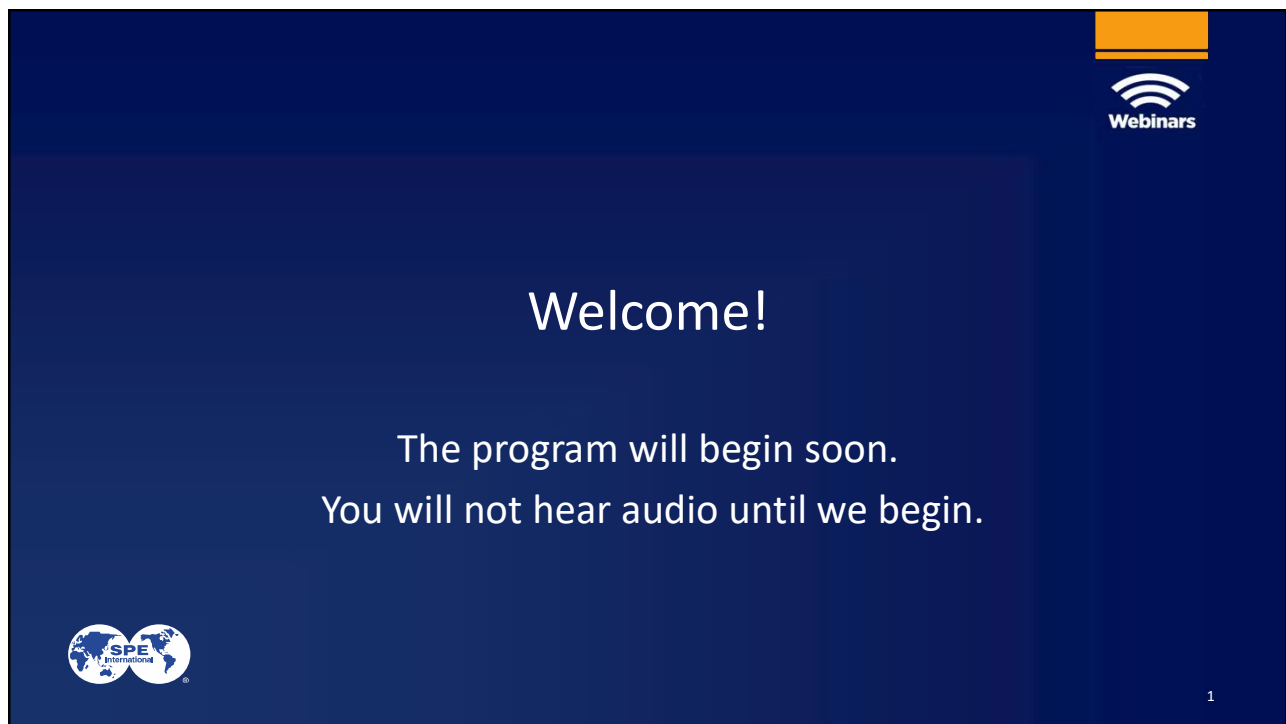




A dark blue rectangular slide with a lighter blue central area. In the top right corner, there is an orange rectangle above a white Wi-Fi symbol and the word "Webinars". In the center, the word "Welcome!" is written in large white font, followed by two lines of smaller white text: "The program will begin soon." and "You will not hear audio until we begin." In the bottom left corner, there is a circular logo with two globes and the text "SPE International". In the bottom right corner, there is a small white number "1".

Webinars

Welcome!

The program will begin soon.
You will not hear audio until we begin.

SPE International

1



Automating ROP Optimization in Real-Time Drilling Operations Using Big Data Analytics & ML

Kriti Singh
07/14/2023



DUPTS – Drilling Uncertainty Prediction

connect.spe.org/dupts/home

DUPTS holds

+ 2,000 members distributed globally

Covering

NOC, IOC
Service company members and Academia

Roadmap

Data and Modeling
Diagnostics and Forecasting


Drilling Uncertainty Prediction
Technical Section



DUPTS provides international multi-disciplinary forum for technical discussion and a consensus-based arena related to drilling uncertainty & prediction, which focuses mainly on artificial intelligence, machine learning and data science solutions supporting drilling, planning and execution challenges.

3

DUPTS – Drilling Uncertainty Prediction

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Technical Webinars

Conducted by international experts

We take part in special events

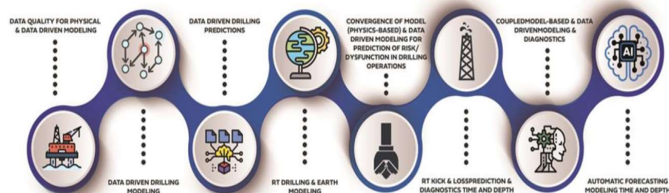
Åmsterdam Energy Summit 2023
Technical programs around the world

Student Competition

Computer Vision 2022
Drilling Data Competition 2021



DUPTS – ROADMAP



- ✓ Clarifying existing challenges in drilling domain.
- ✓ Pointing education resources.
- ✓ Stimulating the community to share knowledge and collaborate in this area.
- ✓ Spread the awareness about AI, ML and data science.

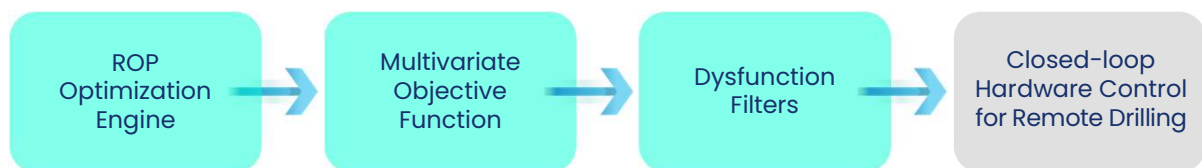
Agenda



- Introduction
- Review of the ML model used for ROP prediction
- Semi-automated machine learning pipeline for model training
- Review of SPE publications
 - Field test results
 - ROP Optimizer
 - Automated calibration factor
- Summary
- What's next?



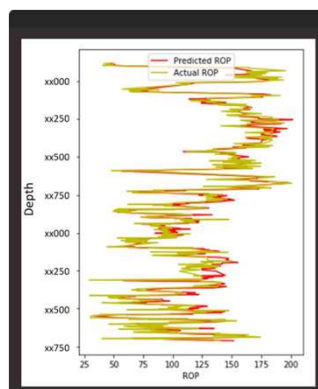
Rotary Automation Milestones



Review - Machine Learning Model Published in URTeC 2019 - 343



Feature	Weights (%)
Differential Pressure	52.74
Surface Torque	19.05
Lagged MSE	14.19
Surface Weight on Bit	6.76
Lagged Surface RPM	4.61
Lagged Surface Torque	0.15



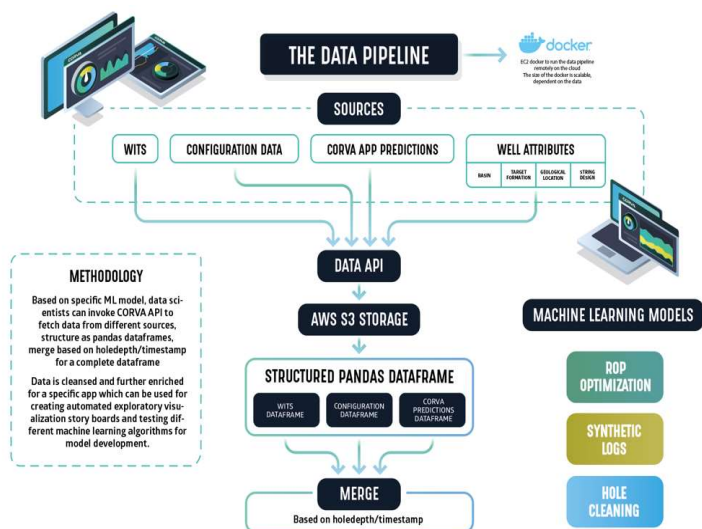
MAPE on blind
wells < 15%



Input Parameters



- WITSML data
- BHA data
- Survey data
- Mud data
- Corva Engineering calculations



8

Input Parameters



Engineered Features are added:

- Bit Hydraulic Horsepower per Square Inch
- Bit Run Distance
 - Proxy for bit wear
- Lagged Features
 - Lagged MSE is a proxy for formation strength

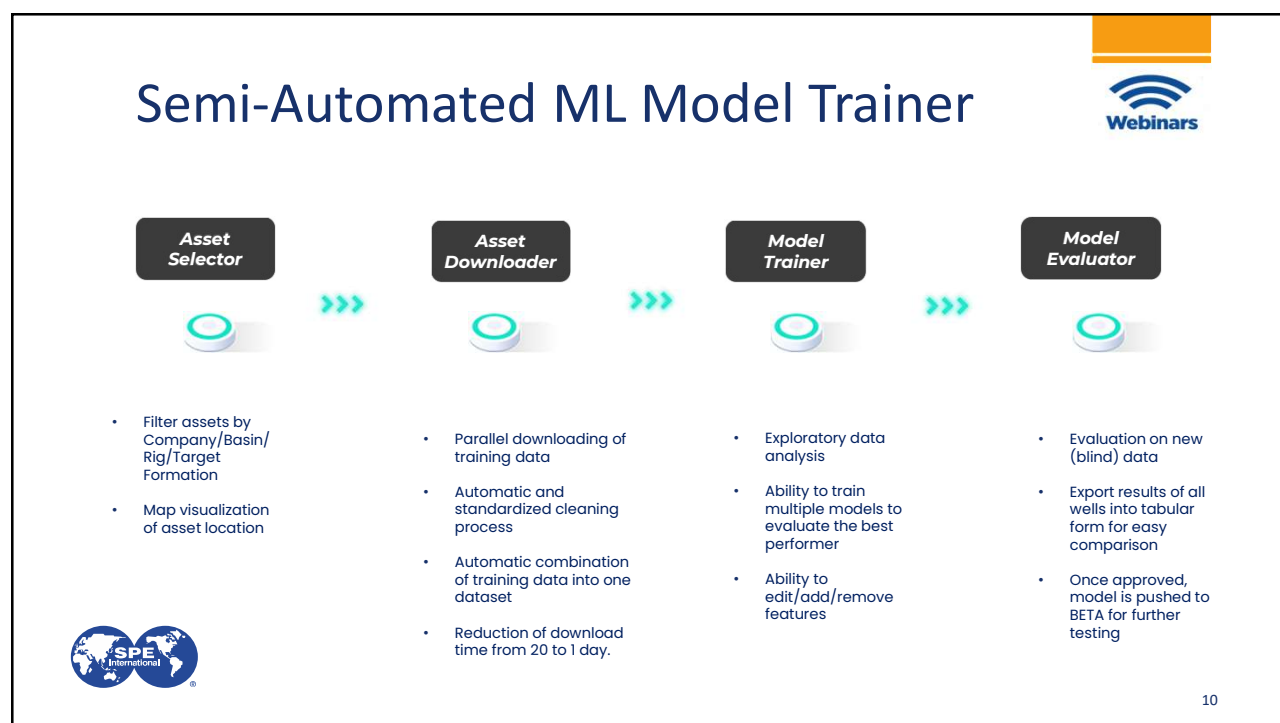


ML Model Inputs
Bit hydraulic horsepower per square inch
Bit run distance
Bit size
Bit total flow area
Differential pressure
Hole depth
Hook load
Lagged differential pressure
Lagged MSE
Lagged mud flow rate
Lagged TDRPM
Lagged rotary torque
Mud density
Mud flow rate
Mud plastic viscosity
Mud yield point
Rotary RPM (TDRPM)
Rotary torque
Standpipe pressure
Weight on bit



Current working model is a Multi-Variate Regression Model





Asset Selector



1.5.2.2. Basin filter

```
[37]: basins = filtered_assets['basin'].unique()
      basins = basins[basins != None]
      basins.sort()
      basins_SM = ipywidgets.SelectMultiple(
        options=basins,
        value=(),
        rows=20,
        description='Basins:',
        disabled=False
      )
      basins_SM
```

Basins:

- Marietta Basin
- Alberta
- Anadarko
- Appalachia
- Ardmore
- Bakken
- Cold Lake
- Delaware
- Delaware-Permian
- Eagle Ford



1.5.2.3. Formation filter

```
[49]: formations = filtered_assets['target_formation'].unique()
      formations = formations[formations != None]
      formations.sort()
      formations_SM = ipywidgets.SelectMultiple(
        options=formations,
        value=[],
        rows=10,
        description='Formations:',
        disabled=False
      )
      formations_SM
```

Formations:

- DEAN
- Dean Sand
- JO MILL
- Jo Mill
- LOWER SPRABERRY MFS
- LOWER SPRABERRY SHALE
- Lower Spraberry
- Lower Spraberry Sand
- Lower Spraberry Shale
- MIDDLE SPRABERRY



Asset Downloader

	overall	asset_id	wits	configurations	predictions	hydraulics
0	False	False	False	False	False	False
1	False	False	False	False	False	False

1.6. EC2 Invocation

1.6.1. Setup Template

```

[10] aws_instances = list(asset_id) // 1
aws_instances

[11] 2

[12] template = {
    "AWSTemplateFormatVersion": "2010-09-09",
    "Description": "AWS CloudFormation template for the Asset Downloader",
    "Parameters": {
        "Repository": {
            "Type": "Text",
            "Default": "https://github.com:aws-samples/asset-downloader.git",
            "ConstraintDescription": "Repository URL must be a valid GitHub repository URL."
        },
        "Branch": {
            "Type": "Text",
            "Default": "main",
            "ConstraintDescription": "Branch name must be a valid GitHub branch name."
        },
        "HandlerFunction": {
            "Type": "Text",
            "Default": "ec2_handler",
            "ConstraintDescription": "Handler function name must be a valid Lambda function name."
        },
        "InstanceCount": {
            "Type": "Text",
            "Default": "1",
            "ConstraintDescription": "Instance count must be a positive integer."
        },
        "EnvironmentVariables": {
            "Type": "Text",
            "Default": "None",
            "ConstraintDescription": "Environment variables must be a valid JSON object."
        }
    },
    "Resources": {
        "Function": {
            "Type": "AWS::Lambda::Function",
            "Properties": {
                "FunctionName": "AssetDownloader",
                "Runtime": "python3.9",
                "Handler": "asset_downloader.handler",
                "Code": {
                    "S3Bucket": "aws-samples",
                    "S3Key": "asset_downloader/asset_downloader.zip"
                },
                "Environment": {
                    "Repository": "${Repository}",
                    "Branch": "${Branch}",
                    "HandlerFunction": "${HandlerFunction}",
                    "InstanceCount": "${InstanceCount}",
                    "EnvironmentVariables": "${EnvironmentVariables}"
                },
                "Timeout": 300
            }
        },
        "Instances": {
            "Type": "AWS::EC2::Instance",
            "Properties": {
                "ImageId": "ami-0c558f264085437bb",
                "InstanceType": "t3.medium",
                "SubnetId": "subnet-1a2b3c4d",
                "SecurityGroups": ["sg-1a2b3c4d"],
                "KeyName": "keypair",
                "UserData": "cloud-init",
                "Tags": [
                    {
                        "Key": "Name",
                        "Value": "AssetDownloader-Instances"
                    }
                ]
            }
        }
    }
}

Following environment variables loaded from SageMaker logs: ["API_KEY", "API_KEY", "API_KEY", "API_KEY"]

```

1.6.2. EC2 Runner

Instantiate the ec2 runner and setup based on the template above

```

[13] ec2_runner = boto3.client('ec2')
ec2_runner

[14] run_instances(aws_instances, template)

```

1.6.3. Start EC2 instances

Check here Link



Instances (4)

Name	Instance ID	Instance state	Instance type	Status check	Alarm status	Availability Zone	Public IP v4 DNS	Public IP v4	Elastic IP
Directional Tes...	i-0565548f131024a7a	Stopped	t3.medium	-	No alarms	us-east-1a	-	-	-
end-Sub	i-0b3b4d6b3b4d6b3	Running	t3a.small	2/2 checks passed	No alarms	us-east-1f	ec2-18-207-159-251.co...	18.207.159.251	-
SANDL-2K7L...	i-0191472b0d0f9fdaa	Running	t3.2xlarge	Initializing	No alarms	us-east-1f	ec2-3-239-10-248.com...	3.239.10.248	-
SANDL-2K7L...	i-072286d72373c3a2	Running	t3.2xlarge	Initializing	No alarms	us-east-1f	ec2-3-63-35-48.comput...	3.63.35.48	-

Model Trainer Example



	model	train_time	r2	mape
8	(DecisionTreeRegressor(max_features='auto', ra...	24.140379	0.98796	2.429
10	(DecisionTreeRegressor(random_state=630921809)...	2.459478	0.98263	2.525
11	HistGradientBoostingRegressor()	0.656610	0.87770	11.322
12	(StandardScaler(), MLPRegressor(early_stopping...	50.434030	0.85330	12.281
13	(StandardScaler(), MLPRegressor(early_stopping...	27.811588	0.83591	13.263
9	((DecisionTreeRegressor(criterion='friedman_ms...	7.984549	0.79532	15.355
7	(StandardScaler(), LinearSVR())	0.125731	0.67238	19.745
5	Ridge()	0.013557	0.67500	19.854
0	LinearRegression()	0.010579	0.67500	19.856
1	(StandardScaler(), LinearRegression())	0.017687	0.67500	19.856
3	BayesianRidge()	0.014784	0.67500	19.861
2	ARDRegression()	0.016585	0.67070	19.899
4	ElasticNet()	0.048342	0.65831	20.213
6	RANSACRegressor()	0.229651	0.51986	23.228



Model Evaluator



	MAPE [-15, 15]	1.5 Sigma Error Bounds [-20, 20]	ROP Trend Similarity [0.6, 1.0]	[INFO] Median Under- prediction [-5, inf]	[INFO] Median Over- prediction [-inf, 5]	[INFO] Actual-vs- Predicted Slope [0.5, 1.5]	[INFO] Actual-vs- Predicted Intercept [-200, 200]	[INFO] Actual-vs- Predicted R2 [0.5, 1]	[INFO] ROP Distribution Similarity [0.8, 1.0]	Overall
53436232	4.600000	[-15.8, 16.2]	0.940000	0.200000	0.200000	0.890000	17.000000	0.890000	0.990000	Figure
Average	4.600000	nan	0.940000	0.200000	0.200000	0.890000	17.000000	0.890000	0.990000	nan
Median	4.600000	nan	0.940000	0.200000	0.200000	0.890000	17.000000	0.890000	0.990000	nan



Deployer

```
display(HBox([from_dd, to_dd]))
display(load_btn)

display(HBox([from_tree, to_tree]))

display(from_path_txt)
display(to_path_txt)
display(deploy_btn)

display(output)
```

From: alpha

To: qa

qa

staging

production

Load

Error displaying widget: model not found

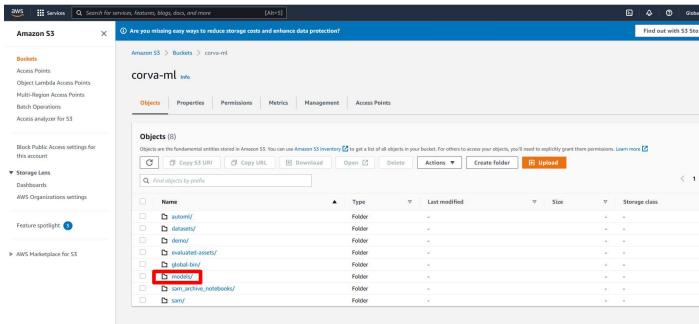
From Prefix: Folder to copy from

To Prefix: Folder to copy to

Deploy







Name	Type	Last modified	Size	Storage class
default/	Folder	-	-	-
default2/	Folder	-	-	-
default3/	Folder	-	-	-
default4/	Folder	-	-	-
default5/	Folder	-	-	-
default6/	Folder	-	-	-
default7/	Folder	-	-	-
default8/	Folder	-	-	-
default9/	Folder	-	-	-
default10/	Folder	-	-	-
default11/	Folder	-	-	-
default12/	Folder	-	-	-
default13/	Folder	-	-	-
default14/	Folder	-	-	-
default15/	Folder	-	-	-
default16/	Folder	-	-	-
default17/	Folder	-	-	-
default18/	Folder	-	-	-
default19/	Folder	-	-	-
default20/	Folder	-	-	-
default21/	Folder	-	-	-
default22/	Folder	-	-	-
default23/	Folder	-	-	-
default24/	Folder	-	-	-
default25/	Folder	-	-	-
default26/	Folder	-	-	-
default27/	Folder	-	-	-
default28/	Folder	-	-	-
default29/	Folder	-	-	-
default30/	Folder	-	-	-
default31/	Folder	-	-	-
default32/	Folder	-	-	-
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default34/	Folder	-	-	-
default35/	Folder	-	-	-
default36/	Folder	-	-	-
default37/	Folder	-	-	-
default38/	Folder	-	-	-
default39/	Folder	-	-	-
default40/	Folder	-	-	-
default41/	Folder	-	-	-
default42/	Folder	-	-	-
default43/	Folder	-	-	-
default44/	Folder	-	-	-
default45/	Folder	-	-	-
default46/	Folder	-	-	-
default47/	Folder	-	-	-
default48/	Folder	-	-	-
default49/	Folder	-	-	-
default50/	Folder	-	-	-
default51/	Folder	-	-	-
default52/	Folder	-	-	-
default53/	Folder	-	-	-
default54/	Folder	-	-	-
default55/	Folder	-	-	-
default56/	Folder	-	-	-
default57/	Folder	-	-	-
default58/	Folder	-	-	-
default59/	Folder	-	-	-
default60/	Folder	-	-	-
default61/	Folder	-	-	-
default62/	Folder	-	-	-
default63/	Folder	-	-	-
default64/	Folder	-	-	-
default65/	Folder	-	-	-
default66/	Folder	-	-	-
default67/	Folder	-	-	-
default68/	Folder	-	-	-
default69/	Folder	-	-	-
default70/	Folder	-	-	-
default71/	Folder	-	-	-
default72/	Folder	-	-	-
default73/	Folder	-	-	-
default74/	Folder	-	-	-
default75/	Folder	-	-	-
default76/	Folder	-	-	-
default77/	Folder	-	-	-
default78/	Folder	-	-	-
default79/	Folder	-	-	-
default80/	Folder	-	-	-
default81/	Folder	-	-	-
default82/	Folder	-	-	-
default83/	Folder	-	-	-
default84/	Folder	-	-	-
default85/	Folder	-	-	-
default86/	Folder	-	-	-
default87/	Folder	-	-	-
default88/	Folder	-	-	-
default89/	Folder	-	-	-
default90/	Folder	-	-	-
default91/	Folder	-	-	-
default92/	Folder	-	-	-
default93/	Folder	-	-	-
default94/	Folder	-	-	-
default95/	Folder	-	-	-
default96/	Folder	-	-	-
default97/	Folder	-	-	-
default98/	Folder	-	-	-
default99/	Folder	-	-	-
default100/	Folder	-	-	-

15

Model Execution



linear-regression-old-updated-metadata/ Copy S3 URI

Objects | Properties

Objects (2)

Objects are the fundamental entities stored in Amazon S3. You can use [Amazon S3 inventory](#) to get a list of all objects in your bucket. For others to access your objects, you'll need to explicitly grant them permissions. [Learn more](#)

Copy S3 URI Copy URL Download Open Delete Actions Create folder Upload

Find objects by prefix

☐	Name	Type	Last modified
☐	metadata.json	json	August 2, 2021, 16:37:50 (UTC-05:00)
☐	model.pkl	pkl	August 2, 2021, 16:37:50 (UTC-05:00)

```
metadata.json - Notepad
File Edit View
{
  "mse":
  {
    "def calculate_mse(row):\n    \"\"\"\n    Calculate mse and add a new colu
  },
  "hsl":
  {
    "def calculate_hsl(row):\n    \"\"\"\n    This method calculates HSI for g
  },
  "bit_run_distance":
  {
    "def calculate_bit_run_distance(row):\n    \"\"\"\n    :param row: pd.Series
  },
  "lagged_features": [
    "rotary_torque",
    "mse",
    "diff_gress",
    "mod_flow_in",
    "rotary_rpm"
  ],
  "transformations": [],
  "target feature": "rpm"
}
```



16

Review – Field Test Results Published in SPE/IADC 2021-204043



- Wolfcamp A
- Same Gamma Ray
- Same BHA
- Same Bit Size



17

Review – ROP Optimizer Presented in SPE/IADC 2022-208751

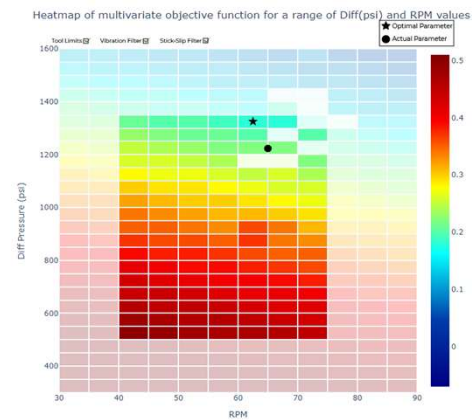


$$\text{multivariate objective} = w_{ROP} \left(1 - \frac{ROP}{N_{ROP}} \right) + w_{MSE} \frac{MSE}{N_{MSE}} + w_{RT} \frac{RT}{N_{RT}}$$

Where:

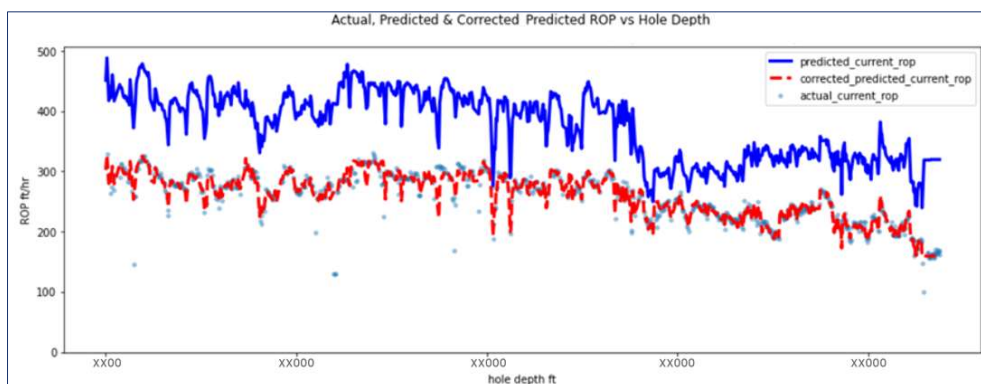
w_i	User specified weight for each component
N_i	Normalization factor for each component
ROP	Rate Of Penetration
MSE	Mechanical Specific Energy
RT	Rotational Tendency

- **Filters:**
- Vibration
- Torsional Severity Ratio
- Parameter Limits



18

Review – Automated Calibration Factor Presented in SPE/IADC 2023-212568



The corrected ROP prediction after applying calibration matches the actual ROP values



19

Field Test Results - Accelerate RIG Uptake



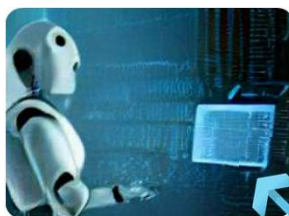
Observed improved rig compliance. The actual ROP response was very close to the predicted values



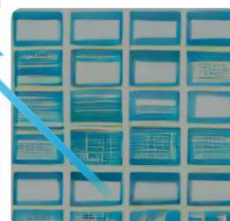
Summary



**Real-time ROP
prediction using ML**



**Augments
Driller's Capability:**
Reduces driller's fatigue by
automatically picking the
optimal drilling parameters



**Identify the optimal set for
drilling parameters**

Reduce cost per foot of drilling

**Reduce hazards by leveraging
RT data (e.g. vibration)**

**RT comparison with
offset wells data**



21

What's next?



- Closed loop automation
- Strategic partnership with a major rig contractor
- Directly control the AutoDriller setpoints using cloud -> cloud -> HMI connection
- Closed loop field testing with major Oil & Gas operators



22



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