Adapted method to detect and predict stuck pipe problems during well drilling, applying time series analysis

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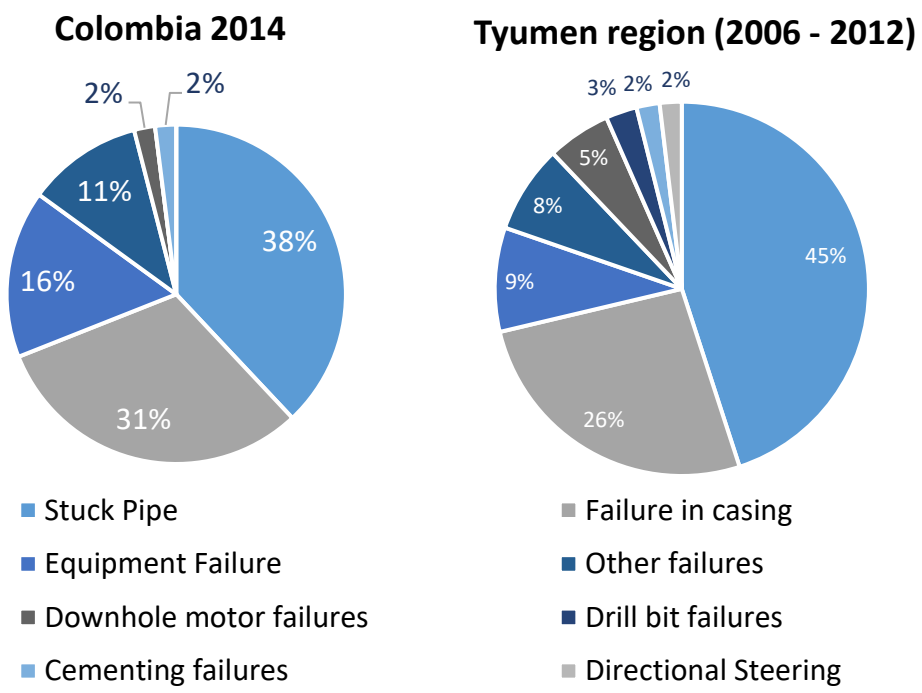
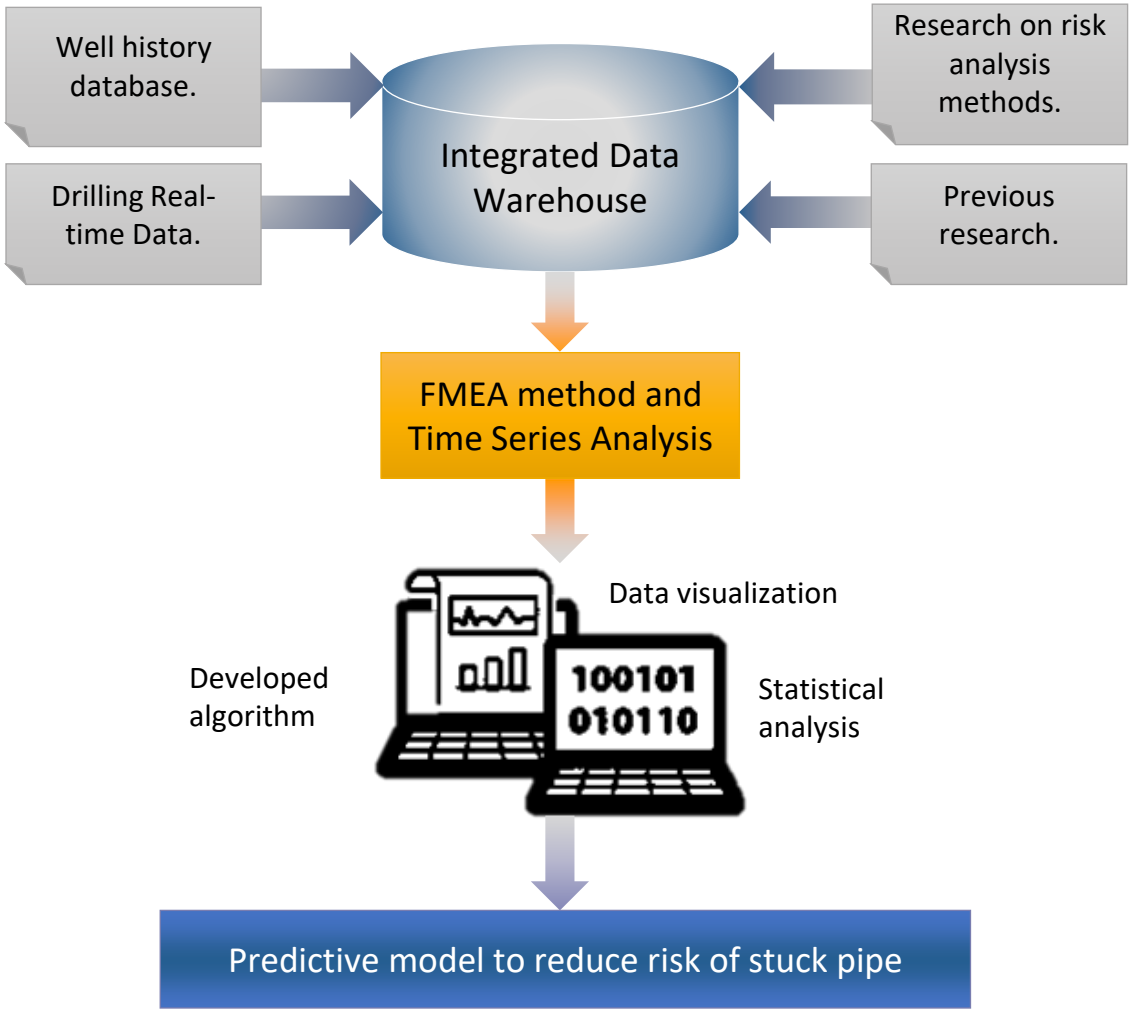
Objective

The aim of this study is to develop a prediction tool, that reduces the risk of stuck pipe during horizontal drilling.

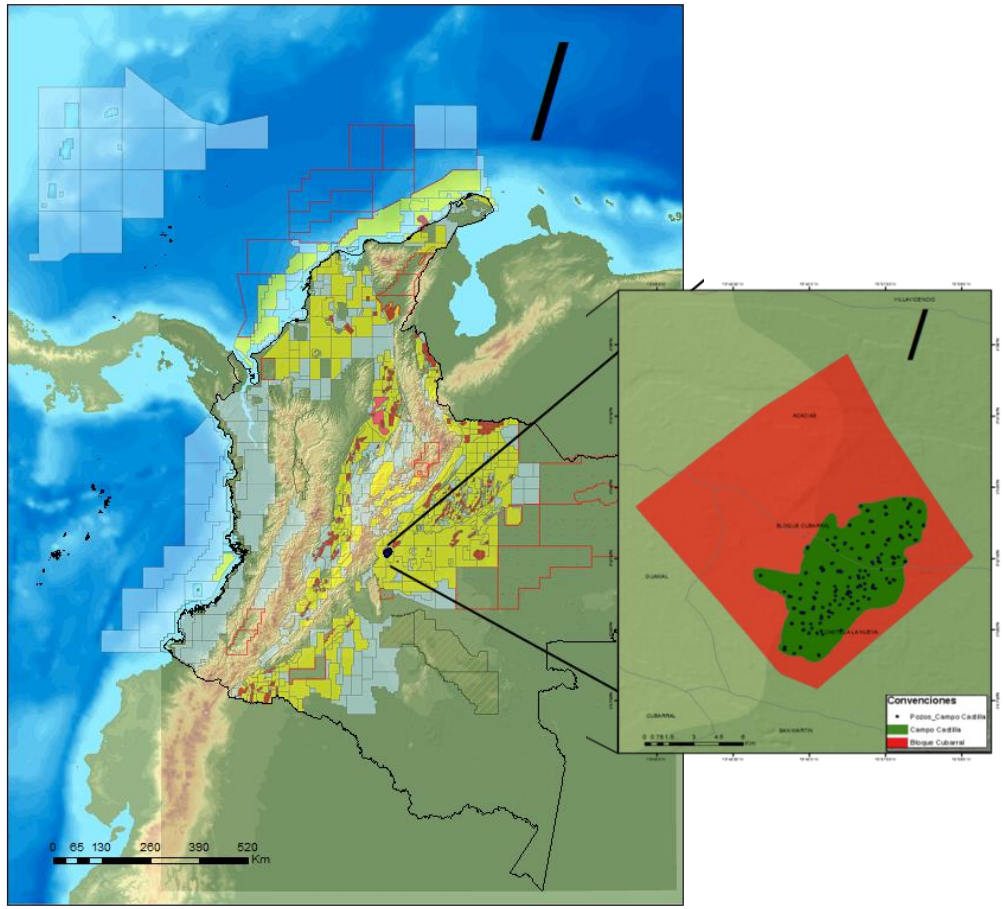
Distribution of failures





Методика оценки качества строительства скважин ОАО «Татнефть». РД 153-39.0-349-05.

Case Study Colombian field



Well name	CK 1	CK 2	CK 3	CK4	CK5
Complication	Unconsolidated formations	Lost of Circulation	No	No	Ledges at 2299
End depth, m.	2376	2842	2122.8	2786.2	2582.3
Symptom	**Value**				
HKL High (s). 1000 lbf	460	214	180	190	240
Torque Cumulative High (s). klbft	24	22	13	15	20
Well Inclination High (ss). °	77.49	69.25	68.74	61.24	87.59
Well P Too High (err). PSI	2230	1800	1700	2106.9	1600
ROP High (s)	37.7	46	27.72	34.71	112.5
RPM High (s)	150	110	70	82	140
WOB High (s). 1000 lbf	7.8	20.5	7	40	18
Cuttings Bed Compact (i). %	7	5.8	2.6	0.63	1.07
Overpull (s). KLBS	50	50	30	0	0
LC To Naturally Fractured Fm (f). Bbl/hr	0	250	0	0	0
Fm Soft (s)	K1 sup	Shale interspersed with quartz sandstones			
Fm Permeable Expected (s)	K1 inf	Fine Quartz Sandstones			

Vertical profile at 65° [m]

FMEA method

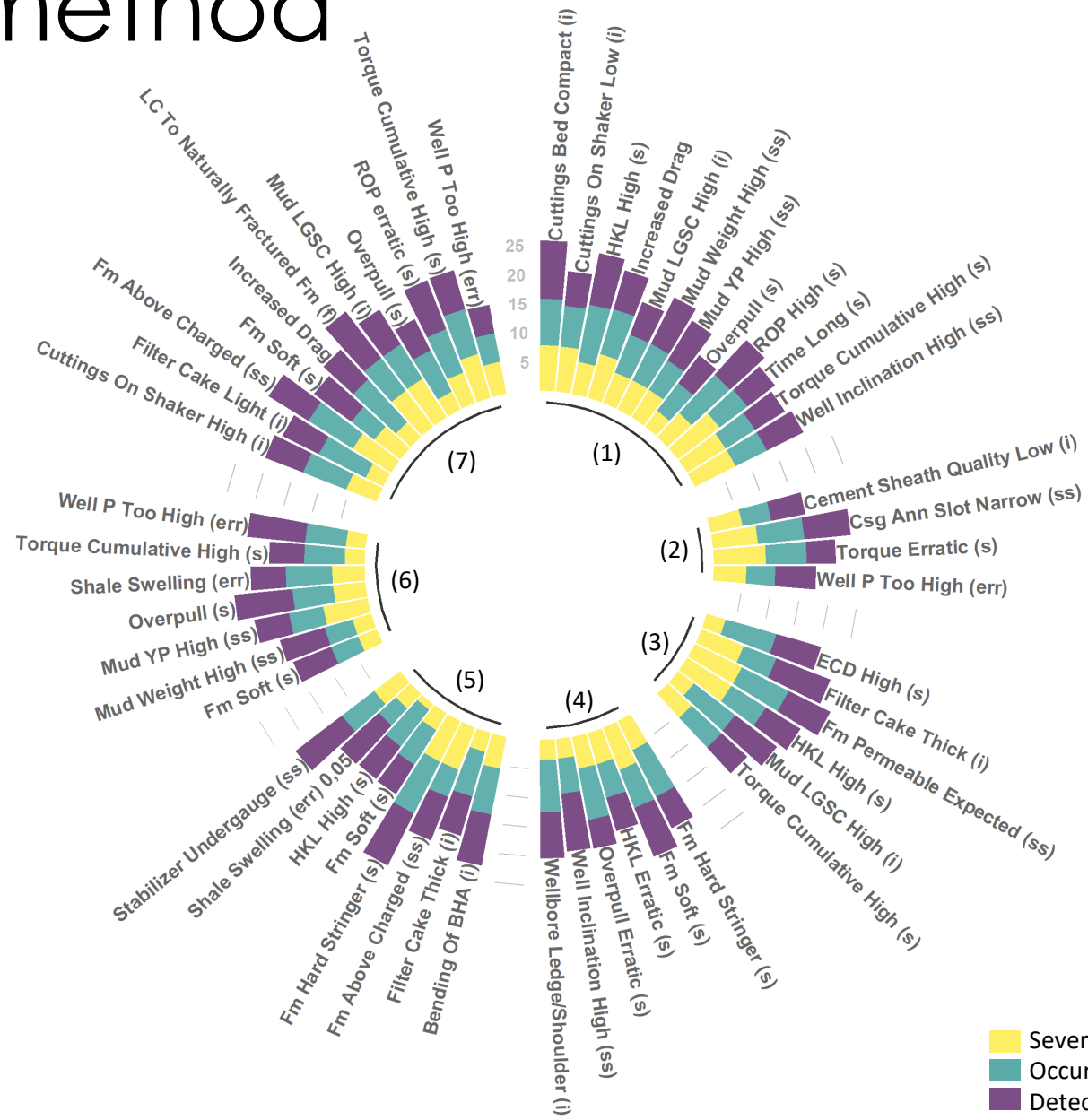
FMEA method (Failure Mode and Effects Analysis) allows the assessment of risks and possible errors in the system, and the ability to classify all symptoms in relation to their causes and resulting consequences.

The following algorithm is used to calculate the risk priority number (RPN) for each emergency mode:

RPN = Severity x Occurrence x Detection

From symptom	Relation strength	To Complication	
Cuttings On Shaker Low (i)	7.9	Accumulation of drilled cutting	(1)
Torque Erratic (s)	6.9	Cement or junk in the hole	(2)
ECD High (s)	8.5	Differential sticking.	(3)
Well Inclination High (ss)	5.8	Key seating	(4)
HKL High (s)	7.5	Ledges	(5)
Torque Cumulative High (s)	6.5	Shale instability	(6)
LC To Naturally Fractured Fm (f)	6.1	Unconsolidated formations	(7)

*Causal relation strength varies from 10 to 0 according the RPN.



Time Series model

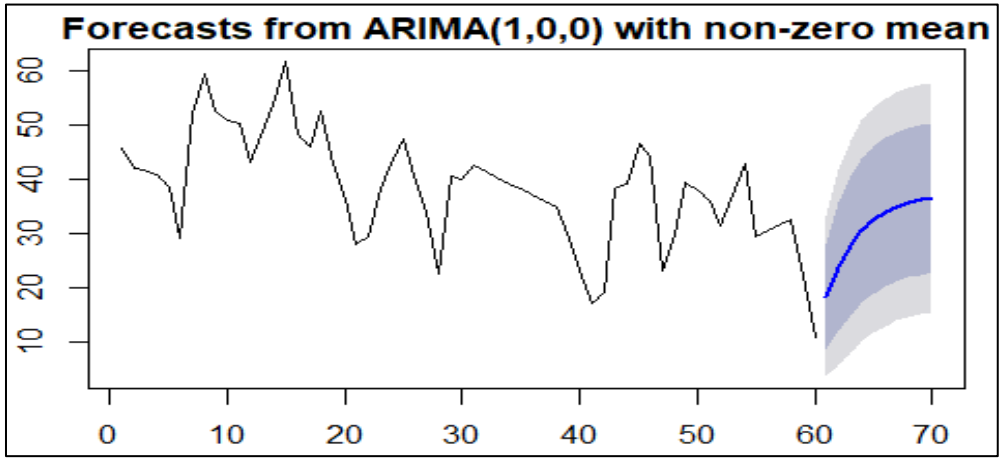
In time series analysis, an autoregressive integrated moving average (ARIMA) model is fitted to time series data to better understand the data or to predict future points in the series (forecasting).

1 The ARIMA model was run with the wells data in which there were not problems of stuck pipe.

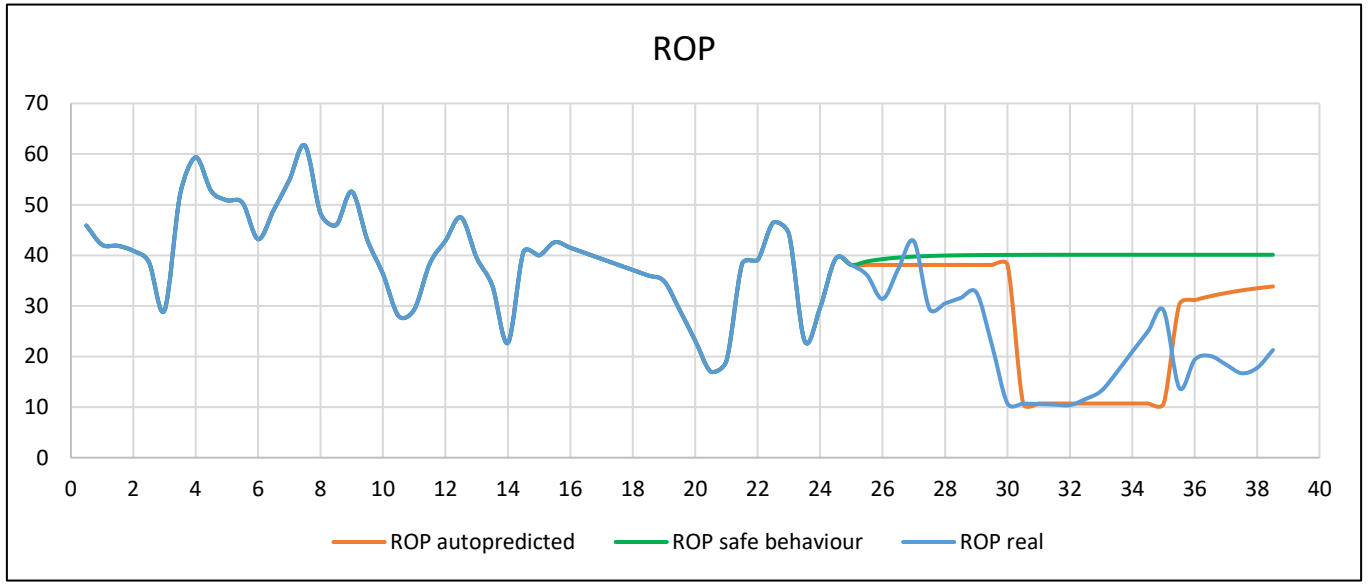
2 The previous models results were verified, identifying similar parameters to stablish the prediction formula.

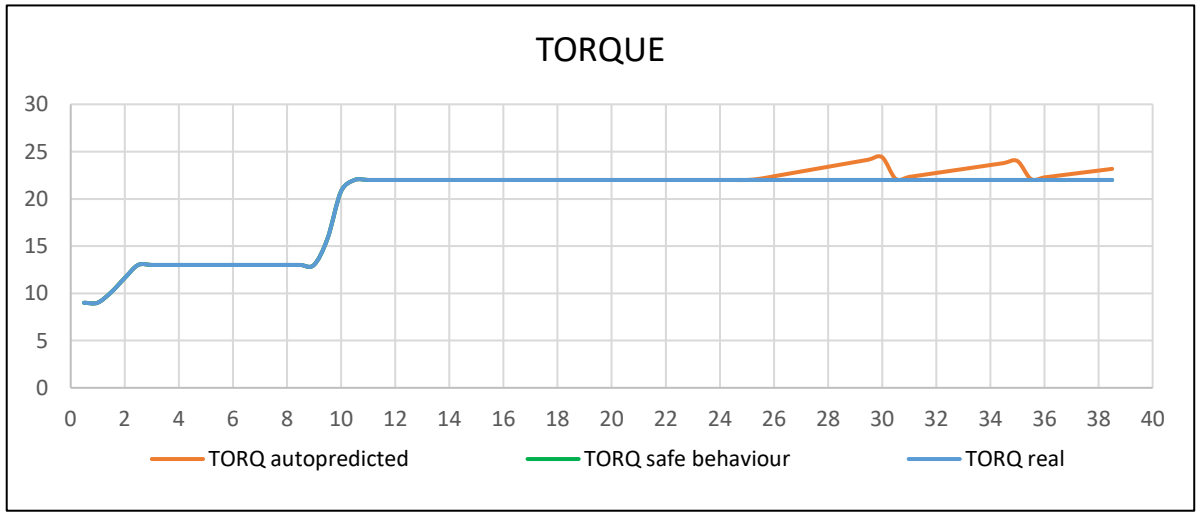
3 The save behavior of the CK1 well was forecast every 5 hrs. with the previous parameters.

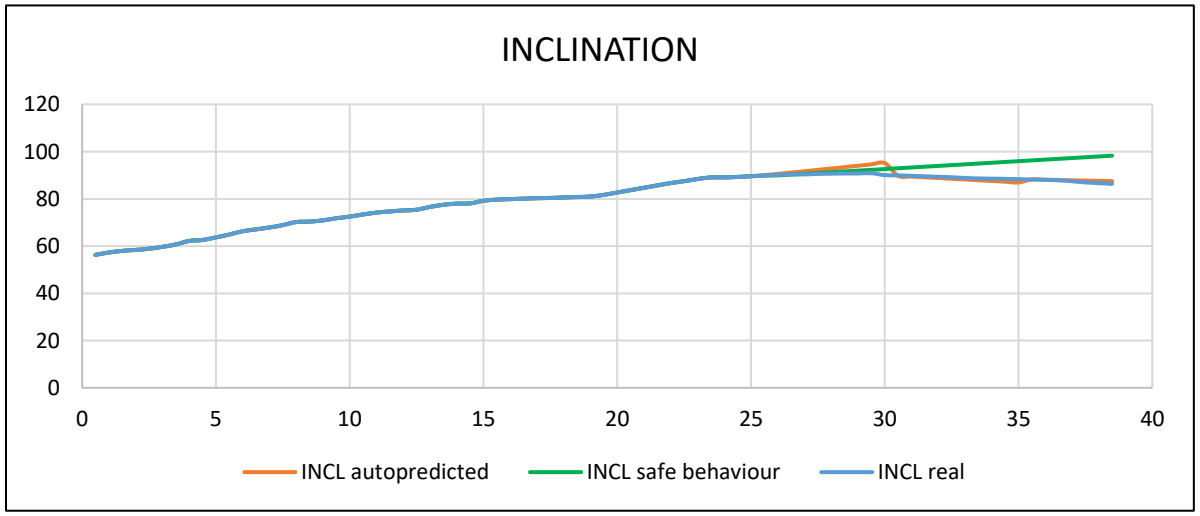
		CK2 (p,d,q)	CK3 (p,d,q)	CK4 (p,d,q)	Formula
ROP	ft/h	(1,0,0)	(1,0,0)	(1,0,0)	ROP $\hat{Y}t = \mu + \phi 1 Yt\text{-}1$
WOB	1000lbf	(2,0,0)	(0,1,0)	(0,1,0)	
TORQ	1000ft.lbf	(0,1,0)	(0,1,0)	(0,1,1)	TORQ $\hat{Y}t = \mu + Yt\text{-}1$
RPM	c/min	(0,1,1)	(1,0,0)	(4,0,0)	
INCL	deg	(0,2,1)	(0,2,1)	(0,2,1)	INCL $\hat{Y}t = 2\ Yt\text{-}1 - Yt\text{-}2 - \theta 1 et\text{-}1 - \theta 2 et\text{-}2$



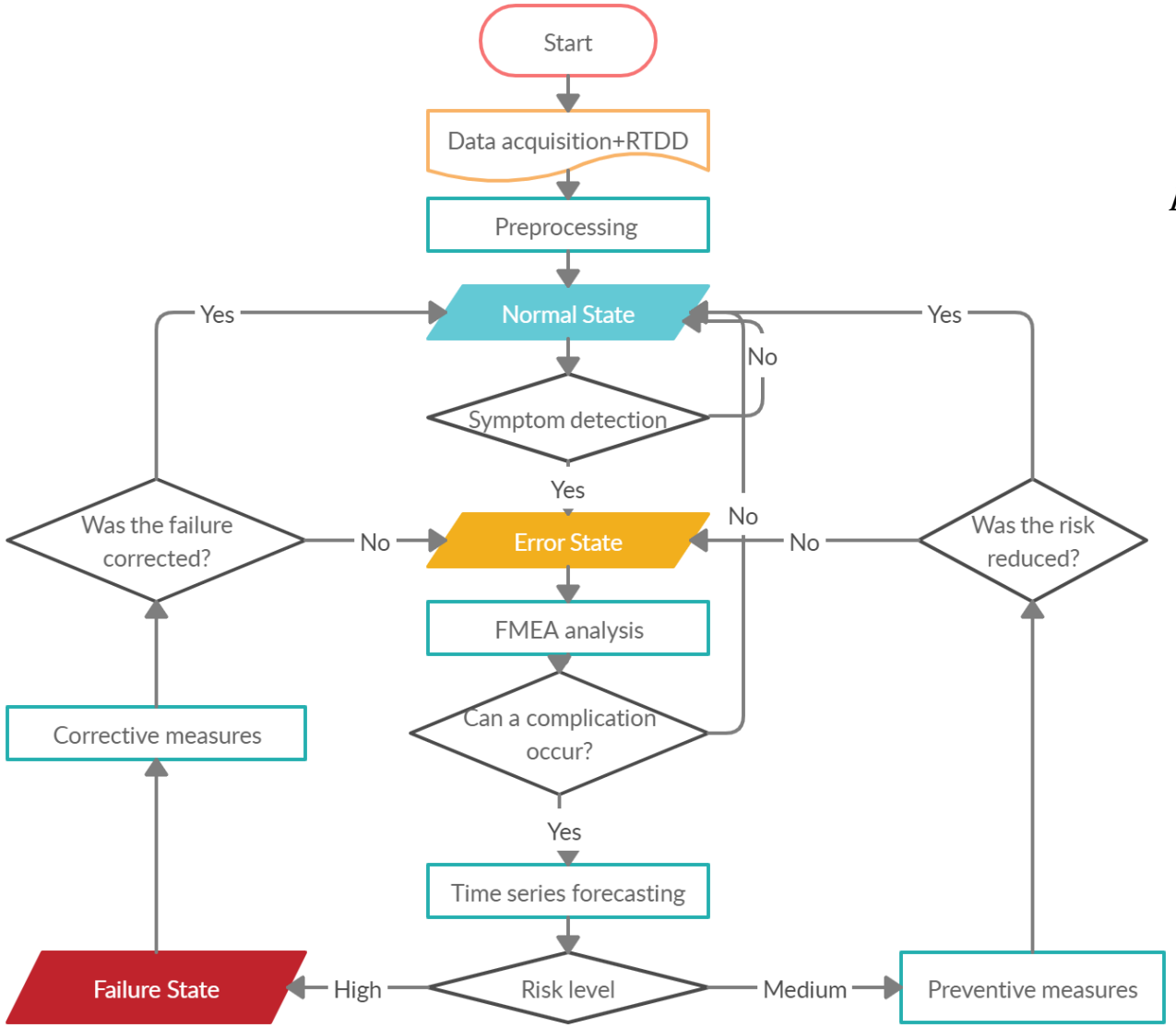
Time series predictions







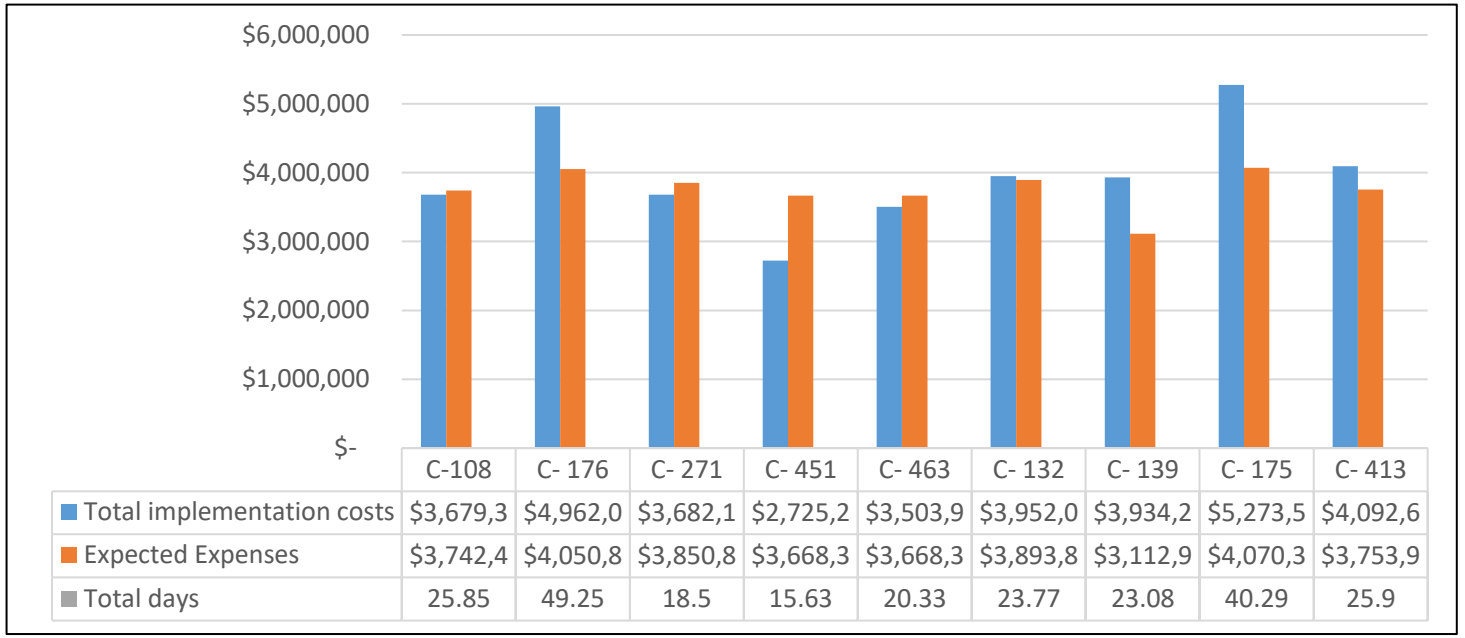
Algorithm



$$Deviation\ (\%) = \left(\frac{\hat{Y}t\ Autopredictive - \hat{Y}t\ safe\ behaviour}{\hat{Y}t\ safe\ behaviour}\right) \times 100$$

RISK LEVEL			
Alert event	**Low**	**Medium**	**High**
ROP	less than 1	from 1 to 3	more than 3
TORQUE	less than 0.96	from 0.96 to 1.05	more than 1.05
INCL	less than 0.9	from 0.9 to 1	more than 1

Economic benefits



	C-108	C- 176	C- 271	C- 451	C- 463	C- 132	C- 139	C- 175	C- 413
Total implementation costs	$3,679,3	$4,962,0	$3,682,1	$2,725,2	$3,503,9	$3,952,0	$3,934,2	$5,273,5	$4,092,6
Expected Expenses	$3,742,4	$4,050,8	$3,850,8	$3,668,3	$3,668,3	$3,893,8	$3,112,9	$4,070,3	$3,753,9
Total days	25.85	49.25	18.5	15.63	20.33	23.77	23.08	40.29	25.9

Method	Strategy	Probability of failure	Failure Cost	Product cost	Product life
FMEA	High reliability	Low	Depends on severity	$50,000	Permanent
ARIMA	Depends on the amount of data	Medium		$13,995	For each field

Conclusions

- ✓ The combination of the FMEA method and the ARIMA model is an economical tool, which uses open source programs as R studio, and can save more than **one million dollars** due to non-productive time during drilling.
- ✓ Using modern methods of risk analysis and time series models in the drilling process, it is possible **to predict** the behavior of the well in the future 5 hours, allowing the identification of complications long before they begin.
- ✓ The complications of stuck pipe were divided into 7 subcategories, along with the establishment of 33 symptoms associated with the causes and effects, in order to effectively **identify** the type of failure that may occur.
- ✓ The behavior of the drilling parameters of the CK1 well was predicted, during the drilling of a horizontal well in the section of 8 ½", the forecast was based on the historical data of the horizontal wells drilled in the same complex geological formation.
- ✓ There are many benefits including Health, safety and environmental factors, because **reacts faster** to problems with small corrections versus **large** corrections or **costly** remedial actions.

Thank you for attention!

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