Shale Analytics

Making Production and Operational Decisions Based on Facts

Re-Frac Candidate Selection & Design

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SUMMARY

What is Shale Analytics and What Can it Deliver?

Definition:
Shale Analytics the application of Big Data Analytics (data science, including data mining, artificial intelligence, machine learning and pattern recognition) in shale.

Shale Analytics uses hard data (facts) for its analysis,
Shale Analytics is a series of solutions, not a data analysis/statistical tool to be used to develop solutions.

SUMMARY

What is Shale Analytics and **What Can it Deliver?**

Deliverables

Data Mining:

Discovering patterns and trends in historical data to identify:

- Best Completion Practices,
- Most impactful reservoir and completion parameters,
- Mapping the Natural Fracture Network Distribution.

Deliverables

Predictive Analytics:

- Data-Driven Predictive Model,
- Uncertainty Quantification of Well Productivity,
- Remaining Reserves & Well placement,
- Service Company Ranking,
- Optimum Completion Design,
- Re-Frac Candidate Selection.

Shale Analytics

"Without Data, You Are Just another Person with an Opinion"

W.E. Deming (1900-1993)

Shale Analytics has been used to analyze more than 3000 wells in:
Marcellus, Utica, Bakken, Niobrara, and Eagle Ford

Average number of parameters analyzed in each of the studies:
175 Parameters

Historical Perspective

- Publications about re-fracturing treatments (re-stimulation) prior to 1990s are sparse.

- The first published work on re-frac dates back to 1960 - followed by another publication in 1973.

- Application of data-driven analytics to the subject of hydraulic fracturing in general, and re-frac, originated at West Virginia University in mid-1990s and continued into mid-2000s.

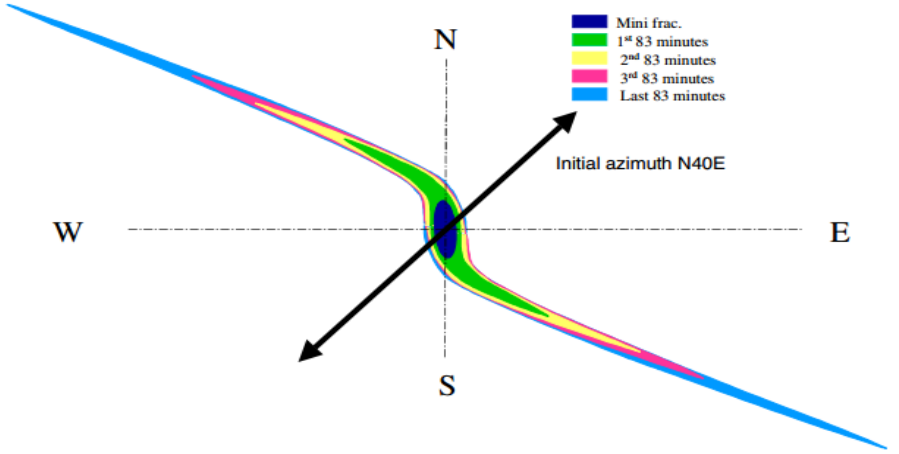
HISTORICAL PERSPECTIVE

- Gas Research Institute started a new Re-Frac Candidate Selection project in 1998 that breathed new life into the re-frac technology.

- Results of this project were extensively published and inspired many new activities in this area.

INTRODUCTION

- Re-Frac is inevitable.
- Why?
  - Large number of hydraulic fracture stages do not contribute to production.
  - When stages contribute to production, the depletion modifies the stresses that controlled the original orientation of the hydraulic fractures.



Two Important Questions

- How would you screen large number of wells in order to identify the best re-frac candidates?
  - It should be obvious that not all wells would respond in the same manner to a re-frac?

    Answer: Shale Analytics

- Once re-frac candidate identified (and ranked), how would you designs a re-frac treatment?

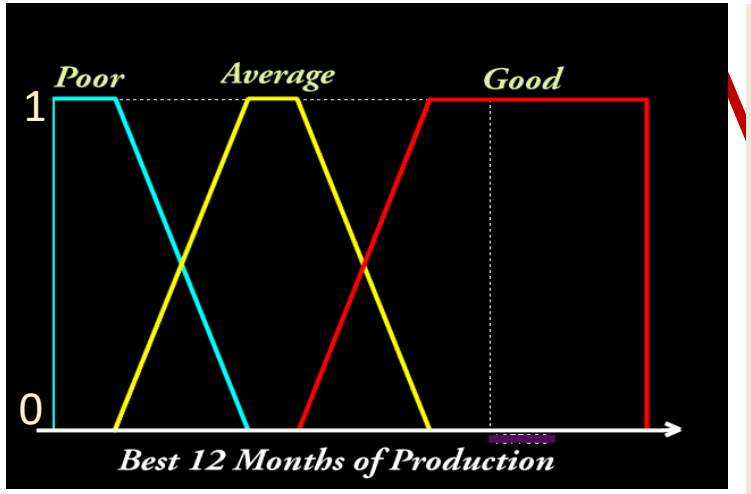
  Answer: Lessons learned from the previous frac jobs in the same field

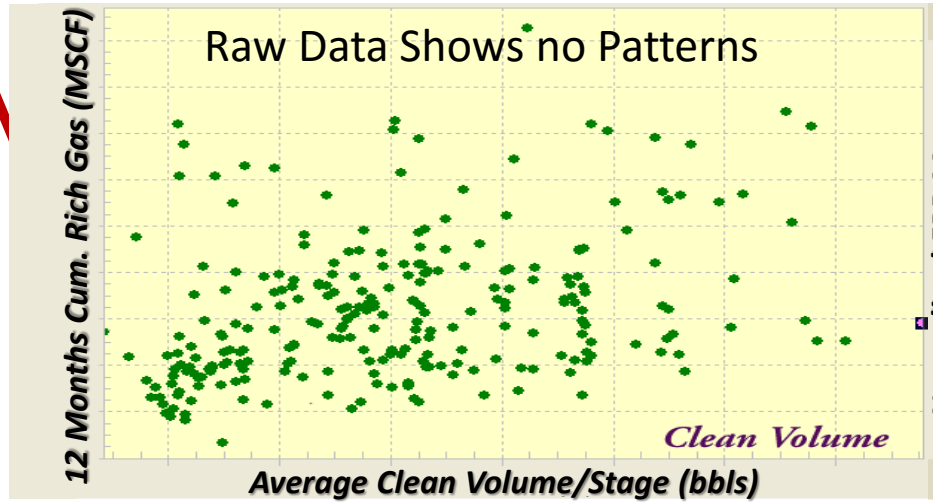
RE-FRAC CANDIDATE SELECTION & DESIGN

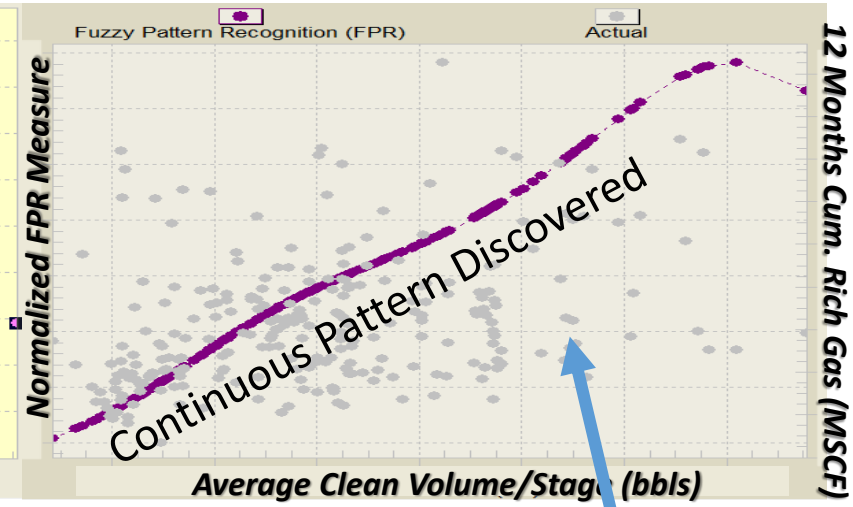
- The process of Re-Frac Candidate Selection and Design includes the following steps:

  - ***Data Driven Predictive Modeling (Predictive Analytics)***
  - ***Look-Back Analysis***
  - ***Re-Frac Candidate Identification and Ranking***
  - ***Re-Frac Design***

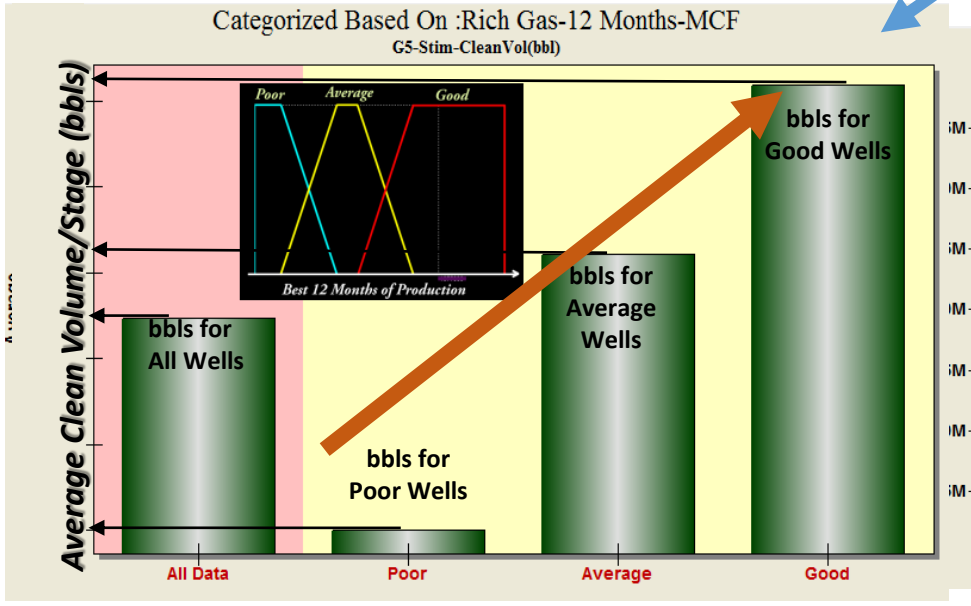
Artificial Intelligence Technology called "Fuzzy Set Theory" is used to Classify Wells based on productivity

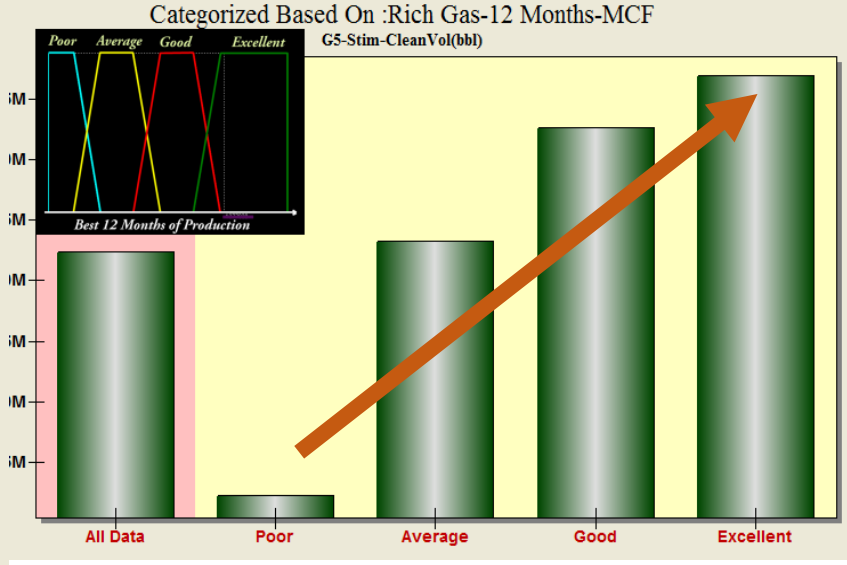


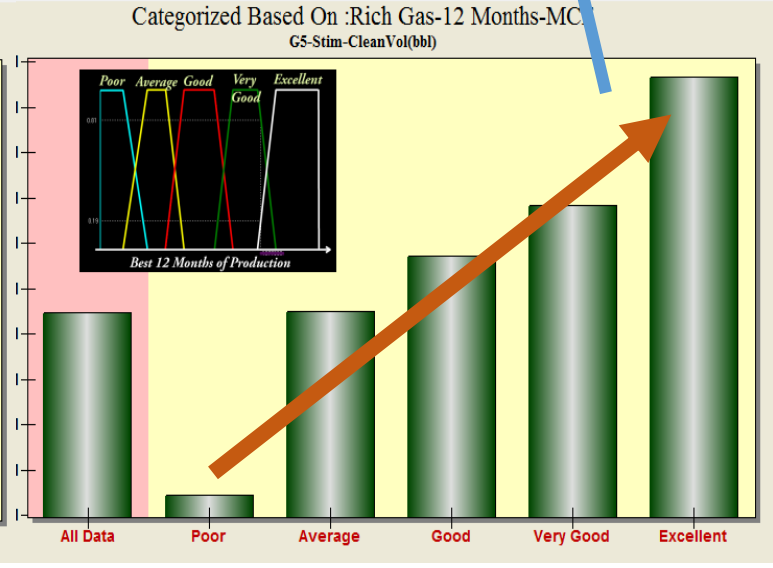




Better Wells have been fracked with higher amounts of Clean Volume per Stage



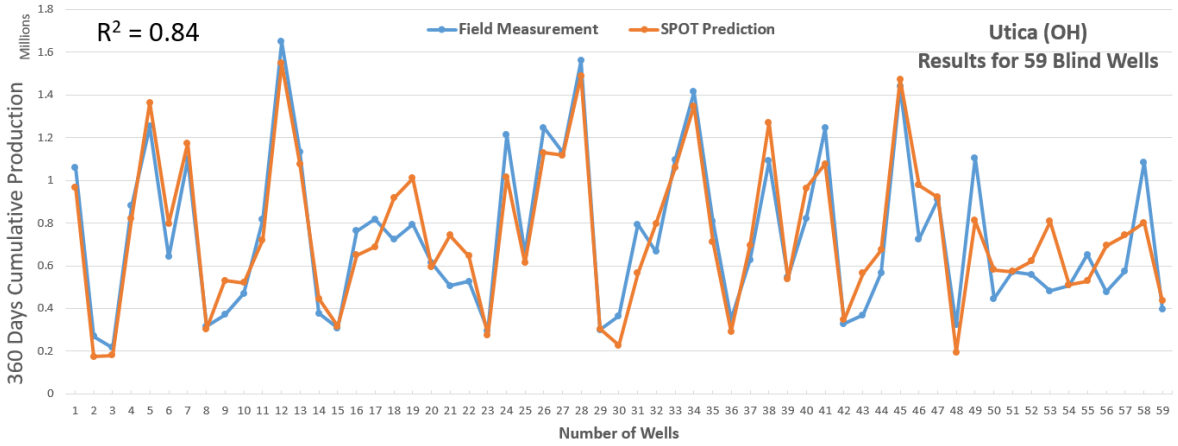


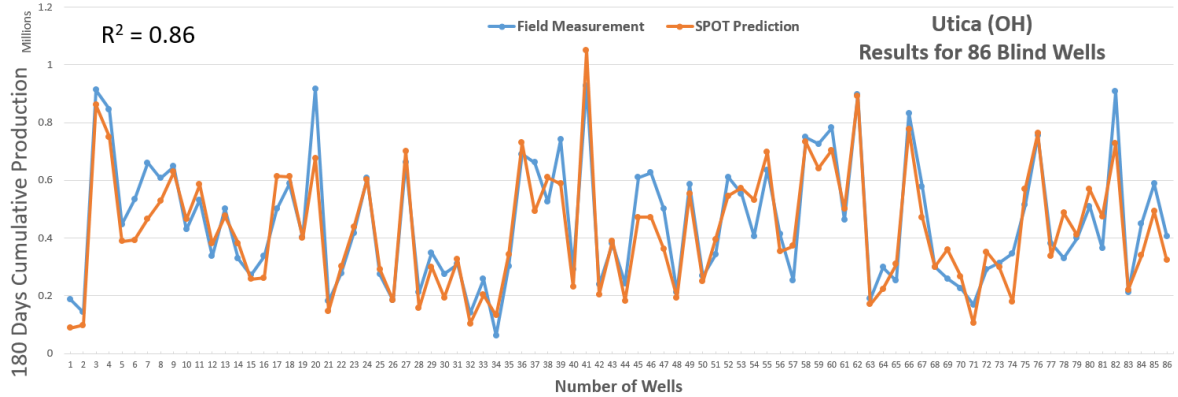


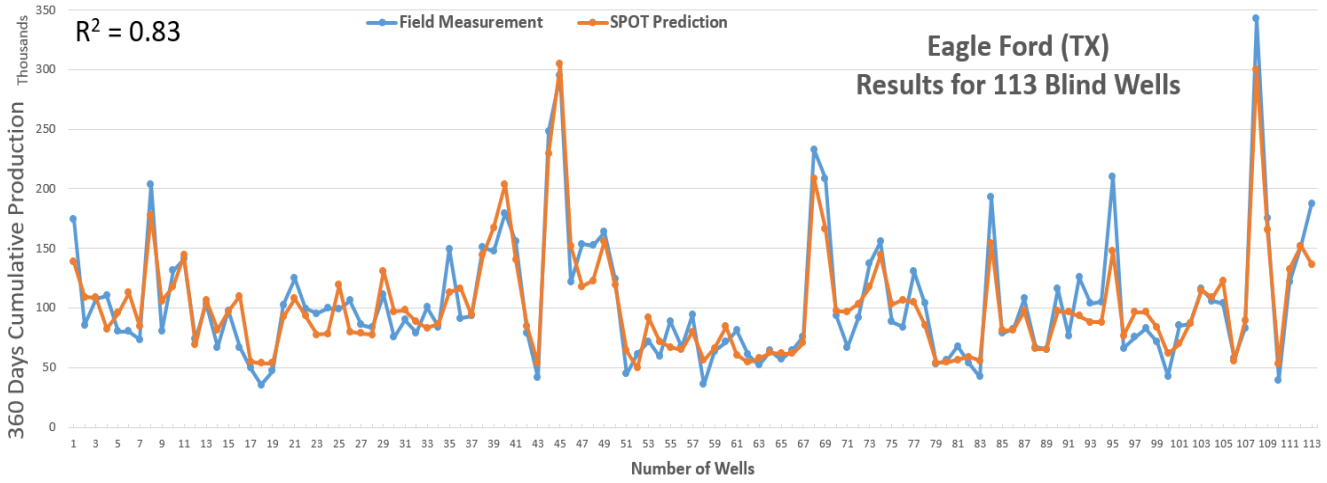
Training Data-Driven Models using Machine Learning to Identify Combined Relationship between Well Productivity and :

- Well Construction Parameters (Azimuth, Inclination, Up/Down-Dip, TVD, etc.)
- Reservoir Parameters (Porosity, S_{WI}, Thickness, TOC, etc.)
- Completion Parameters (Lat. Length, No. of Stages, Stage Length, Clustes/Stg, etc.)
- Frac Parameters (Fluid Type & Amount, Prop. Type & Amount, Inj. Rate and Pressure, etc.)
- Production Parameters (Choke Size, Days on, etc.)

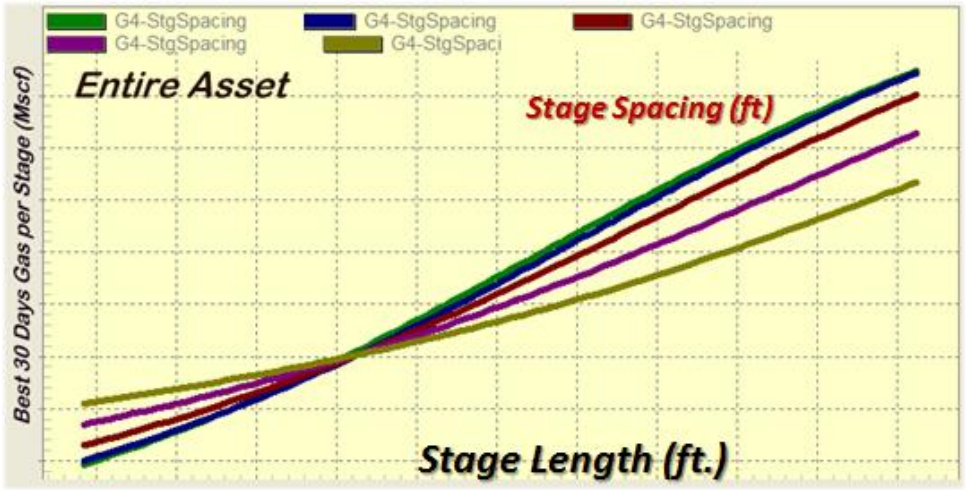
Validate The Model's Predictive Capabilities with BLIND WELLS

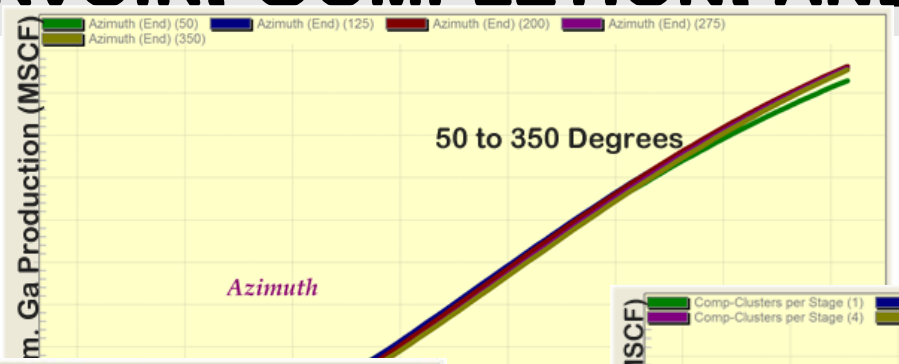




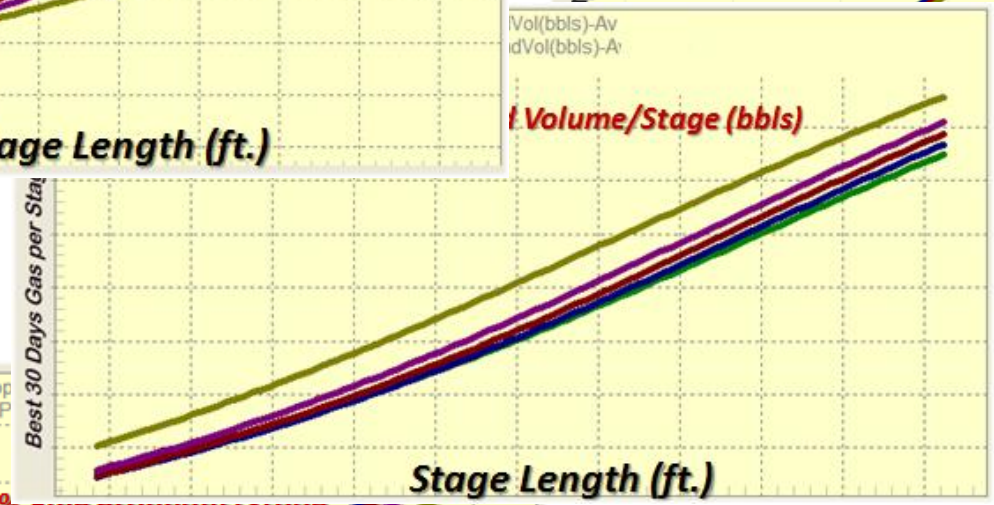


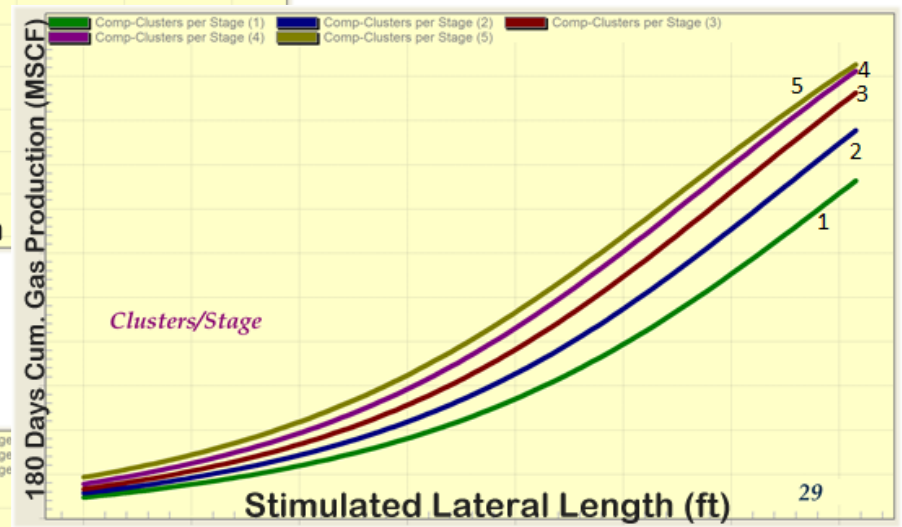
The Predictive Model Generates Well Productivity as a Function of Well, Reservoir. Completion. and Choke Data.

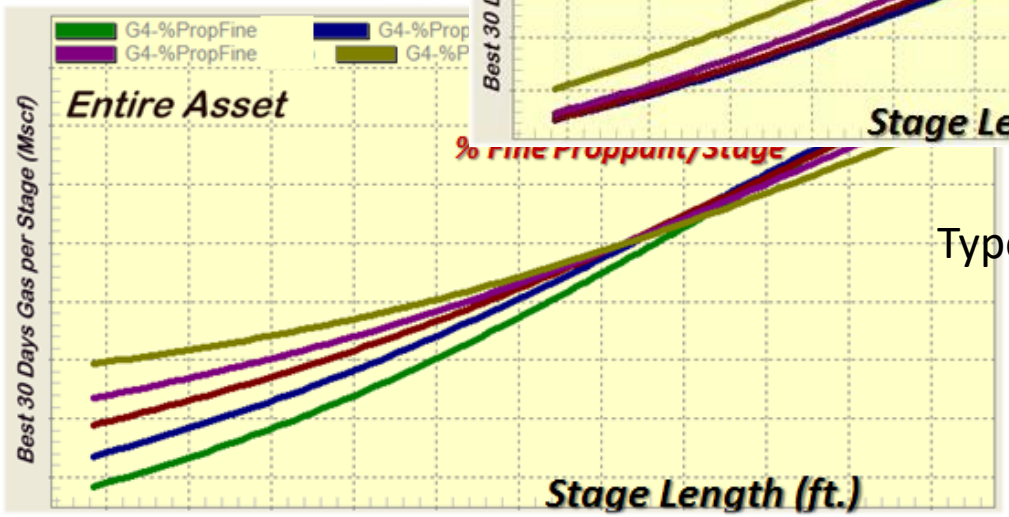




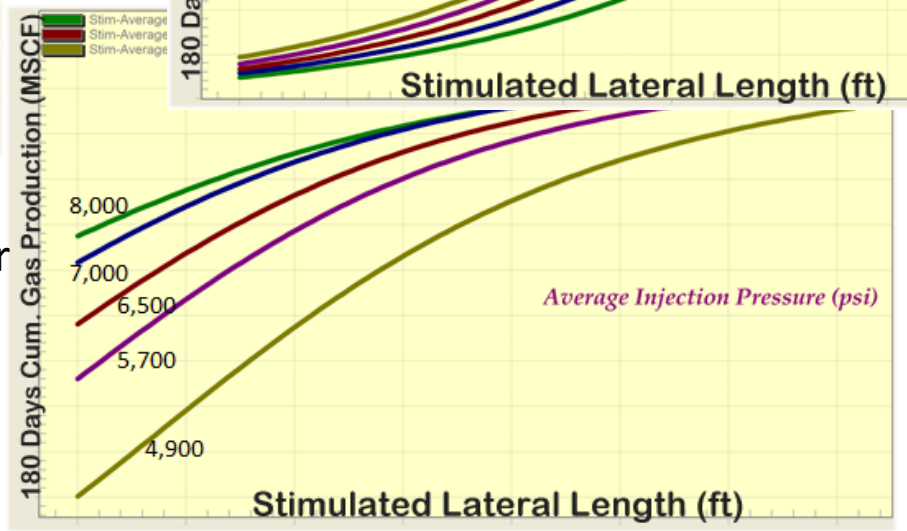
Type Curves Developed for Marcellus Shale (Southwestern PA)







Type Curves Developed for Marcellus Shale (Northeastern PA)



Look-Back Analysis

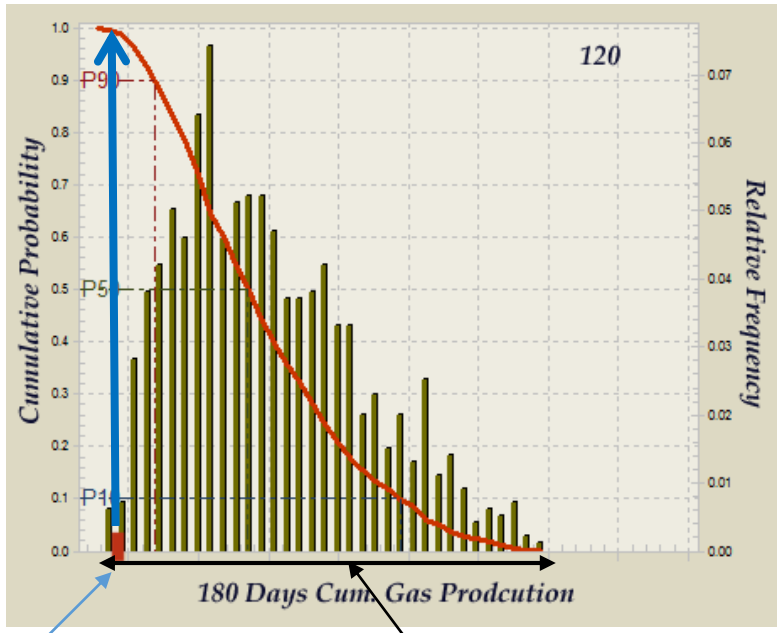
- ***Reservoir Characteristics for each Well is Kept Constant at Actual Measured Values.***
- ***Monte Carlo Simulation is Performed for Completion (design) Practices.***

Completion Parameters Analyzed:

- ***Average Injection Pressure – psi,***
- ***Average Injection Rate – bbl./min,***
- ***Slurry Volume – bbls,***
- ***Proppant Concentration – lbs./gal,***
- ***Proppant Amount – lbs.,***
- ***Total Number of Stages.***

LOOK-BACK ANALYSIS

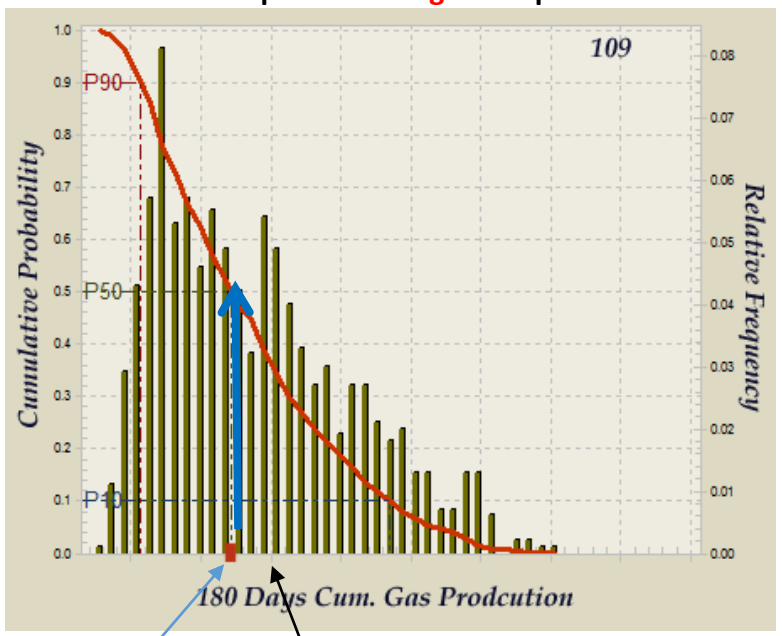
This well was completed Poorly with production at P95



Actual Well Production

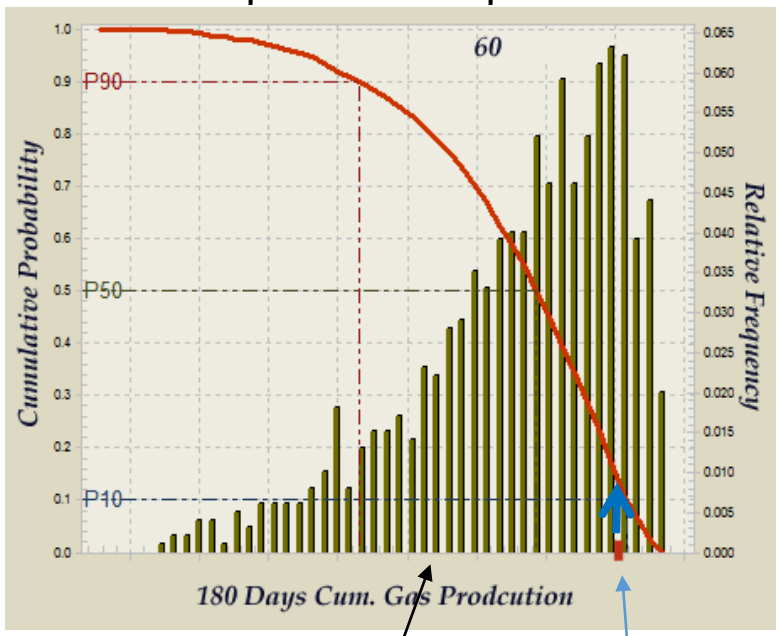
The possible Production range expected from this well

This well was completed Average with production at P50



Actual Well Production

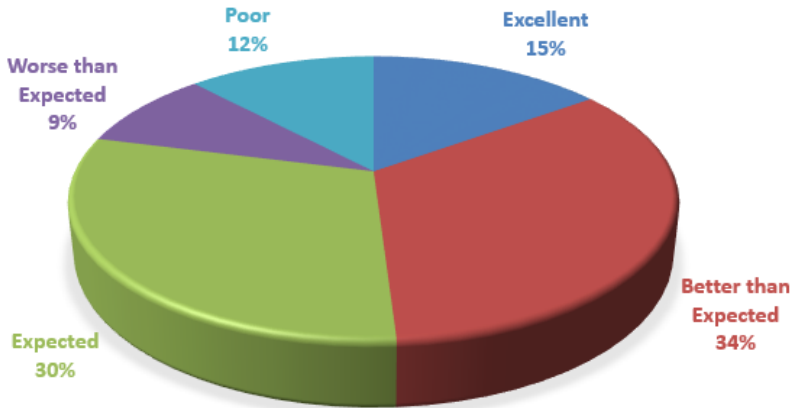
This well was completed Good with production at P10



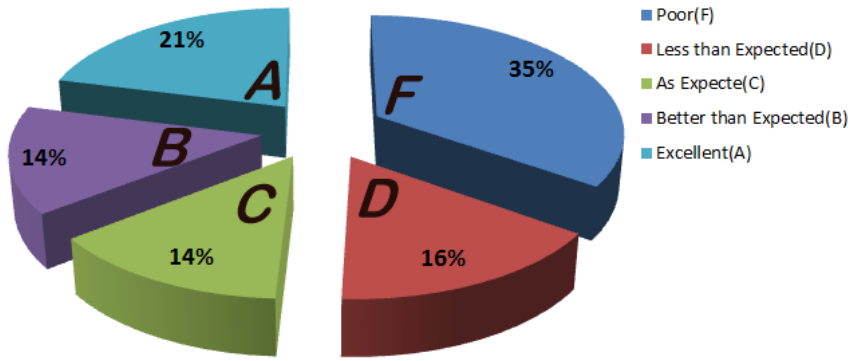
Actual Well Production

LOOK-BACK ANALYSIS

THE EFFECTIVENESS OF THE PERFORMED FRAC JOBS CAN NOW BE EVALUATED:



Historical Frac Job Quality

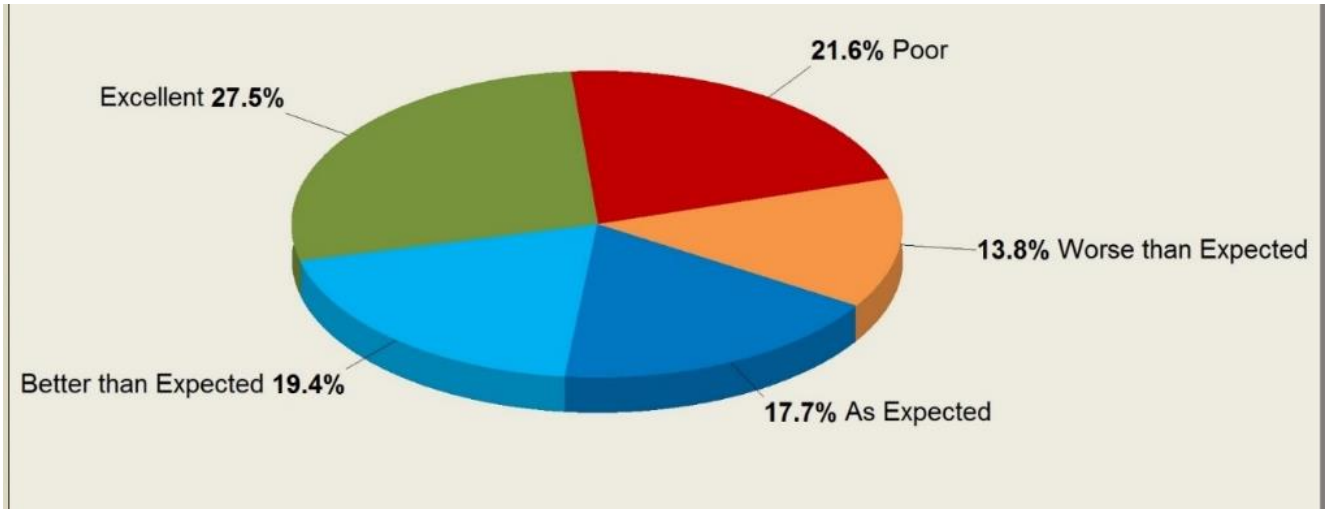


Frac Job Quality in Marcellus Shale – Southwest PA	
Better Than Expected/Excellent	49%
As Expected	30%
Worse Than Expected/Poor	21%

Frac Job Quality in Marcellus Shale – Northeast PA	
Better Than Expected/Excellent	35%
As Expected	14%
Worse Than Expected/Poor	51%

LOOK-BACK ANALYSIS

THE EFFECTIVENESS OF PREVIOUS FRAC JOBS CAN NOW BE EVALUATED:

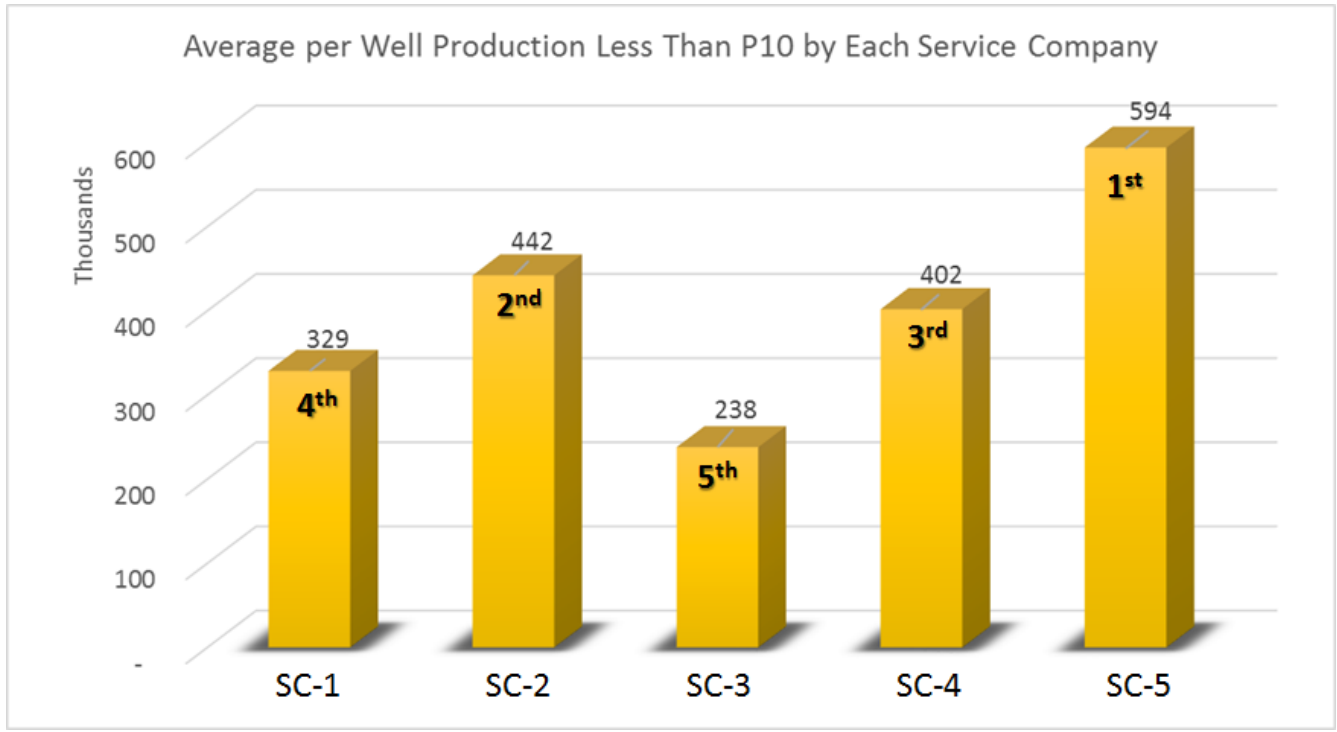


Frac Job Quality in Utica Shale – Ohio	
Better Than Expected/Excellent	47%
As Expected	18%
Worse Than Expected/Poor	35%

LOOK-BACK ANALYSIS

EVALUATE SERVICE COMPANY'S PERFORMANCE

SINCE THE IMPACT OF RESERVOIR CHARACTERIZATION HAS BEEN ISOLATED, WE ARE COMPARING "APPLES" WITH "APPLES"



RE-FRAC CANDIDATE SELECTION

- Determine P10, P50, and P90 values for each well using the Look-Back Analysis.
- Rank wells as re-frac candidate based on their un-realized potentials.
- Perform engineering evaluation on each candidate.

Index	ISI Coded WellName	MSCF			Actual Well Productivity	Output Probability
		P10	P50	P90		
1	Well #0000001	10,008	5,327	2,839	4,816	58
2	Well #0000002	17,320	13,612	9,523	15,582	27
3	Well #0000003	17,535	14,511	10,876	11,520	85
4	Well #0000004	13,699	10,329	7,256	7,685	85
5	Well #0000005	15,568	12,223	9,199	13,629	29
7	Well #0000007	17,485	14,182	9,306	17,859	6
8	Well #0000008	18,025	15,705	12,136	13,117	82
9	Well #0000009	16,478	13,193	9,253	11,004	75
10	Well #0000010	12,675	8,872	5,461	12,027	14
11	Well #0000011	15,233	11,822	8,212	9,459	79
14	Well #0000014	8,855	6,327	4,341	5,786	62
15	Well #0000015	13,339	10,146	6,999	7,999	80
16	Well #0000016	12,672	9,197	6,128	10,580	32
17	Well #0000017	11,043	8,522	6,344	10,660	14
18	Well #0000018	12,685	9,578	7,161	6,772	94
19	Well #0000019	12,381	9,556	7,154	8,880	63
20	Well #0000020	11,423	8,637	6,480	6,437	90

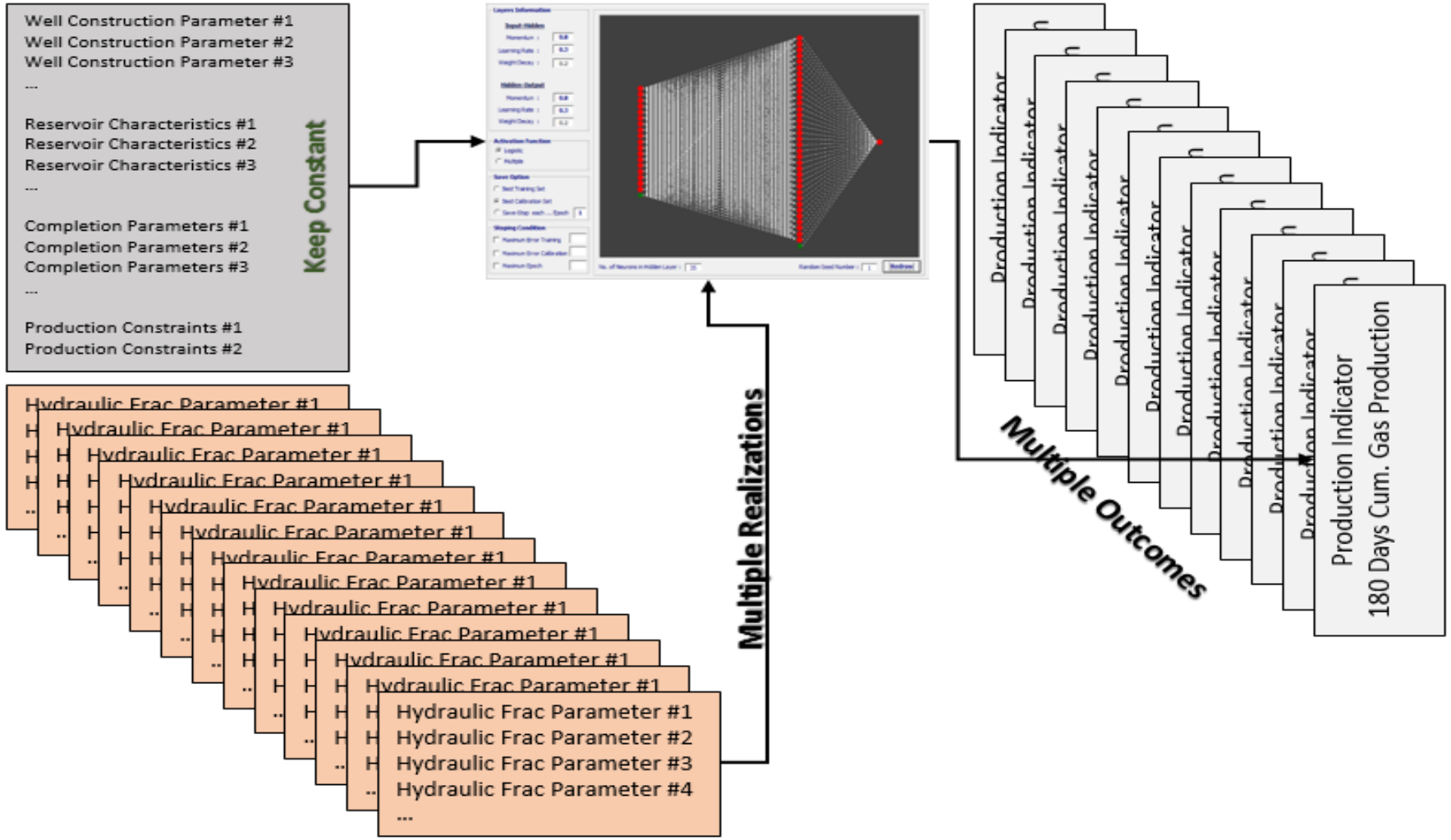
RE-FRAC DESIGN

- The objective of the design of frac job is to have a treatment that is as close to optimum as possible, using lessons learned from previous activities from the same field.

- The quality of the frac job is judged based on the hydrocarbon production that it triggers and sustains.

- In “Shale Analytics”, we learn from the historical data in order to design a new frac job.

RE-FRAC DESIGN



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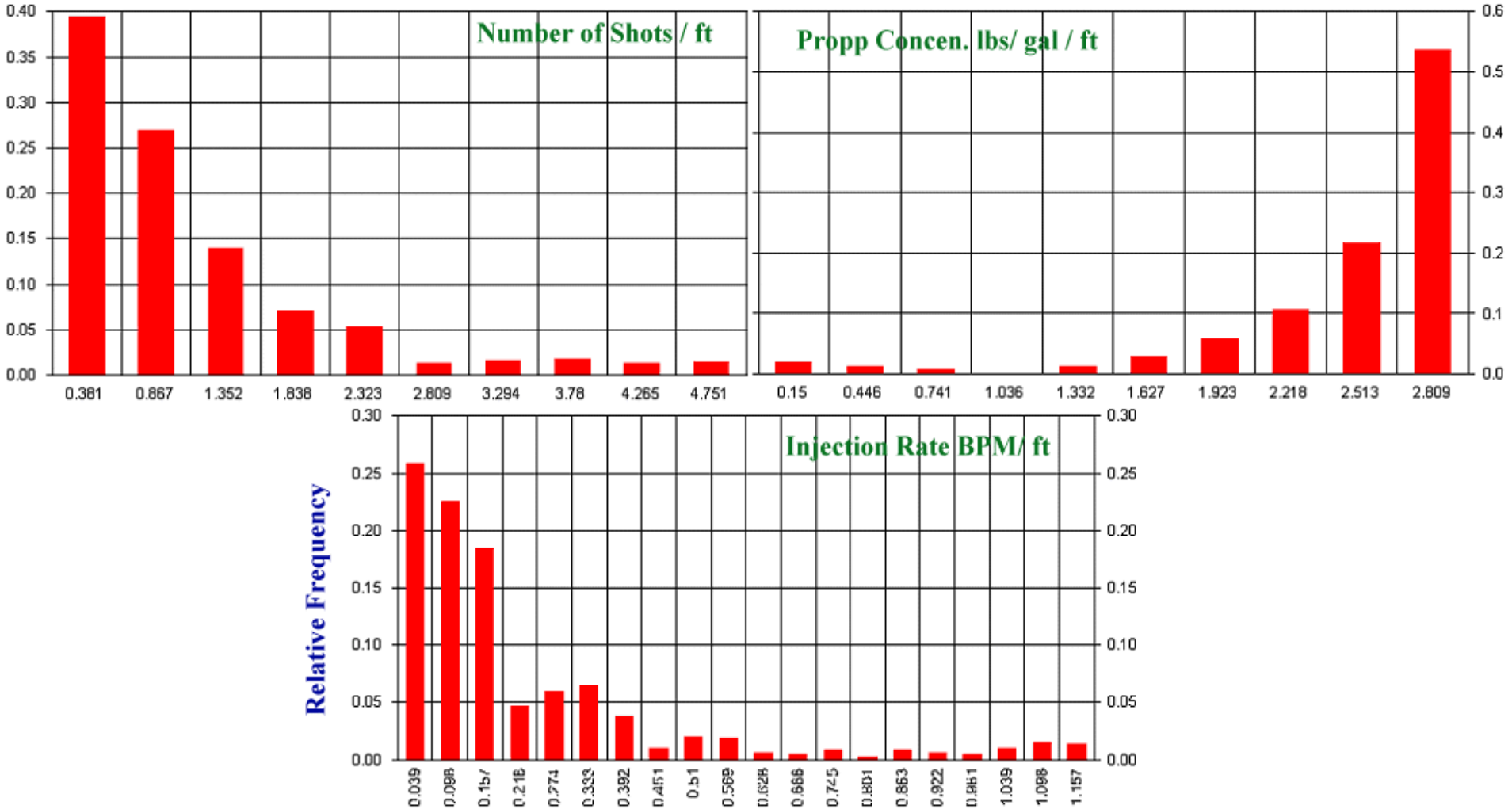


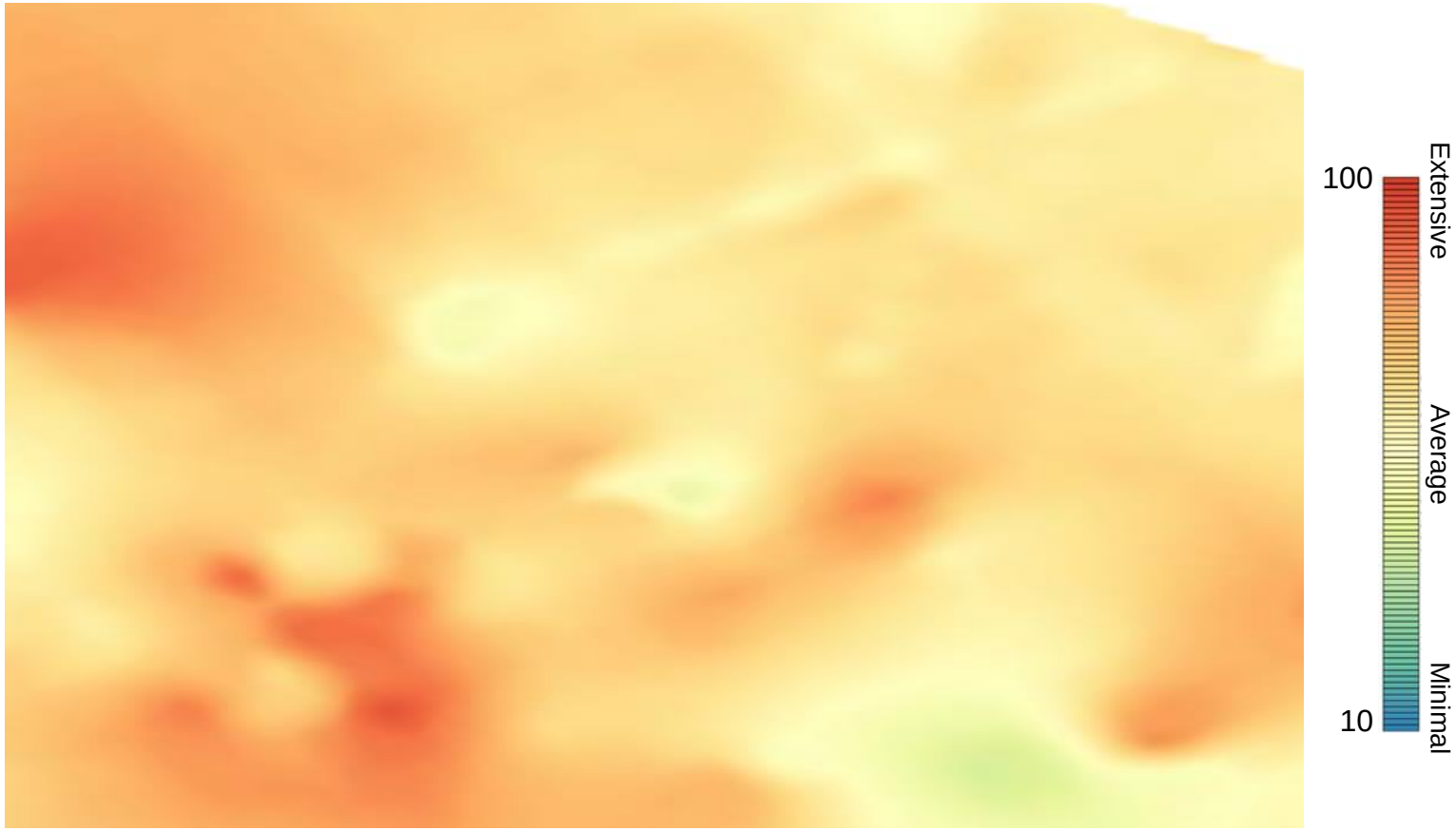
MAPPING THE NATURAL FRACTURE NETWORK

Well Name	WABG-1H	RRPS-3H
Primary Fluid	Gas	Gas
Well Spacing	600	700
Vertical Separation	200	200
Hydrocarbon Pore Volume ($MMft^3$)	9.5	10.2
Perf. Lateral Length (ft.)	4,900	4,920
Job Size – Proppant (lbs./ft.)	950	1,500
Productivity – 180 Days (BOE/psi)	14.0	9.5
NFN Density (dimensionless)	57.3	19.3

MAPPING THE NATURAL FRACTURE NETWORK

Well Name	DB-5H	MS-2H
Primary Fluid	Gas	Gas
Well Spacing	520	520
Vertical Separation	200	200
Hydrocarbon Pore Volume ($MMft^3$)	70.5	65.2
Perf. Lateral Length (ft.)	5,960	5,450
Job Size – Proppant (lbs./ft.)	799	801
Productivity – 180 Days (BOE/psi)	18.9	6.9
NFN Density (dimensionless)	97.3	35.2

MAPPING THE NATURAL FRACTURE NETWORK



CONCLUSIONS

- Without Data, You are just another person with an opinion.
- It is demonstrated that using FACTS to Analyze, Model and Optimize production from Shale is a viable solution.
- Lessons from previous practices in the same asset is the best way to:
  - Identifying re-frac candidates,
  - Design new re-frac jobs,
  - Map Natural Fracture Network