geoconvention
Calgary • Canada • May 13-17 2019

Analyzing the Decision-making Process of Hydraulic Fracturing Operations

Jieyu Zhang and Mirko van der Baan
Department of Physics, University of Alberta, Edmonton, Canada.

Summary

Hydraulic fracturing is a very effective method used in unconventional oil and gas exploration. One of the possible side effects from hydraulic fracturing operations is induced seismicity. When dealing with hydraulic fracturing induced seismic events, thorough geological investigations, proper monitoring and effective mitigation methods can reduce the probabilities of triggering large earthquakes. However, more money and time are invested. When faced with various and helpful yet costly choices during a complete hydraulic fracturing operation, it is essential to make the efficient decisions that can both maximize the profit of the operation and minimize the potential damages. Decision analysis is introduced to decision makers for making effective and efficient decisions. We demonstrate the methodology by creating a simplified hydraulic fracturing operation that only consists of the decisions and information we are interested in. Probabilities of triggering large earthquakes are quantified using fault slip potential. Decisions are evaluated based on the expected monetary value. This paper presents that decision analysis is a feasible way of helping the decision-making process of hydraulic fracturing operations.

Method

Decision analysis theory is applied to solving the cost-profit problem and help with the decision-making process of hydraulic fracturing operations. Normally, there are three elements in a decision analysis: decisions, uncertain events and consequences. Two common models are used for structuring and understanding the relations among the three elements, namely influence diagrams and decision trees.

The influence diagrams illustrate relations among all parts graphically while the decision trees reveal more details (Clemen, 1996). Fig. 1 is an influence diagram describing a typical hydraulic fracturing operation. In the diagram, decisions are divided into two parts, operation plans and management. Operation plans include the details about how to conduct the operation. Management includes the prevention methods and responses to unexpected events like the induced seismicity when they occur. Uncertain events are divided into geological settings, regulations and market, and environmental response. The environmental response can be a large seismic event induced by injection or water contamination when a leakage happens to the well. Consequences from a hydraulic fracturing operation are not only the economic profit but also other outcomes like the environmental and the social impact.

Once an influence diagram is created, a decision tree can be built accordingly. In a decision tree, square nodes mean decisions and circle nodes mean uncertain events. Branches after a square or a circle lead to alternatives for a specific decision or all possible outcomes. At the end of the decision tree, corresponding consequences are listed after the outcomes. The consequences could be monetary values of all the outcomes.

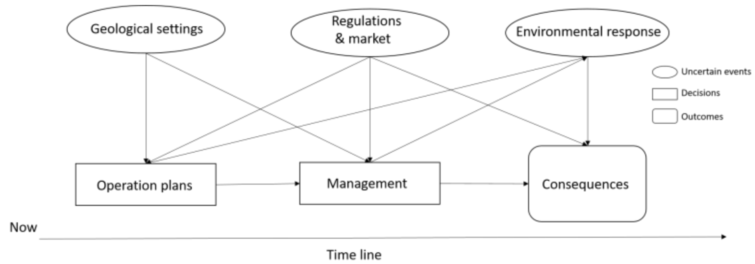

Figure 1. Influence diagram of hydraulic fracturing.

Moreover, the probability of each outcome and the money spent when choosing certain alternatives are presented in the decision trees. In order todetermine whice alternative is better, the expected value is used. The expected monetary value (EV) is defined as

$$EV = \sum_{i}^{k} p_i \times V_i, \qquad \text{(Eq.1)}$$

where k is the total number of all outcomes, p_i is the possibility of i th outcome and V_{m_i} is the value of the outcome. If there are only monetary values in the equation, EV can be referred as expected monetary value (EMV). EMV can be interpreted as the average value of one alternative after many repetitions of choosing that alternative. So for each chance node, all possible outcomes and the consequences with monetary values can be replaced by one EMV, which is the number in red at each circle in Fig. 2. Then at the decision node, the branch with the highest EMV is the alternative to be chosen, which is the number in red at each square in Fig. 2.

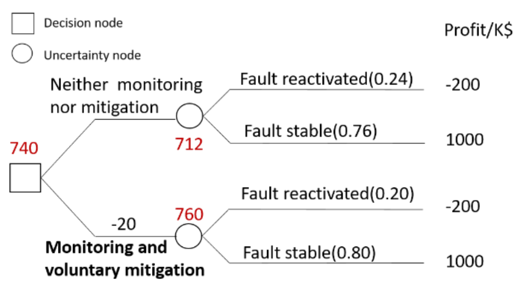

Figure 2. Decision tree of monitoring and voluntary mitigation. Numbers in red are the EMV's. Words in bold is the alternative with the highest EMV.

To determine the probability of reactivating the fault in Eq. 1 , fault slip potential (FSP) is used. FSP is a statistical method of predicting the likelihood of fault reactivation based on the Mohr-Coulomb Failure Criterion (Walsh and Zoback, 2016). According to Coulomb Failure theory, for a fault plane to fail, the normal and shear stress should meet the following:

$$S_s \geq \mu(S_n - P_p) + S_0, \qquad \text{(Eq.2)}$$

where S_s and S_n are the shear and normal stress of the fault plane, P_p is the pore pressure, μ is the coefficient of friction and S_0 is the cohesion. When shear and normal stresses of the plane match the relation in Eq. 2, the fault is reactivated. This analysis is simple if all the Mohr-Coulomb parameters are known exactly, which is rarely the case. Hence, the uncertainties in the parameters should be considered as well. By knowing the distributions of all the parameters, for each Monte Carlo simulation, random values are generated based on the distributions of all parameters. Then the occurrence of fault reactivation is computed using Eq. 2 for this specific realization of parameters. The FSP is then defined as the percentage of failures given all realizations. Better constraints on the Mohr-Coulomb parameters improve the accuracy of the FSP analysis. Once the injection begins, the change in the pore pressure is considered as well. For convenience we will assume that the regional elastic stresses are constant. For simplicity, we use

$$\Delta P_p = \alpha Q\sqrt{t}, \qquad \text{(Eq.3)}$$

where ΔP_p is the change in the pore pressure, α is a calibration factor that ensures ΔP_p is comparable with the original pore pressure, Q is the injection rate, t is the injection duration. This equation is sufficient to illustrate our methodology. It can be replaced by other approaches for computing the *in situ* pore pressure locally as needed.

Results

In order to illustrate how to apply the decision analysis to the decision-making process, here a simplified hydraulic fracturing operation is presented as an example. In this example, decision makers only need to consider three decisions for this operation:

1. Geological investigation with extra data before the operation. This decision can provide with more constrained data sets.
2. Hydraulic fracturing operation. The operation is profitable if accomplished successfully, but it also increases the probability of triggering an earthquake from the injection.
3. Monitoring and voluntary mitigation during the operation. This decision is costly but able to reduce the probability of triggering unwanted earthquakes.

The uncertain event is defined as whether the fault will be reactivated or stable once the operation starts. We assume that if the fault is reactivated, unexpected seismic events will occur and bring economic loss. The information from the risk assessment is also included and treated as uncertain events. The only consequence studied is the profit of the operation.

We will assume there is only one fault in the operation area. If the decision makers decide to conduct a hydraulic fracturing operation, once the treatment starts, the pore pressure change is calculated based on Eq. 3. For monitoring and voluntary mitigation, a pore-pressure threshold is set before the monitoring and once the threshold is reached, the injection rate is reduced as a voluntary mitigation method. In this example, the geological investigation with extra data leads to more constrained Mohr-Coulomb parameters, as shown in Table no. 1. During the treatment, the injection rate is 3000m^3/day, the total injection time is 15 days, and the threshold is reached after 10 days of injection when the injection rate changes to 2000m^3/day in case of voluntary mitigation.

Table 1. Mohr-Coulomb parameters for calculating FSP.

Parameter	Value	Standard deviation with original data	Standard deviation with extra data	Parameter	Value	Standard deviation with original data	Standard deviation with extra data
S_{Hmax}	90MPa	0.3	0.1	S_0	10MPa	0.25	0.05
S_{hmin}	30MPa	0.3	0.1	$n(1)$	0.0971	0.25	0.1
S_V	50Mpa	0.3	0.05	$n(2)$	0.8235	0.25	0.1
$\theta*$	50°	0.35	0.2	$n(3)$	0.5590	0.1	0.05
P_p	8MPa	0.25	0.1	$\Delta P_{p\,NM}$	12.14MPa	0	0
μ	0.6	0.3	0.15	$\Delta P_{p\,M}$	10.34MPa	0	0

Notes:θ is the angle between S_{Hmax} and the north; $n(1)$,$n(2)$ and $n(3)$ are the fault plane normals to the east, north and vertical directions respectively; $\Delta P_{p\,NM}$ and $\Delta P_{p\,M}$ are the change in pore pressure without mitigation and with mitigation.

The decision tree is then constructed by adding the FSP's and corresponding monetary values, as shown in Fig 3. FSP's are calculated based on the distributions of Mohr-Coulomb parametes listed in Table no. 1. For determining the highest EMV, the EMV's from the end of the decision tree should be calculated based on Eq. 1. The computations for the decision tree are best understood by reading from right (end result) to left (start). For example, at the top right of the decision tree, EMV's of neither doing monitoring nor mitigation and doing monitoring and voluntary mitigation are 609K$ and 648K$ respectively. Because there is an additional expense on doing the monitoring and voluntary mitigation, the EMV of monitoring and mitigation is 628K$. Then we choose the highest EMV as the EMV of that decision, which is 628K$. So by choosing the highest EMV at each decision node, the alternatives with highest EMV's are 'investigation with extra data', 'hydraulic fracturing', and 'monitoring and voluntary mitigation'. The results of the decision tree analysis in Fig. 3 suggest that for this operation, the more costly alternatives can lead to the higher EMV's. This is because by choosing these alternatives, the probability of reactivating the fault is decreased. In this example, FSP is employed to obtain the probability. If the decision makers choose to use another approach to calculate the probabilities, the results could be different.

On the other hand, the possible outcomes and corresponding values can be set as certain ranges instead of exact numbers. For instance, the final outcomes (production) and influence factors of hydraulic fracturing operations can be can be considered. All options are assigned corresponding monetary values, leading to a range of predictions and expected outcomes. This approach creates a more complex yet more complete decision analysis. It is important to emphasize that in this case only profit is considered. Decision makers routinely take additional influences into consideration such as the environmental, political and/or societal impact of their decisions. Yet the values of the latter factors are more difficult to assess statistically. In the future, it is worth considering decision analysis in complex decision making processes such as hydraulic fracturing operations.

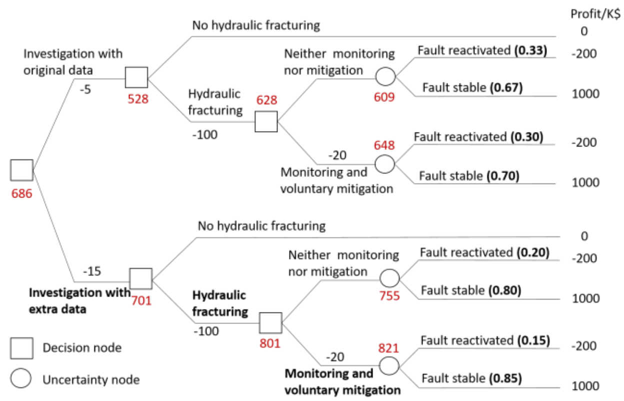

Figure 3. Decision tree of the example. Numbers in bold are the possibilities based on the FSP calculation. Numbers in red are the EMV's of the uncertain events or the decision. Words in bold are the alternatives with highest EMV's.

Acknowledgements

The authors would like to thank the sponsors of the Microseismic Industry Consortium for financial support.

References

Bratvold, R. B., Bickel, J. E., Lohne, H. P., et al. (2009). Value of information in the oil and gas industry: past, present,and future. *SPE Reservoir Evaluation & Engineering*, 12(04):630–638.

Clemen, R. T. (1996). *Making hard decisions: an introduction to decision analysis*. Brooks/Cole, 2 edition.

Walsh, F. R. and Zoback, M. D. (2016). Probabilistic assessment of potential fault slip related to injection-induced earthquakes: Application to north-central Oklahoma, USA. *Geology*, 44(12):991–994.