas to a pipeline can be defrayed against the oil produced from the well alone. So the revenues accruing from the sale of the gas are just additional profit.

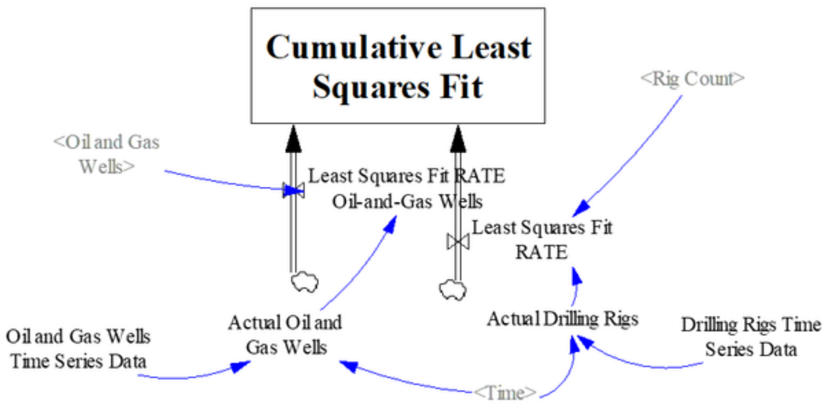
This is the same concept used by foreign semiconductor firms to dump chips in our domestic markets at prices below cost; their domestic sales covered all fixed, indirect and administrative overhead costs. The only costs associated with the chips destined for America were the direct material and labor costs since all other costs were 'covered' by domestic "in-country" sales. For gas coming out of an Oil-and-Gas well, there are no production costs for the gas--just transportation and refining costs. Why? Because all of the production costs are defrayed by the revenues coming from the oil. All of this becomes possible when there is sufficient pipeline capacity to accommodate both the oil and the gas from such wells.

The structure of the model suggests that if the shut-in rate for all well types could be reduced, the re-start rate for all dormant (and DUC) well types could be increased, the need for new wells completed per month would be diminished. In fact, the cost to refurbish a dormant well, might be significantly less than drilling a new well, but the effect might be similar. According to Hendrickson (2021), "Generally speaking, completing an already drilled well is one of the most profitable investments an operator can make."

What Vensim is doing with the structure in Figure 13 is integrating the mean-squared errors between the model-produced data and the time-series historical data. It uses its Powell hill-climbing algorithm to find local optimum settings for selected model parameters. It does this by running hundreds of different simulations and adjusting parameters with each such simulation. Each simulation results in a value for the box variable Cumulative Least Squares Fit. Each simulation performs an integration of all differential equations in the model over the 100-month time horizon. The authors used the structure in Figure 13 to find several optimal parameter values. In one instance, the Cumulative Least Squares Fit, a measure of the amount of error in the fit between the model and the historical data, was reduced from 9.18038e+06 to 8.05329e+05—an order of magnitude reduction coming from 35 simulation runs, each 100 months in duration.

Mathematically, the researchers represent such integrations this way:

Figure 13. The Structure used to Accumulate the Mean-Squared Error between Actual Time-Series Data and the Model-Computed Time-series



$$Cumulative\,Mean\,Square\,Fit = \int_{t_0}^{t_f} \left[\sum_{1}^{n} \left(model\,produced\,data - historical\,time\,series\,data \right)^2 \right] dt$$

where n model variables are differenced with n likened historical time series data. This is what the boxed variable in Figure 13 calculates. The authors also used Vensim to determine the percentages of wells that should be completed as oil wells, gas wells, or both oil and gas wells so as to maximize Accumulated Revenues. As expected, it found that drilled wells should be completed as both oil and gas wells. The reason is apparent—more total revenue coming from two revenue streams. However, the facts are that a few wells do not produce any gas—they must be completed as oil wells; very few wells do not produce any oil—they must be completed as gas wells. Still, the optimization runs clearly point to completing as many wells as oil-and-gas wells as possible is the revenue maximizing policy.

CONCLUSION

What was learned in this research is that there is still a modest need for additional pipeline capacity in the Permian Basin as production continues to grow. Moreover, there is cyclicality in actual pipeline capacity taken in relation to desired pipeline capacity—at times there is too much capacity, at other times there is too little. When actual capacity is less than desired capacity, the Waha Hub price of natural gas is less than the Henry Hub price. The research revealed that the cost of transporting oil or gas by pipeline is many times less expensive than the cost of rail or truck. From the system dynamics model, the authors learned that as the cost to transport natural gas goes down, the price of natural gas rises to the Henry Hub Price. Consequently, it becomes profitable to move the gas to refineries and markets as opposed to flaring it off. It thus becomes expedient to complete wells as oil-and-gas wells instead of just mere oil wells, whenever possible. The researchers learned that production costs for extraction of the gas could be covered by the production costs of producing the oil, since the gas is an automatic result of the horizontal drilling. All of this is evident from the structure of the model (Figures 2-8) as developed and discussed in this paper.

Increased pipeline capacity taken in relation to desired pipeline capacity will increase the rate at which dormant gas and oil-and-gas wells are refurbished and returned to the state of active gas and oil-and-gas wells. This, in turn, will reduce the amount of leaking methane coming from dormant wells. The structures in Figures 3 and 4 depict all of this.

Many possible injections (solutions) to the problem of insufficient pipeline capacity in the Permian Basin exist. Developers can invent new technologies to enable us to construct cheaper pipelines faster that will have greater capacities. To slow the objections of environmentalists, we need to emphatically make the case that pipelines are by far the safest means to transport oil and gas. And that gas is a much cleaner hydrocarbon from which to get energy as compared to coal. (In fact, Europe is now using significant amounts of US-exported Liquefied Natural Gas (LNG) instead of coal to generate electricity (Paraskova, 2019).) We can provide subsidies and tax incentives to encourage more building of pipelines. None of these solutions come without impediments or obstacles. All of this work gets done with projects.

Implications for Pipeline Construction Projects

New project management methodologies and technologies enable projects to be completed quicker and at less cost. The entire pipeline construction project can be broken down into many smaller pipeline construction projects, each having as its objective that of constructing just one mile of the total pipeline. Each of these smaller pipeline projects can be performed in parallel, with proper planning. The result is the completion of a pipeline in weeks instead of months or years. Ultimately, much of the cyclical pipeline capacity behavior reduces to how fast and how inexpensively we can complete pipeline construction projects in the Permian Basin. If the time from the decision to proceed with the new pipeline to its completion can be reduced, the length and severity of the pipeline capacity cycles can be alleviated as well. And the capacities among the components in the infrastructure supply chain can be kept in better balance as well.

Limitations and Future Study

By convening additional experts in the energy industry within the Permian Basin, we can extract their collective views on what the dynamics of new pipeline construction are and how obstacles can be removed. We can then add that collective knowledge to what is already known and articulated here. The possibility for further data-fitting of the model to historical time-series data is yet another opportunity for further study.

REFERENCES

Al-Fasfus, F., Hamza, M., & Elkotayni, K. (2020). The attitudes of the industrial companies towards the implementation of the theory of constraints (A field study). *Academy of Strategic Management Journal*, *19*(2), 1–14.

Alquist, R., & Kilian, L. (2010). What do we learn from the price of crude oil futures? *Journal of Applied Econometrics*, *25*(4), 539–573. doi:10.1002/jae.1159

Barnett, J., & Barron, J. (2020). Oil market volatility is at all-time high. In *Today in Energy*. U.S. Energy Information Administration. https://www.eia.gov/todayinenergy/detail.php?id=43275

Bieker, H. P., Slupphaug, O., & Johansen, T. A. (2007). Real-time production optimization of oil and gas production systems: A technology survey. *SPE Production & Operations*, *22*(4), 382–391. doi:10.2118/99446-PA

Burns, J., & Janamanchi, B. (2006). The dynamics of change management in a technology project context. *International Journal of Information Systems and Change Management*, *1*(2), 115–137. doi:10.1504/IJISCM.2006.010320

Caldwell, E. (2019). The Permian Basin is now the highest producing oil field in the world. *Energy in Depth Texas*. https://www.energyindepth.org/the-permian-basin-is-now-the-highest-producing-oilfield-in-the-world/

Collins, G. (2018). *Addressing the impacts of oil & gas development on Texas roads, testimony to the Texas House of Representatives Transportation Committee*. Rice University's Baker Institute for Public Policy. https://www.bakerinstitute.org/research/addressing-impacts-oil-gas-development-texas-roads/

Conklin, J. (2020). LNG supply glut likely to outlast demand for years, says IGU. *Natural Gas Intelligence*. https://www.naturalgasintel.com/lng-supply-glut-likely-to-outlast-demand-for-years-says-igu/

Coogan, T. (2020). Charts: US shale oil and gas production in the Permian Basin. *The Sounding Line*. https://thesoundingline.com/charts-us-shale-oil-and-gas-production-in-the-permian-basin/

Daneshzand, F., Amin-Naseri, M. R., Elkamel, A., & Fowler, M. (2018). A system dynamics model for analyzing future natural gas supply and demand. *Industrial & Engineering Chemistry Research*, *57*(32), 11061–11075. doi:10.1021/acs.iecr.8b00709

Dettmer, H. W. (1997). *Goldratt's Theory of Constraints: A Systems Approach to Continuous Improvement*. ASQC Quality Press.

DiSavino, S. (2019). New Kinder Morgan pipeline frees natgas long-trapped in Permian. *Reuters*. https://www.reuters.com/article/usa-kindermorgan-permian-idUSL2N26G1JS

Domm, P. (2019). *This Texas area is expected to double oil output to 8 million barrels in just four years, boosting US exports*. Ceraweek by IHS Markit. https://www.cnbc.com/2019/03/08/permian-oil-output-doubling-to-8-million-barrels-boosting-exports.html

Dutta, J., Barma, P. S., Kar, S., & De, T. (2019). A modified Kruskal's algorithm to improve genetic search for open vehicle routing problem. *International Journal of Business Analytics*, *6*(1), 55–76. doi:10.4018/IJBAN.2019010104

Enverus. (2021). *Permian Basin: Ultimate guide for Permian news, information, facts, statistics*. https://www.enverus.com/permian-basin/

Forrester, J. W. (1961a). *Industrial Dynamics*. M.I.T. Press.

Forrester, J. W. (1961b). *Principles of Systems*. Wright-Allen Press.

Forrester, J. W. (1971). *World Dynamics*. Wright-Allen Press.

Gaswirth, S. B., Marra, K. R., Lillis, P. G., Mercier, T. J., Leathers-Miller, H. M., Schenk, C. J., Klett, T. R., Le, P. A., Tennyson, M. E., Hawkins, S. J., Brownfield, M. E., Pitman, J. K., & Finn, T. M. (2016). Assessment of Undiscovered Continuous Oil Resources in the Wolfcamp Shale of the Midland Basin, Permian Basin Province, Texas, 2016. *U.S. Geological Survey Fact Sheet*, 2016–3092. doi:10.3133/fs20163092

Goldratt, E. M. (1990a). The Haystack Syndrome: Sifting Information from the Data Ocean? Croton-on-Hudson, NY: North River Press.

Goldratt, E. M. (1990b). What is this thing called the Theory of Constraints? Croton-on-Hudson, NY: North River Press.

Goldratt, E. M., & Cox, J. (1992). *The Goal - A Process of Ongoing Improvement* (2nd ed.). North River Press Publishing Corporation.

Goldratt, E. M., & Fox, R. (1986). The Race. Croton-on-Hudson, NY: North River Press.

Green, K. P., & Jackson, T. (2014). Pipelines are the safest way to transport oil and gas. *Fraser Institute*. https://www.fraserinstitute.org/article/pipelines-are-safest-way-transport-oil-and-gas

Groom, N. (2020). Special reports: Millions of abandoned oil wells are leaking methane, a climate menance. *Reuters*. https://www.reuters.com/article/us-usa-drilling-abandoned-specialreport-idUSKBN23N1NL

Hendrickson, S. (2021). Here are 4 reasons causing 'dead' DUCS, *OpportuneConnect*. https://opportune.com/insights/article/here-are-4-reasons-causing-dead-ducs/

Holdaway, K. (2014). *Harness Oil and Gas Big Data with Analytics: Optimize Exploration and Production with Data-Driven Models*. Wiley. doi:10.1002/9781118910948

Johns, R. T., & Dindoruk, B. (2013). Gas flooding. Enhanced Oil Recovery Field Case Studies, 1-22.

Kendall, G. I. (1998). *Securing the Future: Strategies for Exponential Growth Using the Theory of Constraints*. St. Lucie Press.

Kim, E. (2019). Monetizing growing Permian Basin supply: A holistic midstream approach to understanding potential bottlenecks. In *Proceedings of SPE/AAPG/SEG Unconventional Resources Technology Conference.* OnePetro. doi:10.15530/urtec-2019-634

Kinder Morgan. (2019). *Gulf coast express pipeline placed in service ahead of schedule*. https://ir.kindermorgan.com/news/news-details/2019/Gulf-Coast-Express-Pipeline-Placed-in-Service-Ahead-of-Schedule/default.aspx

Klein, D., & DeBruine, M. (1995). A thinking process for establishing management policies. *Review of Business*, *16*(3), 31–37.

Kopalek, M. (2019). Permian Basin natural gas prices up as a new pipeline nears completion. In *Today in Energy*. U.S. Energy Information Administration. https://www.eia.gov/todayinenergy/detail.php?id=41213

Lee, S., & Pena-Mora, F. (2007). Understanding and managing iterative error and change cycles in construction. *System Dynamics Review*, *23*(1), 35–60. doi:10.1002/sdr.359

Liehr, M., Grobler, A., Klein, M., & Milling, P. M. (2001). Cycles in the sky: Understanding and managing business cycles in the airline market. *System Dynamics Review*, *17*(4), 311–332. doi:10.1002/sdr.226

Love, P. E. D., Holt, G. D., Shen, L. Y., Li, H., & Irani, Z. (2002). Using systems dynamics to better understand change and rework in construction project management systems. *International Journal of Project Management*, *6*(20), 425–436. doi:10.1016/S0263-7863(01)00039-4

Lyneis, J. M., & Ford, N. D. (2007). System dynamics applied to project management: A survey, assessment, and directions for future research. *System Dynamics Review*, *2-3*(23), 157–189. doi:10.1002/sdr.377

MacRitchie, C., & Zobaa, M. K. (2019). Multiproxy sedimentary organic matter analysis of the upper wolfcamp formation in the collier-1201 well, southeastern Delaware basin, Texas. *Interpretation (Tulsa)*, *7*(4), SK45–SK52. doi:10.1190/INT-2019-0043.1

McMullen, T. B. (1998). *Introduction to the Theory of Constraints (TOC) Management System*. St. Lucie Press.

Modi, K., Lowalekar, H., & Bhatta, N. (2019). Revolutionizing supply chain management the theory of constraints way: A case study. *International Journal of Production Research*, *57*(11), 3335–3361. doi:10.1080/00207543.2018.1523579

Mohaddes, K., & Raissi, M. (2019). The US oil supply revolution and the global economy. *Empirical Economics*, *57*(5), 1515–1546. doi:10.1007/s00181-018-1505-9

Moroney, J. R., & Berg, M. D. (1999). An integrated model of oil production. *Energy Journal*, *20*(1), 105–124. doi:10.5547/ISSN0195-6574-EJ-Vol20-No1-6

Munsamy, M., Telukdarie, A., & Dhamija, P. (2020). Logistics 4.0 energy modeling. *International Journal of Business Analytics*, *7*(1), 98–121. doi:10.4018/IJBAN.2020010106

Naill, R. F. (1992). A system dynamics model for national energy policy planning. *System Dynamics Review*, *8*(1), 1–19. doi:10.1002/sdr.4260080102

Oilfield Knowledge Center. (2021). *Rig count overview & summary count*. Baker Hughes. https://bakerhughesrigcount.gcs-web.com/rig-count-overview

Paraskova, T. (2019). *U.S. natural gas exports to Europe soar nearly 300% in nine months*. https://oilprice.com/Latest-Energy-News/World-News/US-Natural-Gas-Exports-To-Europe-Soar-Nearly-300-In-Nine-Months.html

Passwaters, M. (2021). Permian oil production could near record in 2021 with pipeline capacity to spare. *S&P Global Market Intelligence*. https://www.spglobal.com/marketintelligence/en/news-insights/latest-news-headlines/permian-oil-production-could-near-record-in-2021-with-pipeline-capacity-to-spare-62058588

Patel, A., & Geary, E. (2020). U.S. crude oil and natural gas production in 2019 hit records with fewer rigs and wells. In *Today in Energy*. U.S. Energy Information Administration. https://www.eia.gov/todayinenergy/detail.php?id=44236

Peach, J., & Starbuck, C. M. (2011). Oil and gas production and economic growth in New Mexico. *Journal of Economic Issues*, *45*(2), 511–526. doi:10.2753/JEI0021-3624450228

Pipeline and Hazardous Materials Safety Administration. (2018). *General Pipeline FAQs*. U.S. Department of Transportation. https://www.phmsa.dot.gov/faqs/general-pipeline-faqs

Rahmandad, H., & Hu, K. (2010). Modeling the rework cycle: Capturing multiple defects per task. *System Dynamics Review*, *4*(26), 291–315. doi:10.1002/sdr.435

Robinson, K. (1988). Petroleum geology and hydrocarbon plays of the Permian basin Petroleum province West Texas and southeast New Mexico. U.S. Geological Survey. Open-File Report 88-450-Z, 53. doi:10.3133/ofr88450Z

Roussey, B. (2019). Mega oil and gas discovery in the Permian Basin doubles America's energy reserves. *Energy Central*. https://energycentral.com/c/og/mega-oil-and-gas-discovery-permian-basin-doubles-america%E2%80%99s-energy-reserves

Scheinkopf, L. (1999). *Thinking for Change: Putting the TOC Thinking Processes to Use*. St. Lucie Press.

Sterman, J. D. (2000). *Business Dynamics-Systems Thinking and Modeling for a Complex World*. McGraw-Hill Companies Inc.

Sun, J., Li, G., & Wang, Z. (2018). Optimizing China's energy consumption structure under energy and carbon constraints. *Structural Change and Economic Dynamics*, *47*, 57–72. doi:10.1016/j.strueco.2018.07.007

Tobben, S. (2020). Permian pipeline competition accelerates as capacity exceeds supply. *WorldOil*. https://www.worldoil.com/news/2020/1/3/permian-pipeline-competition-accelerates-as-capacity-exceeds-supply#:~:text=Permian%20pipeline%20competition%20accelerates%20as%20capacity%20exceeds%20supply,rate%20cuts%20and%20could%20mean%20cutthroat%20competition%20ahead

Townsend-Small, A., & Hoschouer, J. (2021). Direct measurements from shut-in and other abandoned wells in the Permian Basin of Texas indicate some wells are a major source of methane emissions and produced water. *Environmental Research Letters*, *16*(5), 054081. doi:10.1088/1748-9326/abf06f

U.S. Energy Information Administration. (2018). *Permian Basin Wolfcamp Shale Play Geology Review*. U.S. Department of Energy. https://www.eia.gov/maps/pdf/PermianBasin_Wolfcamp_EIAReport_Oct2018.pdf

U.S. Energy Information Administration. (2021). *Permian region: Drilling productivity report*. https://www.eia.gov/petroleum/drilling/pdf/permian.pdf

Van Doren, J. F., Van den Hof, P. M. J., Jansen, J. D., & Bosgra, O. H. (2011). Parameter identification in large-scale models for oil and gas production. *IFAC Proceedings Volumes, 44*(1), 10857-10862.

Ventana Systems Inc. (2016). https://www.ventanasystems.com/

Wang, H. (2020). The economic impact of oil and gas development in the Permian Basin: Local and spillover effects. *Resources Policy*, *66*, 101599. doi:10.1016/j.resourpol.2020.101599

Y-Charts. (2021). *WTI crude oil spot price*. https://ycharts.com/indicators/wti_crude_oil_spot_price

James R. Burns is a full professor of operations management and information technology in the Rawls College of Business Administration at Texas Tech University, Lubbock, Texas. He received his MS and PhD degrees in Operations Research from Purdue University. He holds the PMP and CIRM certifications provided by the Project Management Institute and the American Production and Inventory Control Society. He is the author or co-author of several books on management science and information technology and more the 100 journal articles and published presentations. He regularly teaches courses in operations management and project management. His research is focused on new developments in project/process management and on understanding the dynamics of oil and gas production in the Permian Basin. He is interested in the synergistic use of concepts borrowed from Boehm, Covey, Crosby, Deming, Forrester, Goldratt, Hammer, Humphreys, Senge, and others in the design of processes. Currently, he is focused on the identification and removal of impediments/constraints that slow the production of oil and gas in the Permian Basin.

Pinyarat Sirisomboonsuk is an assistant professor of management in the College of Business at the University of Texas Permian Basin (UTPB). She received her Ph.D. in Operations Management (minor in Industrial Engineering) from Texas Tech University. Pinyarat's primary research interests are in the areas of operations management and project management, which incorporate theories from strategic management and organizational theory. She published in International Journal of Project Management and elsewhere. Pinyarat also regularly presented at Decision Sciences Institute conferences and Southwest Decision Sciences Institute conferences. She has taught courses in operations management, project management, business logistics, risk management in supply chains, and business statistics for both undergraduate and graduate levels. Pinyarat received her bachelor's degree in economics with first class honors from Chulalongkorn University in Thailand. She worked as a credit officer at Export-Import Bank of Thailand, a Thai government enterprise, for 4.5 years before continuing her MBA study at Oregon State University. In 2014, she earned her Project Management Professional (PMP) credential. Prior to joining as a faculty member at UTPB, she was a full-time lecturer at the Charlton College of Business, University of Massachusetts, Dartmouth.