Identification of Successful Practices in Hydraulic Fracturing Using Intelligent Data Mining Tools; Application to the Codell Formation in the DJ –Basin

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OUTLINE

- OBJECTIVE
- INTRODUCTION
- METHODOLOGY
- RESULTS & DISCUSSION
- CONCLUSIONS

OBJECTIVE

- Develop a methodology to identify the successful practices in oil and gas related operations.
- Apply the methodology to a stimulation/restimulation database in DJ Basin.

INTRODUCTION

- Patina Oil & Gas has over 3,400 producing wells in the DJ Basin, and has restimulated over 230 Niobrara/Codell completions.
- It is estimated that the results achieved by Patina, in terms of incremental recoveries, are up to 60% better than other operators in the region.

INTRODUCTION

- This study is probably one of the most comprehensive analyses of its kind ever to be performed on a set of wells in the United States.
- The methodology can be applied to any operation such as reservoir characterization, field development strategies, reservoir management, etc.

METHODOLOGY

- The process of “Successful Practices Identification” being introduced here, incorporates state-of-the-art data mining, knowledge discovery and data-knowledge fusion techniques.
- The process includes five steps that must be performed in sequence.
- Result of each step is a key component of the next step.

METHODOLOGY

- The process includes five steps.
  - Step one: Data Quality Control
  - Step two: Fuzzy Combinatorial Analysis
  - Step three: Intelligent Production Data Analysis
  - Step four: Neural Model Building
  - Step five: Successful Practices Analysis
    - Stage one: Single well analysis
    - Stage two: Groups of wells analysis
    - Stage three: Full field analysis

METHODOLOGY

- **Step one: Data Quality Control**
  - Identification of outliers in the dataset
  - Identification of missing data elements in the dataset
  - Examination of dataset size and determining if the dataset is large enough for the analysis.
  - Remediation of the identified problems using intelligent systems approach.
  - Identification and clean up of the erroneous records in the dataset

METHODOLOGY

- **Step two: Fuzzy Combinatorial Analysis**
  - Examination of each of the features in the dataset in order to identify their influence on the process outcome.
  - Each feature's influence is examined on the process outcome both individually and in combination with other features.

METHODOLOGY

- **Step three: Intelligent Production Data Analysis - IPDA**
  - The word “intelligent” refers to the use of intelligent systems techniques in the production data analysis process.
  - Unlike the statistical analysis (static in nature), IPDA is a dynamic analysis aimed at capturing the depletion and pressure decline in the field as new wells are drilled and put into production at different rates.

METHODOLOGY

- **Step three: Intelligent Production Data Analysis - IPDA**
  - The dynamic nature of this analysis (simultaneous analysis of the data in four dimensions x, y, z, and t) allows the user to identify the sweet spots as well as bad (unproductive) spots in a field as a function of time.

METHODOLOGY

- **Step four: Neural Model Building**
  - Building a predictive neural model based on the available data.
  - This is a familiar step in today's intelligent systems analysis.
  - Many applications in the oil & gas industry use neural networks in their analysis.

METHODOLOGY

- **Step five: Successful Practices Analysis**
  - The three stage successful practices analysis combines the following components:
    - Neural network model
    - Monte Carlo simulation
    - Genetic algorithms search and optimization, &
    - Fuzzy set theory

    to identify the successful practices on the basis of
    - a single well
    - groups of wells, and
    - full field.

METHODOLOGY

- **Step five: Successful Practices Analysis** (continue)
  - **SINGEL WELL ANALYSIS**
    - Each well is thoroughly analyzed using the neural model with a series of 2-D and 3-D sensitivity analysis graphs in order to identify the well's potential behavior at different operational conditions.
    - This is to identify the distance of actual practices from the successful practices as a guide for future activities such as stimulation, restimulation, and workover.
    - A Monte Carlo Simulation is also performed on each well to identify potential highest outcome from a particular well, if the best practices were performed.

METHODOLOGY

- **Step five: Successful Practices Analysis (continue)**
  - **GROUPS OF WELLS ANALYSIS**
    - Grouping wells based on:
      1. Geological characteristics of the reservoir.
      2. Clustering based on a variety of attributes and parameters:
         A. Hard K-Mean Clustering
         B. Fuzzy C-Mean Clustering

METHODOLOGY

- **Step five: Successful Practices Analysis** (continue)
  - **GROUPS OF WELLS ANALYSIS**
    - Analysis is performed on a group of wells based on a single parameter at a time and then on several parameters simultaneously in the form of combinatorial analysis.
    - General trend in each case is identified for any particular parameter and reported as the most and the least successful practices.

METHODOLOGY

- **Step five: Successful Practices Analysis** (continue)
  - **FULL FIELD ANALYSIS**
    - Very much like the group of wells analysis, only here all the wells in the field are involved.
    - Single parameter trend analysis
    - Combinatorial trend analysis
  - A note of caution: As we move from single well analysis to groups of wells and to all the wells in the field, implicitly, the law of averages is more and more enforced.

RESULTS & DISCUSSIONS

- **Step one: Data Quality Control**
  - The original database for stimulation of Codell wells in the DJ basin needed considerable “quality control” efforts in order to remove erroneous records including records that did not belong to that database and had to be removed.
  - This process reduced the number of wells in the dataset from 177 to about 150 wells.

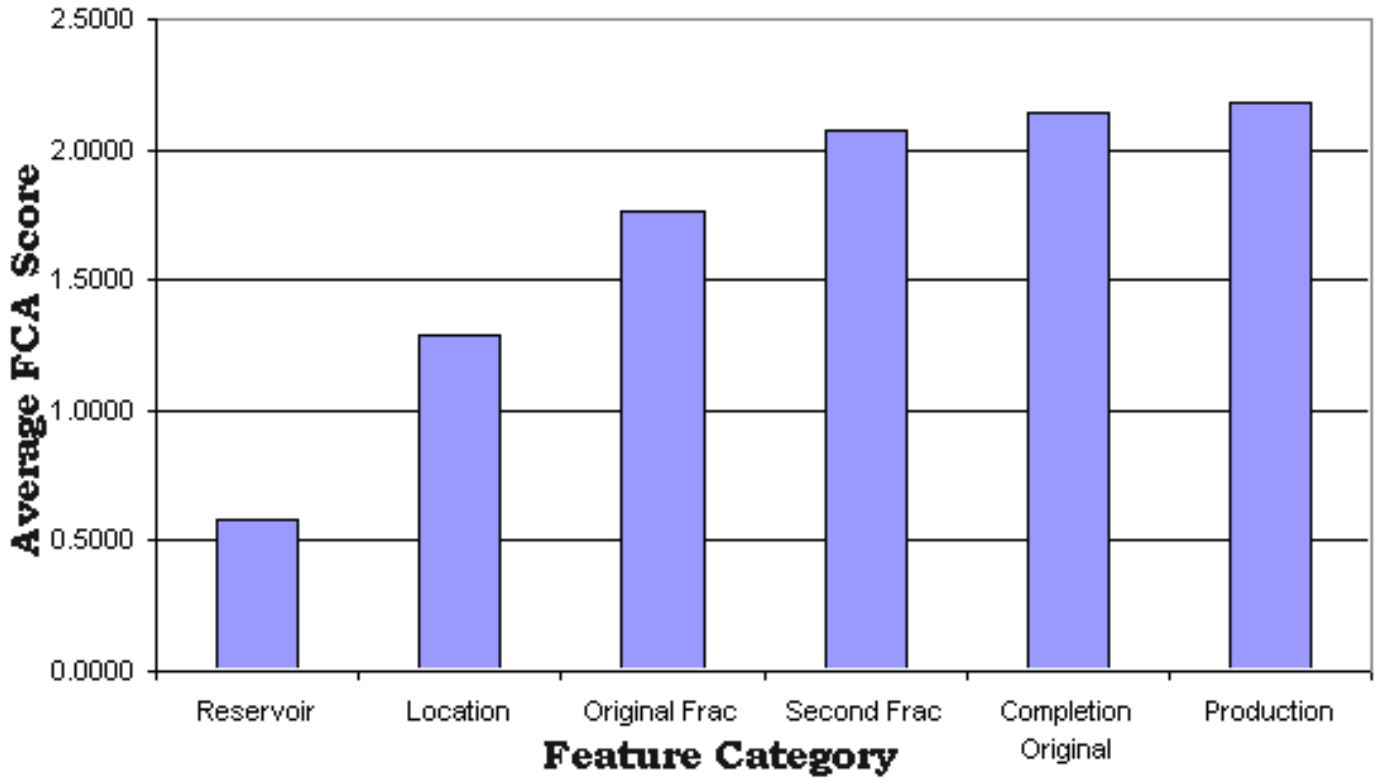
RESULTS & DISCUSSIONS

- **Step two: Fuzzy Combinatorial Analysis**
  - **The analysis was performed for the combination of up to five features.**

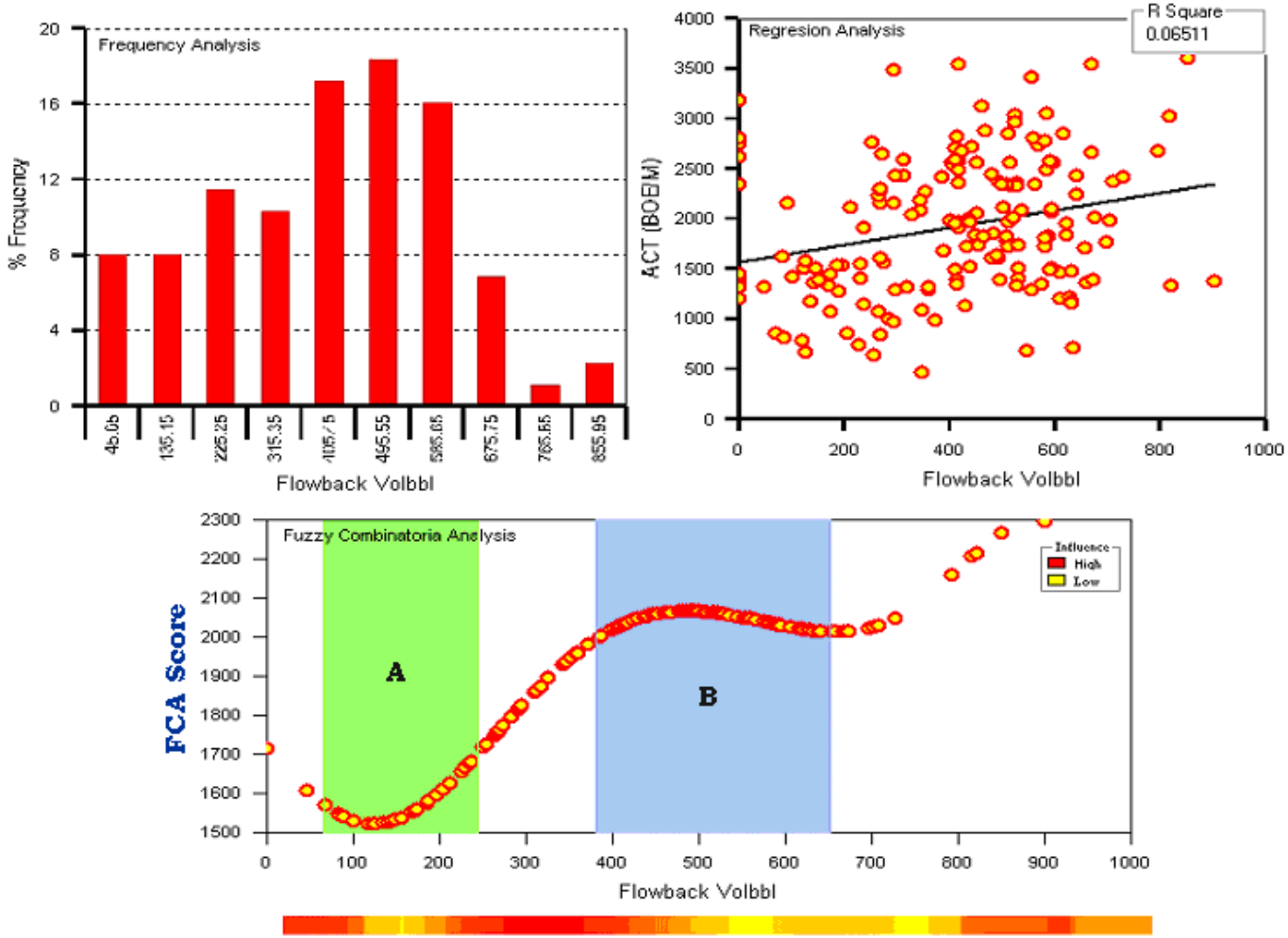
Rank	Feature	FCA Value	Rank	Feature	FCA Value
1	Flowback Volbbl	0	22	Frac Type	2.2848
2	CO -Phi-H	0.5811	23	No-CO-Perfs	2.303
3	Bicarbonate ppm	0.6666	24	Chloride ppm	2.3298
4	Peak Visc	0.7486	25	NI- Perfed-H	2.3302
5	Lat	0.7734	26	Water pHLab	2.3665
6	Orig20/40 Sand-Mlbs	0.9214	27	Pre-Refrac Mcfd	2.3956
7	Long	1.1	28	Cum MMcf	2.4009
8	Refrac Date	1.1934	29	Water Source	2.4018
9	ViscShear 100-30Min	1.3324	30	Iron ppm	2.4351
10	TotHardness ppm	1.518	31	MGAL	2.496
11	Calcium ppm	1.6692	32	TotalPerfs	2.5045
12	AvgRate BPM	1.7415	33	Sulfate ppm	2.5164
13	Est-Ult- GOR	1.7706	34	New Perfs	2.552
14	No-NI -Perfs	1.7863	35	Sodium ppm	2.6039
15	AvgPsi	1.8438	36	Magnesium ppm	2.6108
16	ViscShear 100-5Min	1.9401	37	ViscShear 100-0Min	2.6649
17	Top CO Perf	1.9819	38	Pre- FracISDP	2.7127
18	TDSolid ppm	2.0084	39	TestedPH	2.8066
19	MMcf	2.0777	40	Post- FracISDP	2.8256
20	Orig Fluid-Mgal	2.0855	41	Mlb20-40	2.8907
21	DOFP	2.2451	42	Communication	2.9554

RESULTS & DISCUSSIONS

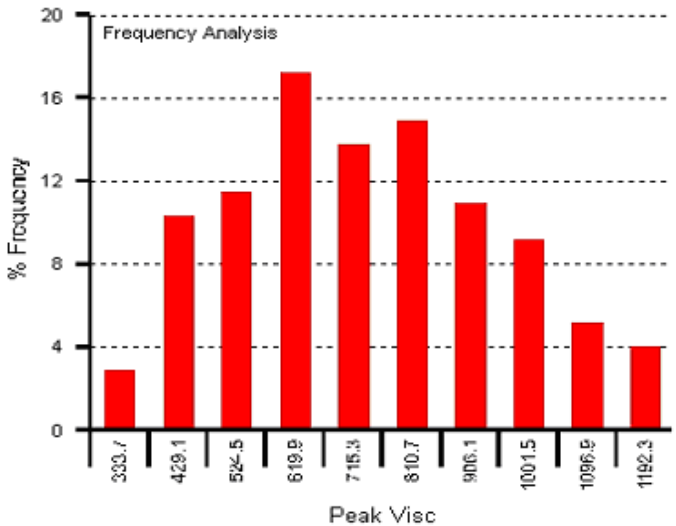
- **Step two: Fuzzy Combinatorial Analysis**

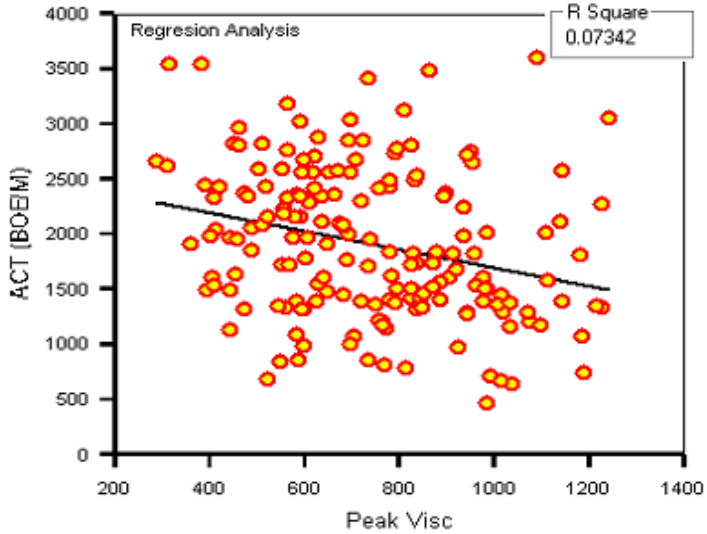


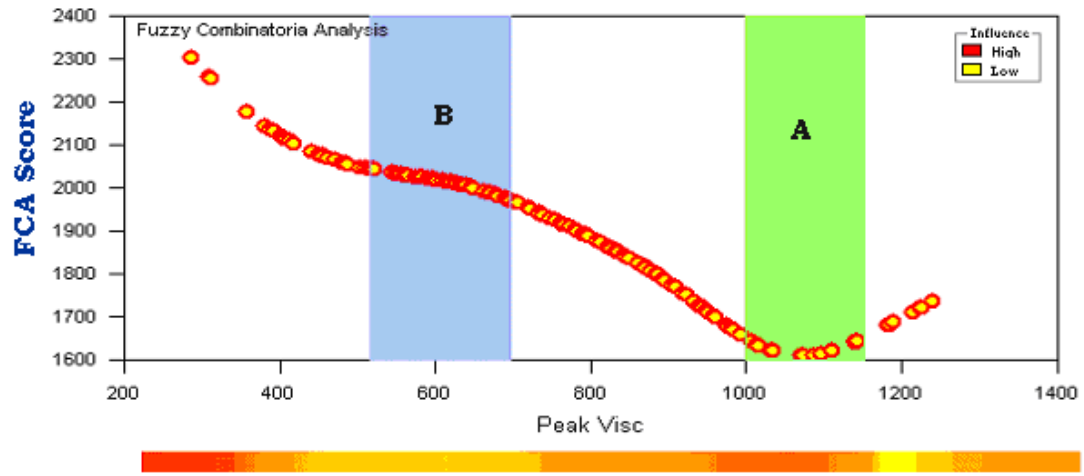
RESULTS & DISCUSSIONS



RESULTS & DISCUSSIONS







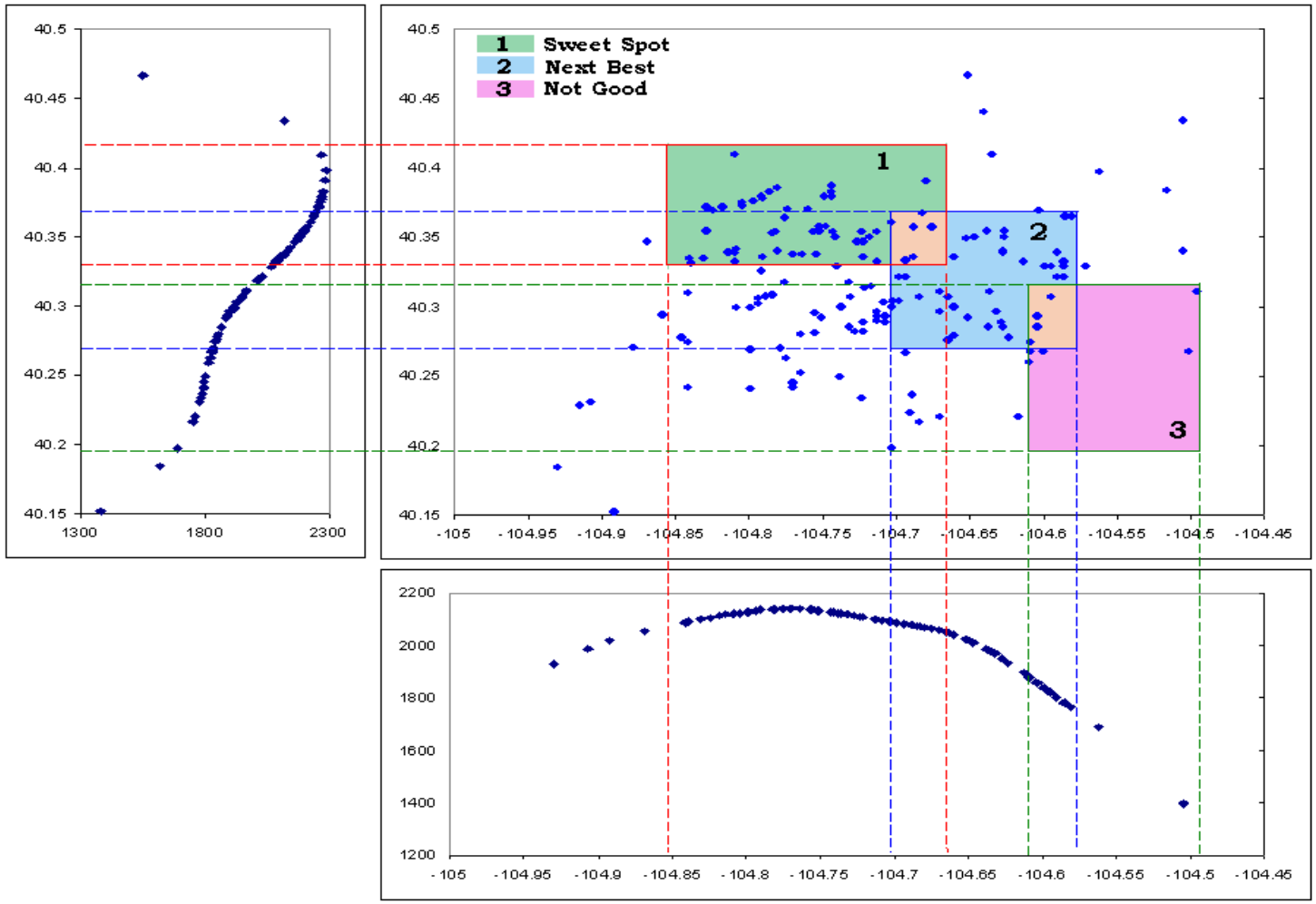
RESULTS & DISCUSSIONS

- **Step three: Intelligent Production Data Analysis – IPDA**
  - The objective of this part of the analysis is to assist the operator in future field development strategies by identifying the locations of the field that would be a prime candidate for further investment (infill drilling, stimulation, restimulation or workovers) as well as identifying the portions of the field in which no new investments are recommended.

RESULTS & DISCUSSIONS

- **Step three: Intelligent Production Data Analysis – IPDA**
  - This task is performed based on the successful practices of the operating company in the past.
  - The result of this task is also used in the step five during the “Group of Wells Analysis”

RESULTS & DISCUSSIONS



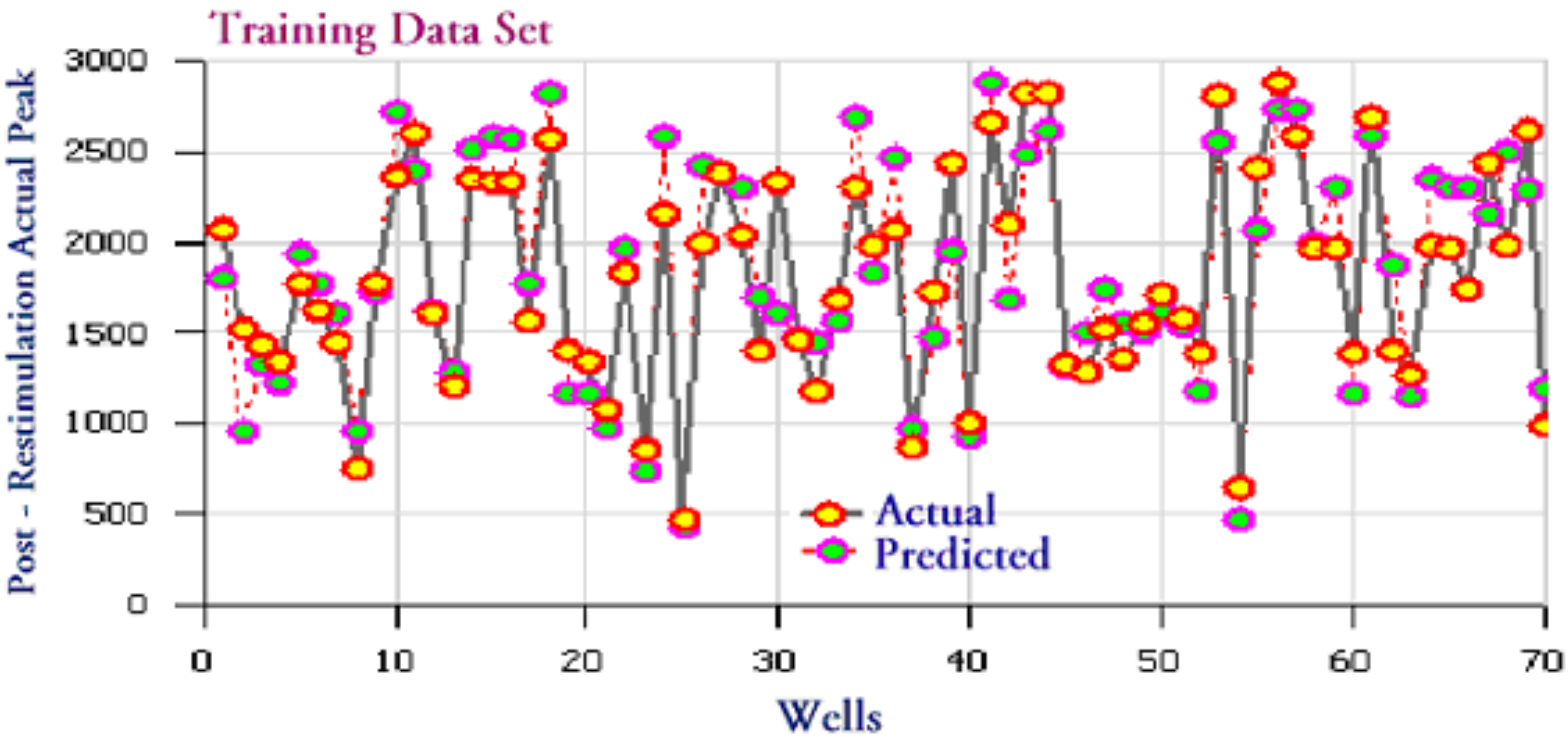
RESULTS & DISCUSSIONS

- **Step three: Intelligent Production Data Analysis – IPDA**
  - The regional segmentation is supported by the "Post-Restimulation Actual Peak Production," and the reservoir quality identifier which is the product of gas saturation and Codell net pay.

	Region 1	Region 2	Region 3
Longitude - Low	-104.854	-104.704	-104.61
Longitude - High	-104.666	-104.579	-104.496
Latitude - Low	40.33	40.27	40.197
Latitude - High	40.42	40.369	40.315
Actual Peak (BOE)	**2,234**	**1,792**	**1,235**
Res. Quality (Gas-ft)	**2.58**	**2.47**	**2.25**
No Wells Included	58	50	9

RESULTS & DISCUSSIONS

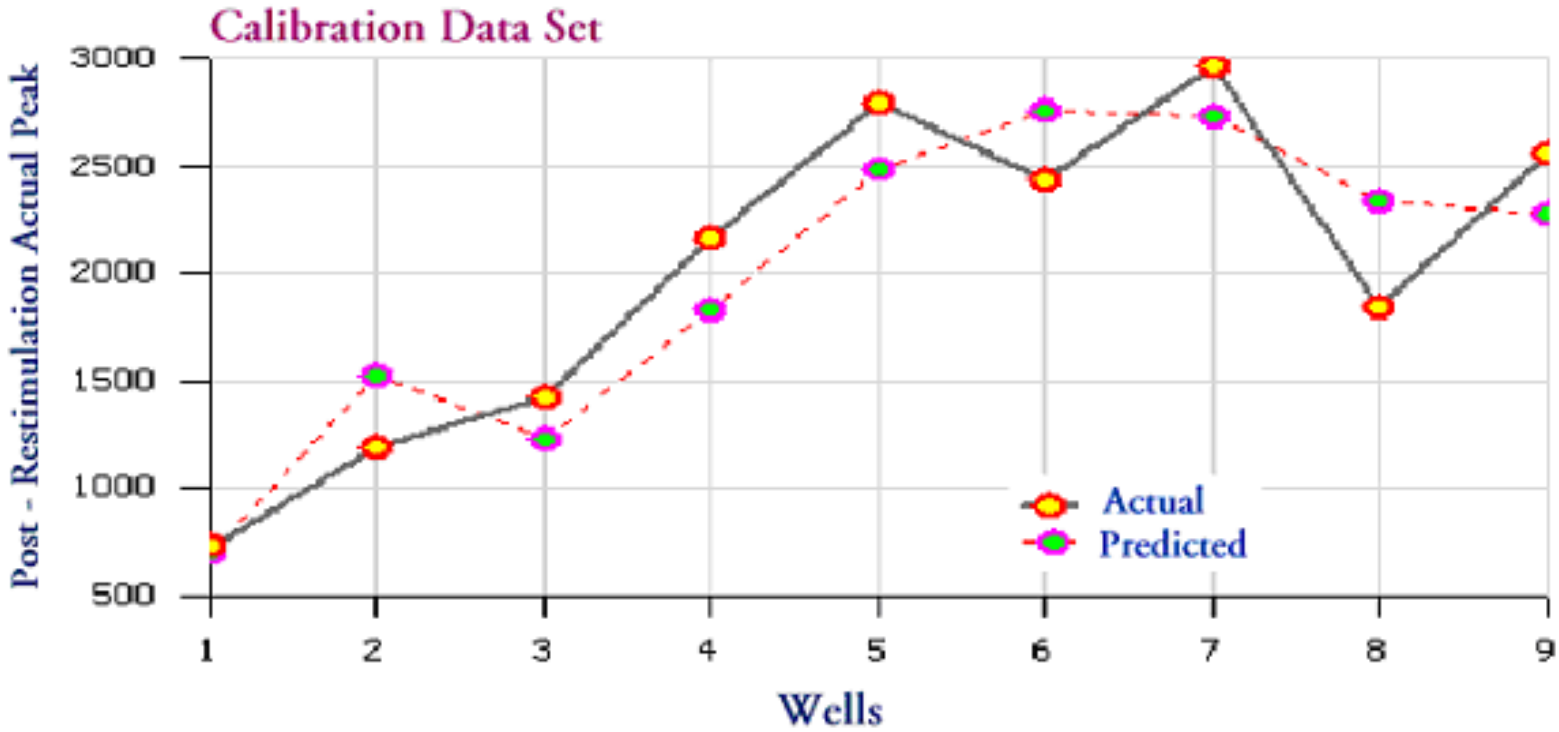
- **Step four: Neural Model Building**



	Training	Calibration	Verification
Rsquare	0.783	0.821	0.516
Correlation Coefficient	0.901	0.907	0.809

RESULTS & DISCUSSIONS

- **Step four: Neural Model Building**



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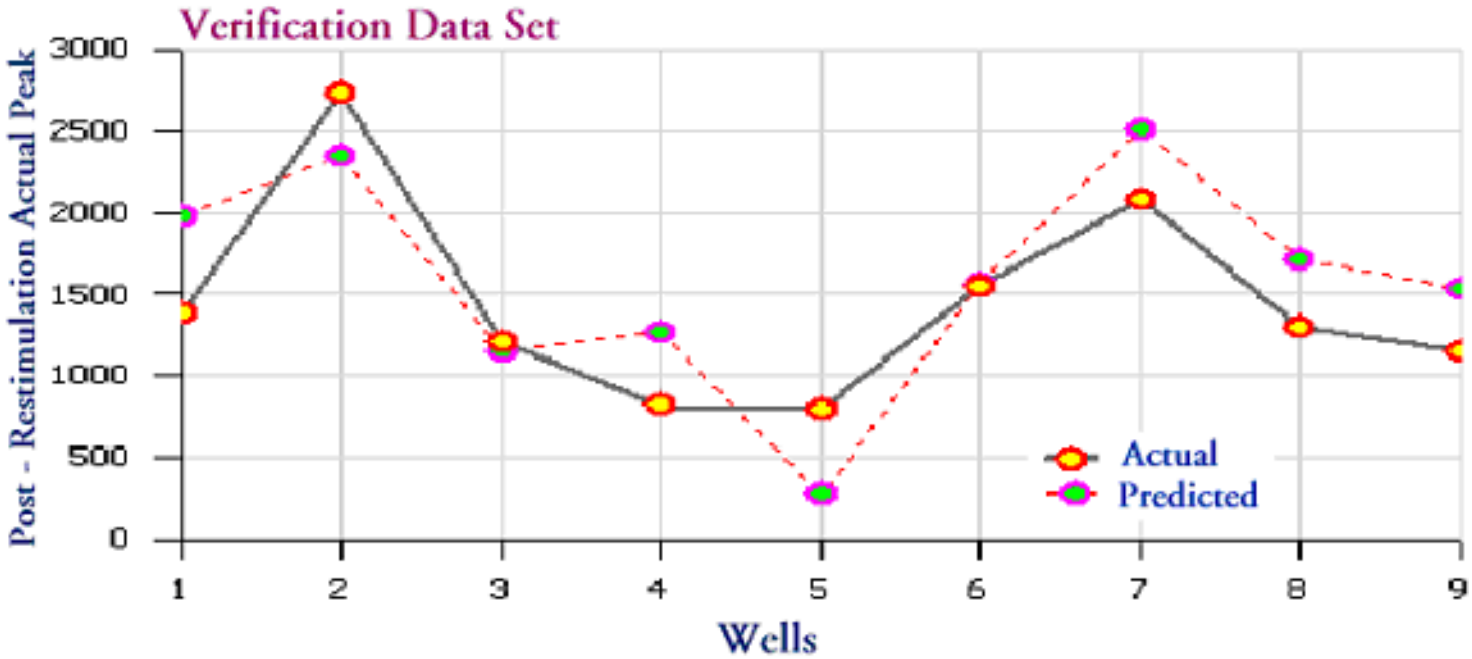
RESULTS & DISCUSSIONS

- **Step four: Neural Model Building**



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Correlation Coefficient	0.901	0.907	0.809

RESULTS & DISCUSSIONS

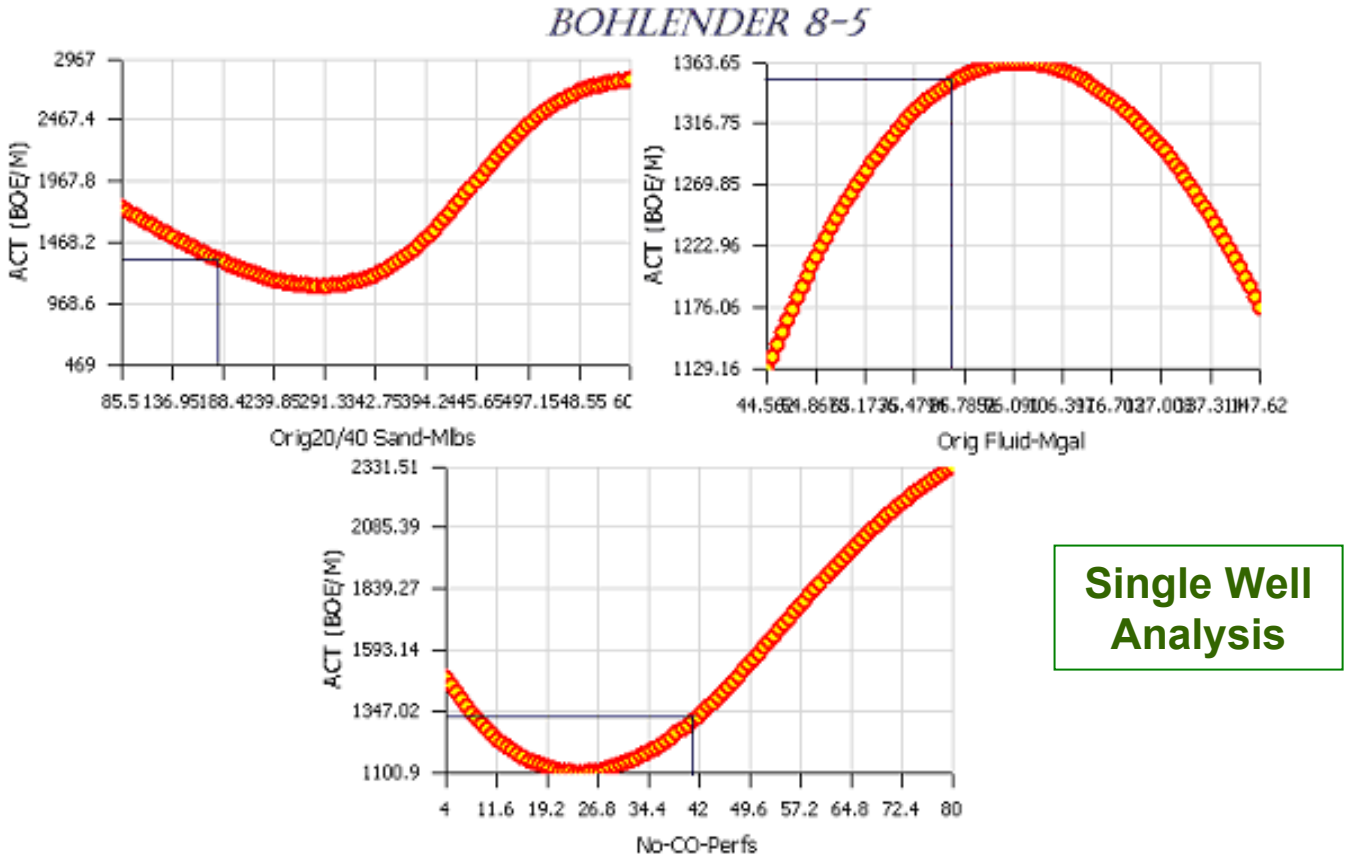
- **Step four: Neural Model Building**

Category	Input Parameter in Neural Network
Well Location	Latitude
Well Location	Longitude
Reservoir Quality	Codell porosity-net pay product
Reservoir Quality	Nibrara porosity-net pay product
Completion	Number of perforations in Codell
Original Stimulation	Amount of sand used as proppant (Mlbs)
Original Stimulation	Amount of fluid used (Mgal)
Result of cluster Analysis	Entropy

	Training	Calibration	Verification
Rsquare	0.783	0.821	0.516
Correlation Coefficient	0.901	0.907	0.809

RESULTS & DISCUSSIONS

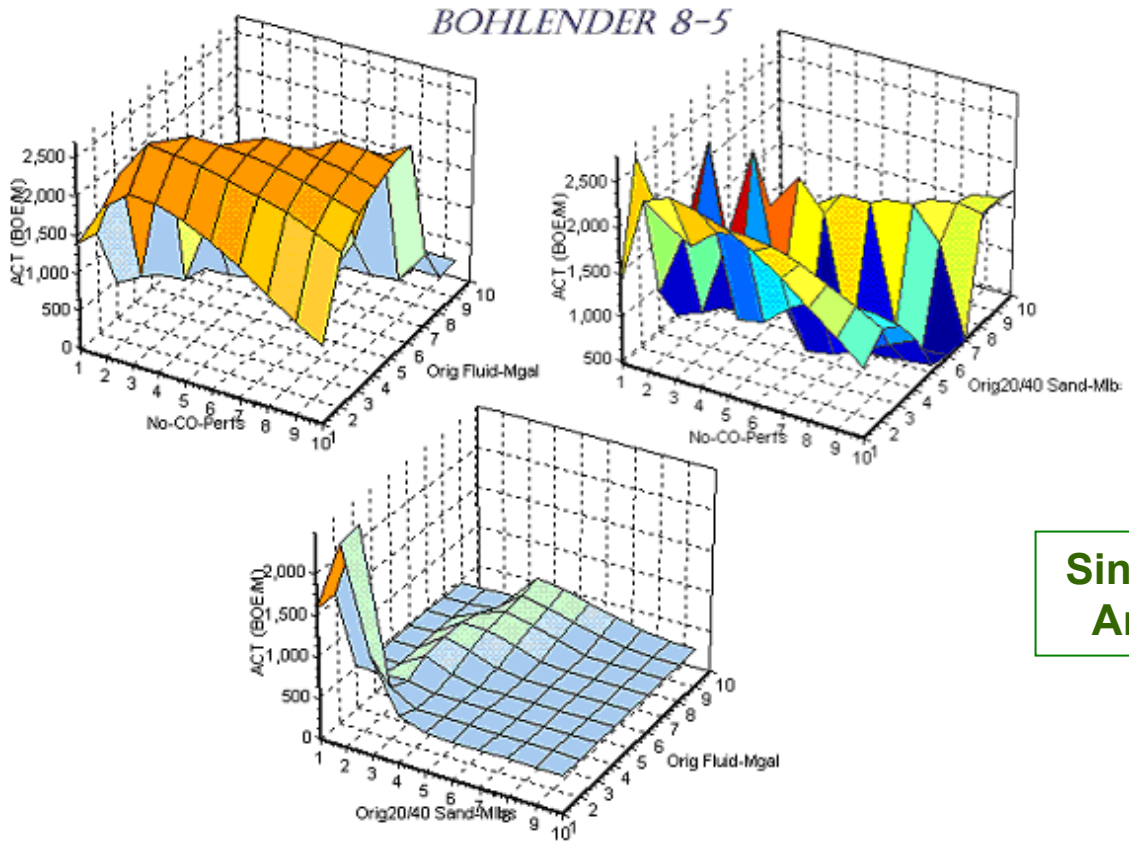
- **Step five: Successful Practices Analysis**



Single Well Analysis

RESULTS & DISCUSSIONS

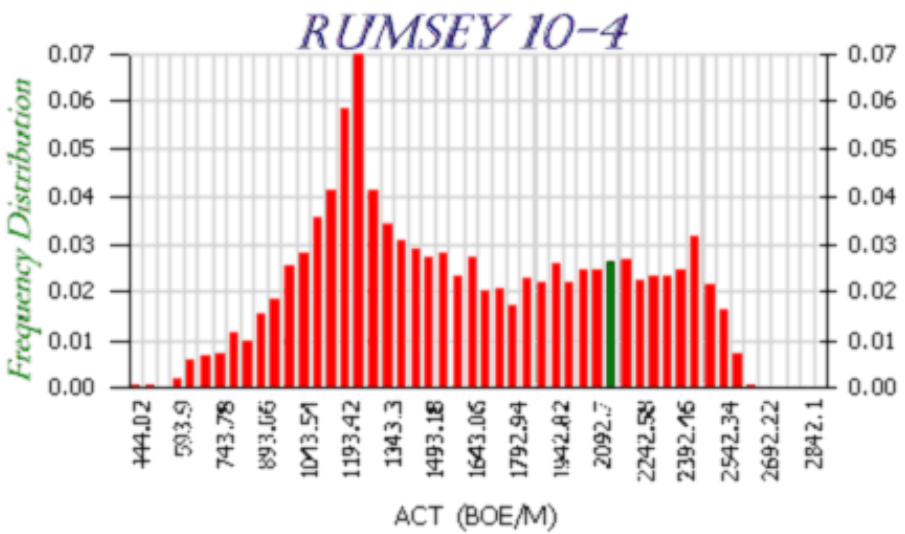
- **Step five: Successful Practices Analysis**

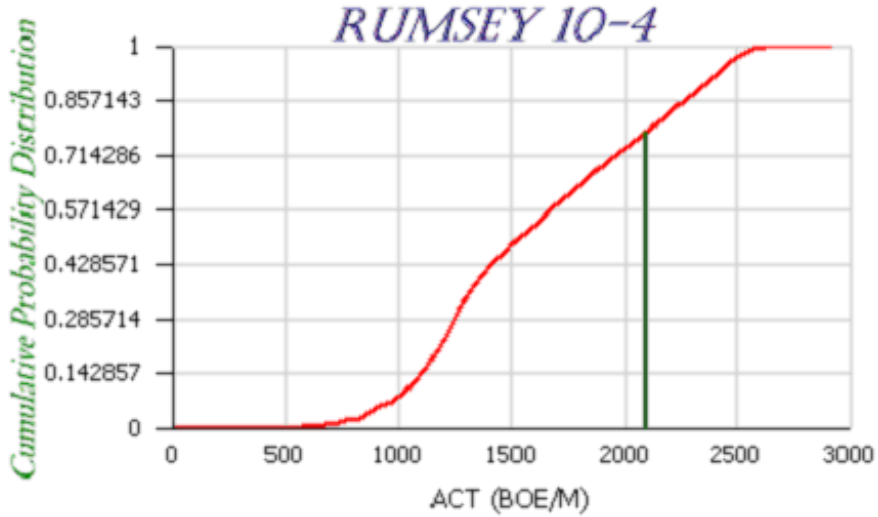


Single Well Analysis

RESULTS & DISCUSSIONS

- **Step five: Successful Practices Analysis**





Single Well Analysis

Variable	Distribution	Minimum	Maximum
No. of Perforation in Codel (Number)	Uniform	4	80
Original 20-40 Sand pumped (Mlbs)	Uniform	85.5	600
Original Fluid Pumped (Mgal)	Uniform	44.5	147.6

RESULTS & DISCUSSIONS

- **Step five: Successful Practices Analysis**

PARAMETER BEING STUDIED: 20-40 Sand (Mlb)												
No. of Wells	Percent of Total	Curves Shape Characteristics					Curves Statistics					
		Curve Type	Shape Type	Order	Trend	Convexity		Min.	Avg.	Max.	Entry Value	End Value
73	83%	Line	Line	ax+b	Descending		Min	292	292	504	504	292
							Max	2,855	2,927	2,927	2,927	2,855
							Average	1,566	1,714	1,862	1,862	1,566
							Stand. Dev.	675		619	619	675
							Variance	455,463		382,917	382,917	455,463
6	7%	Line	Line	ax+b	Ascending		Min	986	986	1,046	986	1,046
							Max	2,281	2,346	2,346	2,281	2,346
							Average	1,763	1,821	1,878	1,763	1,878
							Stand. Dev.	481		493	481	493
							Variance	231,429		242,924	231,429	242,924
4	5%	Polynomial	U-Turn	X^2-Type	Ascending/ Descending	Concave	Min	1,895	1,895	1,920	1,895	1,920
							Max	2,984	2,990	2,990	2,986	2,984
							Average	2,346	2,357	2,369	2,348	2,362
							Stand. Dev.	401		394	401	394
							Variance	160,761		155,206	160,592	155,254
4	5%	Polynomial	Half-Parabolic	X^2-Type	Descending	Concave	Min	2,142	2,142	2,205	2,205	2,142
							Max	2,586	2,621	2,621	2,621	2,586
							Average	2,431	2,451	2,472	2,472	2,431
							Stand. Dev.	172		160	160	172
							Variance	29,618		25,718	25,718	29,618

RESULTS & DISCUSSIONS

- **Step five: Successful Practices Analysis**

  The dominant trend for amount of proppant would imply that high “Actual Peak” would be achieved if low amounts of sand were used in treatment. The trend indicates that placing more sand in the fracture will not bring significant increase in “Actual Peak”.

RESULTS & DISCUSSIONS

- **Step five: Successful Practices Analysis**

PARAMETER BEING STUDIED: Peak Viscosity												
No. of Wells	Percent of Total	Curves Shape Characteristics					Curves Statistics					
		Curve Type	Shape Type	Order	Trend	Convexity		Min.	Avg.	Max.	Entry Value	End Value
53	60%	Polynomial	Half-Parabolic	X^2-Type	Descending	Concave	Min	354	354	1,062	1,062	354
							Max	1,743	3,078	3,078	3,078	1,743
							Average	1,040	1,746	2,451	2,451	1,040
							Stand. Dev.	285		350	350	285
							Variance	81,320		122,668	122,668	81,320
31	35%	Line	Line	ax+b	Descending		Min	307	307	1,906	1,906	307
							Max	1,605	2,990	2,990	2,990	1,605
							Average	793	1,704	2,615	2,615	793
							Stand. Dev.	249		224	224	249
							Variance	61,836		49,957	49,957	61,836
3	3%	Polynomial	U-Turn	X^3-Type	Ascending-Descending	Concave	Min	1,523	1,523	2,432	2,377	1,523
							Max	2,119	2,530	2,530	2,530	2,119
							Average	1,804	2,147	2,490	2,471	1,804
							Stand. Dev.	245		42	67	245
							Variance	59,828		1,746	4,554	59,828

RESULTS & DISCUSSIONS

- **Step five: Successful Practices Analysis**

  The dominant trend implies that:

  - Low viscosity frac fluids are preferred to higher viscosity fluids
  - This agrees with the trends identified in the amount of proppant analysis. Indeed, for low proppant concentrations there is no need for high viscosity fluids.

CONCLUSIONS

- A new and novel methodology for comprehensive “Successful Practices Identification” of the oil and gas operations has been developed.
- This methodology uses state-of-the-art data mining, knowledge discovery and data-knowledge fusion techniques inspired by virtual intelligence paradigms.

CONCLUSIONS

- The new methodology was applied to hydraulic fracturing database of about 150 wells in the Codell formation in DJ Basin
- This methodology has the potential to open new doors in comprehensive and detail field studies as a complement to field wide simulation and modeling studies.

CONCLUSIONS

- Analysis such as the one presented here can be performed at a relatively low cost and can provide much needed insight at a short time to the engineers and field managers.

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