Statistical Analysis of "Significant Incident" Data for Barnett Shale Gas Wells

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Introduction

When the gas industry began to court the Fort Worth City Council in 2003 regarding gas drilling inside Fort Worth, Texas, a city of about 300 square miles in area, the council was told a story about the riches that would be coming to the citizens and the city government if the city would help promote drilling. Other than a rosy picture of wealth and the extreme unobtrusiveness of the industry infrastructure, thanks to the modern technique of horizontal drilling, and the picture of happy rich citizens and a prosperous city government, no other information was given or asked for. The City Council agreed to promote the project and promised to see that city processes would be industry friendly.[1]

Every single unpleasant and unwelcome consequence of urban gas drilling and production remained unaddressed and unknown to citizens and the Council. During the period 2003-2007 many serious issues that obviously were known to the industry at the very beginning slowly began to be revealed through activities of the industry. One example is the matter of pipelines. The Council never heard a word about them until 2008.[2]

In September 2007, it was casually revealed by industry that they intend to put about 3000 wells inside Loop 820[3], which encompasses about 160 square miles of the 300 square mile area of Fort Worth. As a person with a scientific mind, I soon realized that this would imply about 5600 wells inside Fort Worth, and at an average of 8 wells per drilling pad that would mean over 700 drilling pads inside the city. As I went further with the implications it became obvious that this plan could not happen without enormous impact on the city.

Each drilling pad would require about 2 acres of land[4], and this would mean 7 drilling pads on every page of the MAPSCO[5] book of Fort Worth street maps.

Soon I began thinking about how the gas would be transported to market. Clearly, this would require pipelines. By mid 2008 many others had begun to be aware of the requirement for pipelines and drillers were being asked by potential mineral lessors for

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[1] Telephone conversation with City Councilman Chuck Silcox, September 7, 2007
[2] Chuck Silcox, Gary Hogan, Gas Drilling Task Force member, various verbal communications 2007-2008
[3] Julie Wilson, VP for Business Development, Chesapeake at Trinity Trees hearing, September 5, 2007
[4] It is not that this is such a large percentage of the 300 square mile area of the City that is of concern, it is the regular distribution of these 2 acres pads throughout the city that creates the impact.
[5] http://www.mapsco.com/detail.aspx?ID=3309

specific locations for the drilling pads and the pipelines to serve them. Chesapeake filed its first suits for eminent domain against homeowners who didn't want a proposed gas gathering pipeline running underneath their front yards (as close as 10 feet from their home foundations)[6]

My research revealed the enormity of the dangers. These dangers were being ignored and unmentioned by the industry as they scrambled to complete their acquisition of mineral leases inside the city. Chesapeake was refusing to specify locations for drilling pads and pipelines in their leases. Take it or leave it, potential lessors were told.

In the summer of 2008 I completed the study presented in this paper and began to present the results to as many neighborhood associations and other clubs and associations as I could. By November 2008 I had given talks on this study to over 2300 citizens of Fort Worth, and on November 21, 2008 I gave it as an invited paper at the Pipeline Safety Trust yearly national conference in New Orleans, LA. The talk was webcast on the internet.

Purpose

This study produces a calibrated mathematical model of the gathering pipeline Significant Incident (SI) rate as a function of the total number of producing wells in a given region. It uses official data published by the US Department of Transportation Pipeline Hazardous Materials Safety Administration (PHMSA) and their Texas agency for data collection and regulation, the Texas Railroad Commission (TRC). The purpose of this model is to forecast the expected SI rate in the City of Fort Worth as the industry increases the number of producing gas wells in the City.

Methodology

"Significant Incident" is an official term whose definition[7] prescribes the conditions under which a pipeline accident must be reported formally to PHMSA through the responsible state agency. This study concerns only the gas gathering line portion of the data collected for the Barnett Shale gas play in the period 2004-2007. This limitation ensures that the results will be appropriate for the technology, and regulation, maintenance, and inspection policies in use in the Barnett Shale.

The data for gas gathering pipeline SIs in the Barnett Shale region do not include the number of gathering pipeline miles for the yearly totals. Instead we are given the total number of producing gas wells in the play for each year. Therefore, we cannot directly relate the number of SIs reported for a given year to the gas gathering pipeline mileage in use for the year. However, for drilling pads distributed in as regular a fashion as possible given surface land use the average number of miles of gas gathering pipeline

[6] Chuck Silcox, private communication
[7] http://primis.phmsa.dot.gov/comm/reports/safety/SigPSI.html#_nggather

per well is very nearly constant for fields containing a substantial number of wells.[8] The number of SIs in a gas field bears a direct, positive slope, linear relation to the number of pipeline miles involved. If a pipeline network is located in a rural area where there are few humans per square mile its SI rate will statistically be smaller than the same pipeline network placed in an urban setting, all other factors being equal (the chemistry of the raw gas, etc.)

The available data are principally for a largely rural or sparsely populated setting in the Barnett Shale from 2004-2007. At the end of 2007 there were no gas gathering pipelines in Fort Worth. The first application for one came in the summer of 2008, and that line has yet to be constructed. While there are, in November 2008 some 1367 gas drilling permits inside Fort Worth, those wells that are not very close to a gas processing plant are not yet producing gas, and about 100 have yet to be drilled.

Resulting forecasts using the model developed and calibrated herein will be almost certainly only a lower bound on what one may expect in this urban setting of 300 square miles with a population density of 2333 people per square mile.

Analysis

To get an idea of how the number of gas gathering incidents per year has changed nationally over time I looked at data from http://primis.phmsa.dot.gov/comm/reports/safety/SigPSI.html#_nggather .and http://tonto.eia.doe.gov/dnav/ng/ng_prod_wells_s1_a.htm. The data is shown in Figure 1, below.

The number of gas gathering pipeline incidents should, in fact, be proportional to the number of miles of pipe in use. And the length of gas gathering pipeline needed should also be proportional to the number of operational wells for each year. Figure 1 demonstrates the postulated functional dependence for national data. Since the data comes from many different gas fields with different geometries and different ages the slope of the regression line is not appropriate for the Barnett Shale data, however. That is why it is necessary to analyze Barnett Shale data separately.

[8] This may not be immediately obvious. Consider construction estimation. It is a fact that regardless of the exact floor plan of a home, the number of board feet of stud and plate lumber is proportional to the number of square feet of wall in the house. The error in this rule of thumb is small enough that this estimation method is widely used. Similarly, the number of miles of gathering pipeline is proportional to the number of gas wells.

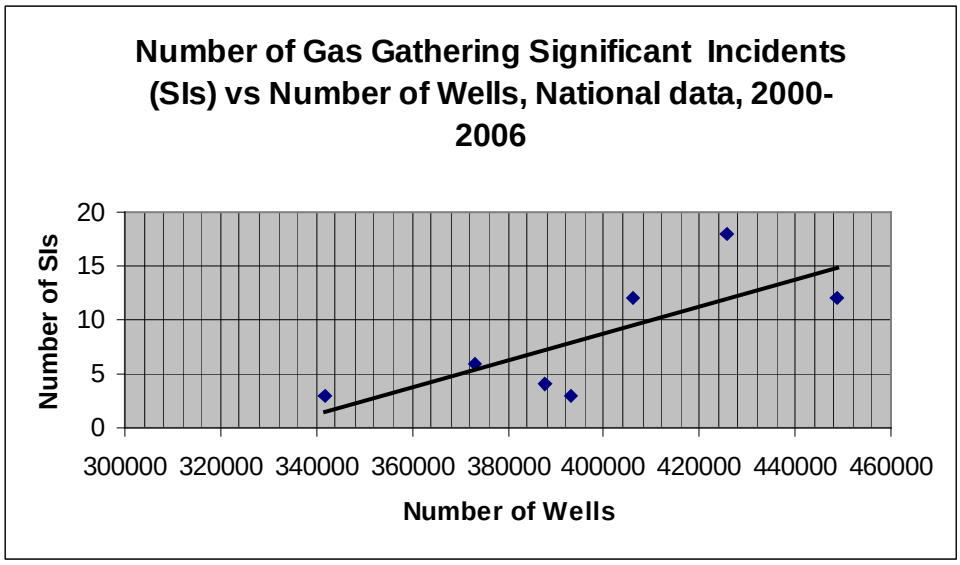

FIGURE 1—National Gathering Line Significant Incidents vs Number of Wells, 2000-2006

Table 1 gives data extracted from the Texas Railroad Commission website for the Barnett Shale and inferences drawn from that data to obtain needed information. Column 2 results from parsing the data in the first referenced Texas Railroad Commission page, below, to isolate incidents that occurred in the Barnett Shale. The New Production column is inferred data consistent with the claim in the second web page referenced below that there were a total of 7,766 gas wells in the Barnett Shale as of June 3, 2008. This would imply that only about 73% of the permits in column 3 had resulted in operational wells.

Year	No. Incidents	No. Permits	New Production	Operational Wells
2004	0	1112	817	817
2005	3	1629	1196	2013
2006	2	2507	1841	3854
2007	4	3657	2686	6540

TABLE 1—Data Extracted/Projected From http://www.rrc.state.tx.us/divisions/og/statistics/fielddata/barnettshale.pdf and http://www.rrc.state.tx.us/divisions/og/statistics/production/ogisgpwc.html[9]

We can plot data from columns 2 and 5 of Table 1 and apply linear regression analysis to obtain an estimate of the expected number of incidents per year for a collection of a certain number of wells in the Barnett Shale. This plot and regression analysis are given in Figure 2. The number of operational wells for 2007 in column 5 was estimated

[9] November 22, 2008: These two URLs no longer are valid.

by linear projection from October through December since the data were compiled before the year was over.

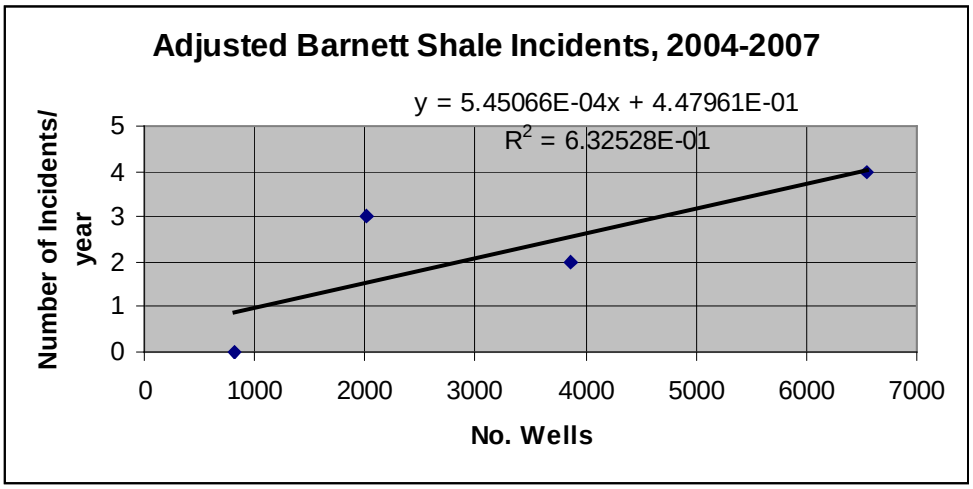

FIGURE 2—Number of Gas Gathering Line Incidents per Year vs Estimated Number of Operational Wells in the Barnett Shale

Figure 2 tells us that if the industry succeeds in placing 3000 wells in Fort Worth there will, on average, be approximately one SI every 6 months in Fort Worth[10] for as long as the wells remain active. If 5600 wells is achieved, the SI rate would be about 1 every 3.5 months. Again, this result is extremely conservative for reasons given above.

Modeling and Simulation

Consider a field of N gas wells and supporting gas gathering infrastructure. In this field gathering line SIs occur with some probability per unit gas gathering pipe length per unit time. As we have seen above we can also describe this process in terms of probability of occurrence per well per unit time because each well can be thought of as "owning" a certain average number of miles of gas gathering line. That is the method we choose here.

If we have the probability per well per unit time, then the probability per, say, 1000 wells per unit time is simply 1000 times the probability on a per well basis.

The probability for a field of N wells, then, is easily calculated in similar fashion.

To simulate this process of the generation of a time sequence of SIs we must have a mathematical equation that gives the probability sought. In this case the process we are dealing with is obviously a member of the large class of processes that are known

[10] An earlier analysis based on an earlier version of the TRC web site page at http://www.rrc.state.tx.us/divisions/og/statistics/fielddata/barnettshale.pdf yielded a result of 1 significant incident every 7 months. The number of active wells per year has changed slightly.

as Poisson processes. These processes are those in which the occurrence of an event is independent of the past history. The probability of occurrence is a negative exponential function of time. We consider time units to be small enough that in a single unit of time the probability of more than one event occurring is vanishingly small. In counting these events over a period of t units of time the probability of a given number of counts, k, observed over time, t, for a process whose average time between occurrences is λ is given by the Poisson distribution[11],

$$P(\lambda, k, t) = e^{-\lambda t} \frac{(\lambda t)^k}{k!} \qquad (1)$$

In the case of a 3000 well field, the data in Figure 2 gives $\lambda = 1/6$. We can use Equation (1) to calculate the probability that there will be exactly zero (k = 0) occurrences in any given time, t months. The Poisson distribution is a standard function in Excel. The reader is encouraged to set up a spreadsheet to calculate probabilities and experiment. If we set k = 0, and $\lambda = 1/6$ and use the goal seek function to find t such that P = 0.99, we find t = 28.8 months. This says that only 1% of the time will there occur a time between successive events as long as 28.8 months.

So, when there are 3000 gas wells in Fort Worth, we can expect, conservatively, that the average time between SIs will be 6 months and the time between successive events will exceed 28.8 months only 1% of the time.

It is also instructive to construct a Monte Carlo model that will generate time histories of occurrences that obey this stochastic process. To do this we need to generate Poisson variates from uniform random variates. This is very simple to do.[12] The algorithm is

1. Generate U ~ U(0,1), a uniform random number between 0 and 1. This is easily done with the Excel function, RAND().
2. Return $t_i = t_{i-1} - (1/\lambda)\ln(U)$

This can be easily programmed into an Excel spreadsheet. An example of one possible 28 event sequence (an arbitrary choice) is shown in Figure 3. In this replication the maximum time between events was about 17.6 months. In this figure the vertical axis is meaningless, a necessary requirement to produce an Excel graph.

[11] Probability, Random Variables, and Stochastic Processes, A. Papoulis, McGraw Hill, 2nd Ed., 1984, p 210
[12] Simulation Modeling and Analysis , Law and Kelton, McGraw Hill, 3nd Ed., 1991, p 507

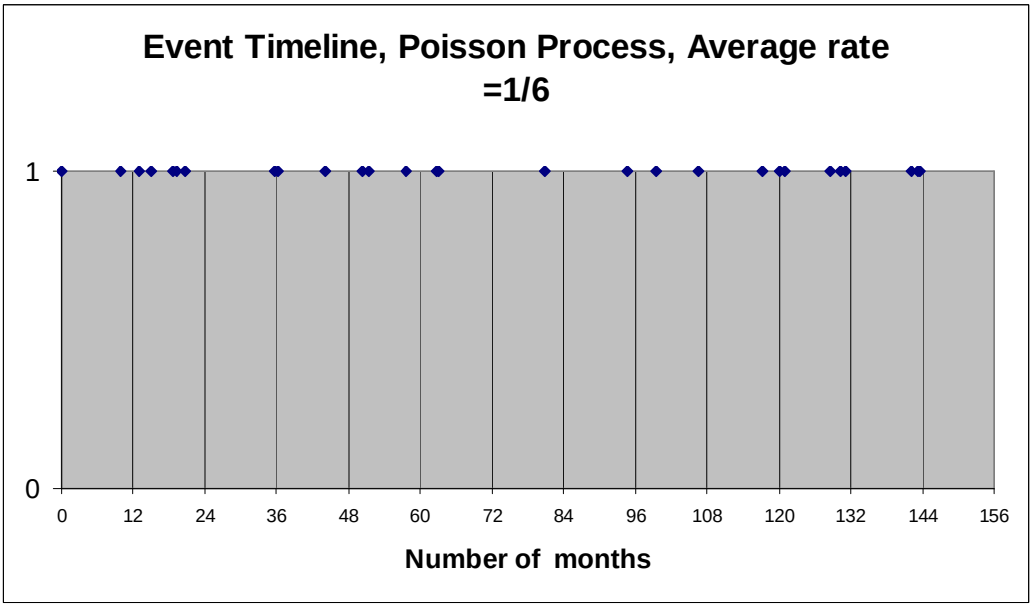

FIGURE 3—Example of a 28 Event Time Sequence for a Poisson Process with Average Time Between Events of 6 Months

Conclusions

Fort Worth already has 1367 permitted wells. The rate of applications for drilling permits and the rate of drilling new wells will determine how quickly Fort Worth reaches a level of 3000 producing wells. It has been estimated by two methods that 3000 wells will be reached between November 2009 and sometime in the first quarter of 2011. There is still time to alter the future this study predicts. What is required is a limitation on where gas gathering lines and wells can be sited within the city. At this time Fort Worth has zoning ordinance requirements that could limit all gas production activities to heavy industrial zoned areas (zoning designation K). However, the City Council is ignoring that ordinance and permitting wells as close as 200 feet from otherwise restricted use buildings with a variance that, so far, has only been denied once.

Gas gathering lines are allowed right through people's front yards with no setback limitation at all, and no permit required. However, a city permit is required for each location where a pipeline passes beneath a street. There has never been a restriction or a denial of those permits. Each driller insists on using only their own gathering pipelines, so there is no effort to economize and reduce citizen exposure to potential injury or death by sharing gathering lines. Families with pipelines running through their property are vulnerable to having their homes destroyed by fire or explosion or perhaps being asphyxiated by lethal unodorized gas. Conservatively estimated, this could happen somewhere in the city every 6 months, on average, given best technology practices, and

modern regulation, inspection, and maintenance practices when 3000 producing wells are operating in the city.

If the city declares a moratorium on new drilling permits and new pipeline plans and produces a master plan that properly addresses public safety, this future can be avoided or mitigated. While there are legal opinions today that there is no stopping eminent domain for right of way for gathering lines, there are an equal number of opinions that private profit does not trump public safety and that proper zoning does trump drillers' plans to put pipelines through residential zoned areas. These legal opinions have yet to be tested.

The implication of an SI every 6 months inside the city, or every 3.5 months if 5600 wells are drilled, is that there will be a decreased growth rate, if not a population decline, due to the increased safety risks for residents. This will most likely cause a decline in property values and associated property tax revenues for all tax entities in the city. As the desirability of Fort Worth as a place to live decreases, home values will also decrease. It is not a pretty picture.