Pushing the limits: Improving performance and breaking paradigms in offshore Mexico

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Abstract

Given the increased demands on the production of hydrocarbons and cost-effective for the development wells driven by the operator, the industry is challenged to continually explore new technology and methodology to improve drilling performance and operational efficiency. In this paper, two recent case histories are presented to showcase the technology, drilling engineering and real-time optimization that resulted in record drilling times.

The wells are located onshore Veracruz and shallow water in Gulf of Mexico, with numerous drilling challenges, which typically resulted in significant Non-Productive Time (NPT). With close collaboration with the operator, early planning with clear understanding of offset wells challenges, led to a well path that minimize drilling in the Upper Cretaceous "Brecha" Formation, reducing stuck pipe probabilities, while meeting the requirements to penetrate the geological targets laterally to increase the area of contact in the reservoir section. In addition, utilizing new directional drilling technology and a proven drilling engineering process to optimize the drilling bottomhole assembly, bit selection, drilling parameters and real-time optimization, which resulted in record drilling times.

The records drilling times in the two case histories can be replicated and further improved. A list of lesson learned and recommendation for the future wells are discussed. This includes the well trajectory planning, directional drilling BHA optimization, directional control plan, drilling parameters to optimize hole cleaning and vibration management to ultimately increase the drilling performance. Also, includes a proposed drilling blueprint to continually pushing the limit of incremental drilling performance in the Jurassic geological formation in shallow waters, Gulf of Mexico.

Keywords: Shallow waters, Gulf of Mexico, Jurassic geological formation, offshore.

Superando los límites: Mejorando el performance y rompiendo paradigmas en costa afuera en México

Resumen

Dada la creciente demanda en la producción de hidrocarburos y eficiencia en costos para pozos de desarrollo dirigida por los operadores, la industria está siendo desafiada a explorar continuamente nuevas tecnologías y metodologías para mejorar el desempeño de la perforación y la eficiencia operacional. En este artículo, se presentan dos casos recientes para mostrar la tecnología, ingeniería de perforación y optimización en tiempo real, la cual resultó en tiempos record de perforación.

Los pozos están localizados en aguas someras del Golfo de México, con numerosos desafíos a la perforación, los cuales típicamente resultan tiempos no productivos (TNP) significativos. Con la colaboración cercana del operador, planeación temprana con un entendimiento claro de los retos en los pozos de correlación, condujeron al diseño de una trayectoria direccional que minimiza la perforación en el Cretácico Superior (Brecha), reduciendo las probabilidades de atrapamiento mecánico, cumpliendo los requerimientos de perforar a través de los objetivos geológicos en forma lateral para incrementar el área de contacto en la sección del yacimiento. Además, utilizando nueva tecnología y un proceso probado de ingeniería para optimizar el ensamble de perforación (BHA), la selección de barrena, parámetros de perforación y monitoreo en tiempo real condujeron a tiempos record de perforación.

Los tiempos record de perforación en los dos casos pueden ser replicados y mejorados. Una lista de lecciones aprendidas y recomendaciones para pozos futuros es discutida. La lista incluye planeación de la trayectoria, optimización de ensambles de fondo direccional, plan de control direccional, parámetros de perforación para optimizar limpieza de pozo, administración de las vibraciones para finalmente incrementar el desempeño de la perforación. Además, se incluye un plan de perforación con el que continuamente se puedan superar los límites del desempeño de la perforación en la formación geológica Jurásico en aguas someras del Golfo de México.

Palabras clave: Aguas someras, Golfo de México, formación geológica Jurásico, costa afuera.

Introduction

The Ek-Balam oilfield, part of the Cantarell field, is located 80 km offshore in the Bay of Campeche and approximately 95 km northwest of Ciudad del Carmen. The Cantarell field is an aging supergiant that is by far the largest oil field in Mexico and one of the largest in the world. Its reservoirs are formed from carbonate Brecha (late Cretaceous), resultant rubbles from the asteroid impact that created the Chicxulub Crater. In this paper, an analysis of the drilling performance of the last two wells (Balam-3 & Balam-63) recently drilled that resulted in substantial operator's drilling costs savings; in equipment rental time, personnel and zero non-productive time (NPT) during the jobs. Using the repeated successes in the Balam oilfield, a planning and execution plan is laid out to demonstrate that incremental drilling performance to achieve the technical limit is possible through application of new rotary steerable technology, strict Drilling Engineering & Operational Process discipline and close collaboration with the operator.

EK-Balam Oilfield: Meeting the Mexico energy demand

The Cantarell Complex is a mature oilfield, in the stage of frank decline, however, it still has opportunity for continued exploitation, particularly in rocks of the Upper Jurassic Kimmeridgian age (Juárez/Acededo, 2016). The strategy in mature fields demands an exhaustive analysis of all the variables that lead to very stringent exploitation strategy, to make the reserves economically viable. In the case of Balam field, it is in the late development stages, presenting a constant challenge given the depletions and structural complexity (Jurassic) presented in it. (Juárez/Acededo, 2016). Major drilling challenges observed in this field included losses, stuckpipe, wellbore instability and delays due to weather conditions, attributing to an average NPT of 45% in the Balam oilfield. Furthermore, the changes in tectonic regime, transgressions and sea level regressions further exacerbate the drilling challenges. In **Figure 1**, a generalized lithologies of the Balam oilfield is presented.

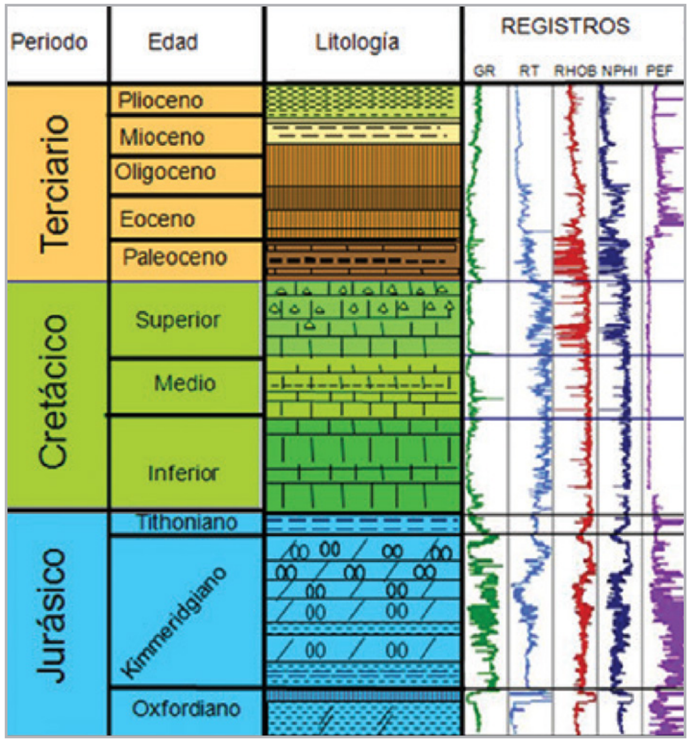


Figure 1. Geological Column Type of the Balam Field. (Juárez-Acevedo, 2016).

Plan and execute with success

In planning the Balam-3 & 63 wells, the standardized drilling engineering process was adopted and strictly adhered. The Drilling Engineering process, **Figure 2,** is designed to provide a standardized step to safely achieve technical limit and accurately position wells through the lifecycle of a job. To start, early collaboration between the operators, service companies and rig contractor allowed alignment within the team especially when establishing the Scope of Work (SOW) for the project. This includes superimposing the technology capability with the drilling challenges and associated risks. Generalized example of SOW are directional profile with target DLS, casing exit procedures, logging requirement etc; specific to a target well.

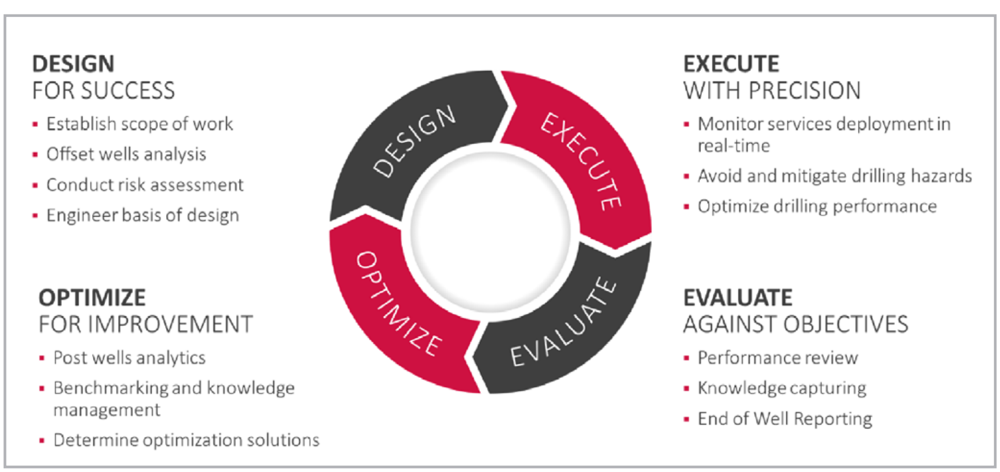


Figure 2. Drilling engineering process.

Design phase

Offset Analysis & Risk Assessment

Offset wells were analyzed to prepare the well specific drilling program, including possible challenges and hazards that were detected during the drilling of those offset wells.

Additional barriers are put in place to further reduce the risk of drilling hazards to as low as reasonably feasible (ALARP). Collaboration and good communication with the operator are critical to obtain quality offset well data to achieve accurate risk profile, as well as contingency planning (if required) to ensure successful operations. Summary of the key drilling hazards, which are primary causes of NPT, categorized by formations, **Table 1**.

Formations	Brecha KS	JSK, Terrigenous, Upper Anhydrite
Drilling Hazards / Risks	• Shock & Vibrations leading to downhole tool failure (Low frequency torsional oscilation as bit stick slip) • Solids induced pack-off Stuck Pipe due to total losses. • Lost circulation • Hole Cleaning issues	• Shock & Vibrations leading to downhole tool failure (High frequency torsional oscilation HFTO on anhydrite) • Mechanical Stuck Pipe due to ledges on anhydrite • Lost circulation • Hole Cleaning issues • Wellbore instability • Differential Stuck Pipe in sands of Jurassic.

Table 1. Drilling Hazards in the Balam field.

According to offset wells in the Ek-Balam Field, the fastest well drilled was Balam 99Iny, which was drilled in 90 days, Balam 43 was drilled in 145 days, Balam 13 was drilled in 180 days and Balam 75 was drilled in 290 days, **Figure 3.**

When the offset well data for the field was analyzed, it showed that 45% of the rig time was Non-Productive Time, **Figure 4** due to several issues related to Hole stability, Directional Drilling Tool Failures, Logistics and Bad Weather conditions.

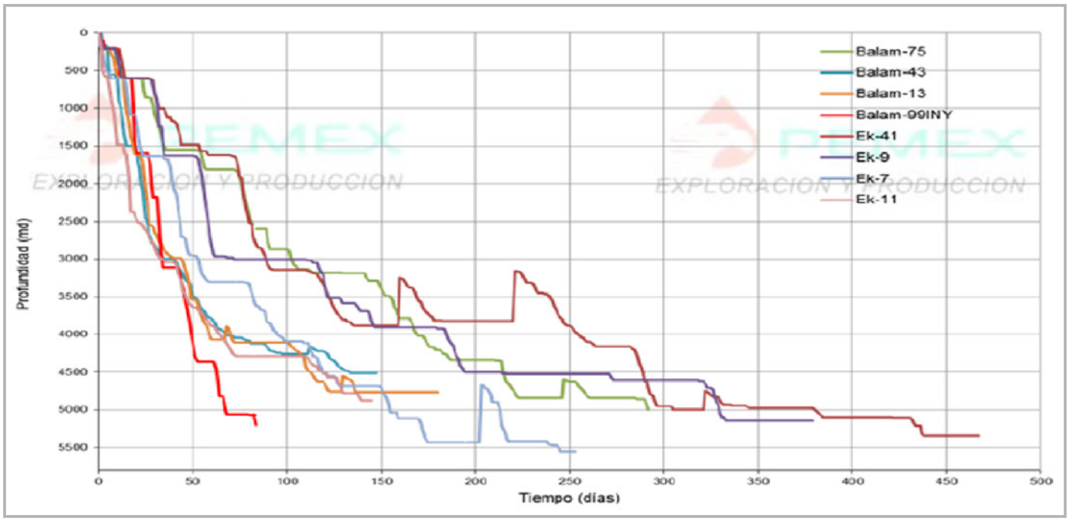


Figure 3. Days vs depth plot - EK & Balam wells with NPT.

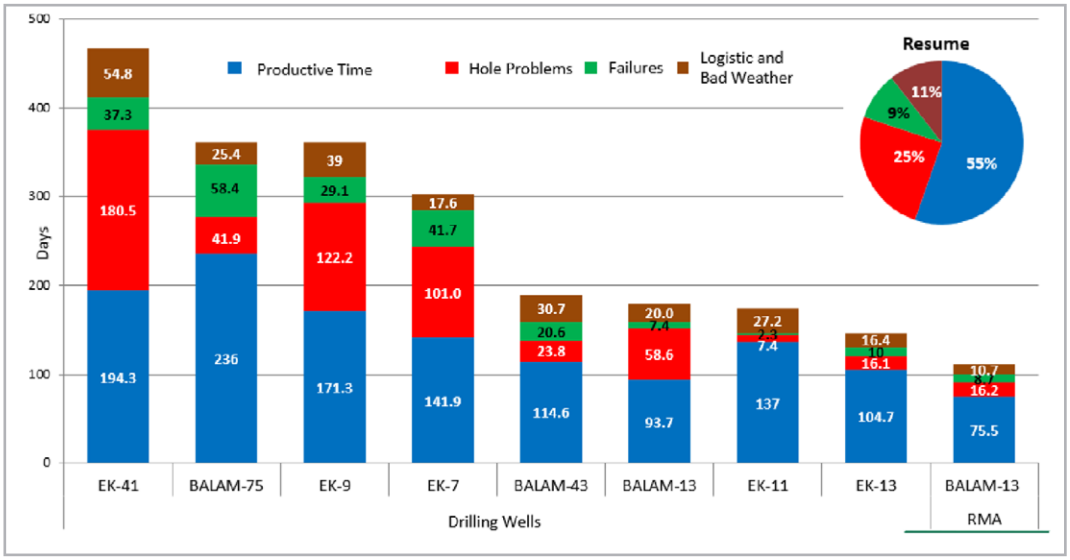


Figure 4. Days vs depth plot - EK & Balam wells with NPT.

From the offset well analysis and comprehensive risk assessment conducted, a risk mitigation plan was designed together with the operator, with the goal of improving drilling performance by reducing the 8-1/2in hole section drilling times and NPT. Summary of the key items are listed below:

1. Utilize the latest “Push-the-Bit” RSS technology to evaluate drilling performance against conventional drilling BHA benchmarks, reducing under gauge stabilization to ¼” to minimize contact area wich translate in lower friction and lower torsional oscillation in addition to high rpm during operations (avobe 180rpm) to reduce stick slip vibrations.
2. Inclusion of LWD and PWD (Pressure While Drilling) in the BHA with real-time data transmission.
3. Due to the stuck pipe and wellbore instability, minimize stabilization in the BHA.
4. Downhole sensors in the RSS for real-time monitoring of shock & vibration dysfunctions.
5. Low wellbore tortuosity to aid casing running operations.
6. The communication and programming of the tools should be bidirectional, for controlling efficiently the build up rate in real time and avoid undesired dogleg severity.
7. Use of industry best practices for hole cleaning, backreaming & tripping procedures.
8. Monitor the DEC in real time to corroborate a correct cleaning of the hole.
9. Jar placement design for contingency stuck pipe risk.
10. In the anhydrite zone, drill tangentially to avoid mechanical entrapment.
11. Real-time drilling parameters monitoring through the RTOC in Ciudad del Carmen at the operator’s offices.

BHA design - Rotary steerable sysem

A new RSS design was proposed, which is based on “Push-The-Bit” technology, which has a maximum stabilization diameter of 1/4” under hole gauge. The new RSS utilizes 3 independent steering pads that can steer the well at up to 300 RPM. Each pad is driven by drilling mud and hydraulically independent of each other. These features improved the reliability of the RSS.

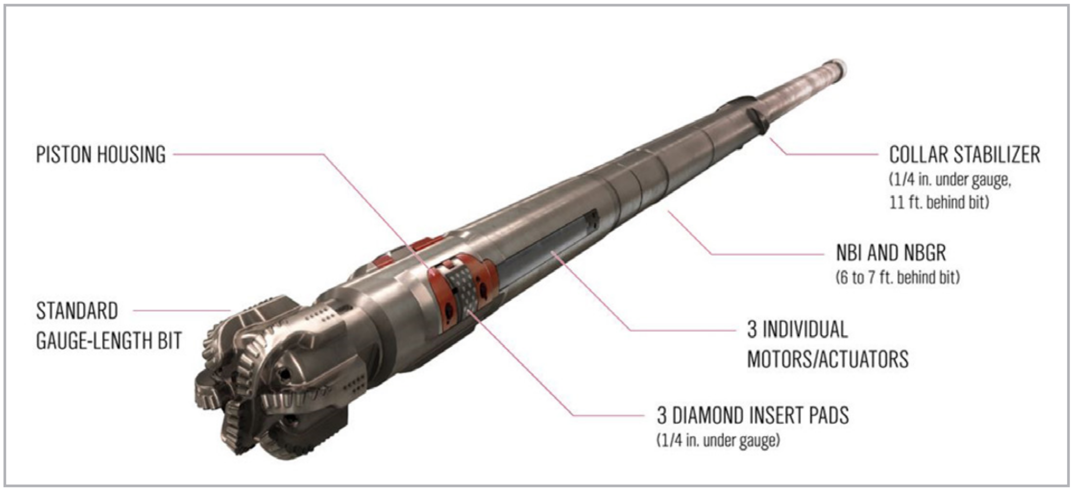


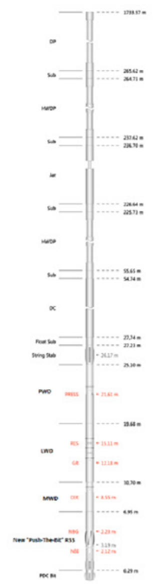
Figure 4. Schematic of the RSS used in the Balam-3 & Balam-63.

By analyzing the drilling performance of different RSS BHA's in the offiset wells, we observed that the ROP in some formations was controlled to achieve the desired Build Up Rate (BUR). To avoid the same issue with controlled ROP, the RSS was configured with a flow restrictor to reach optimal differential pressure on the RSS steering pads allowing more lateral push force to deviate the Bit to achieve planned DLS. Proprietary drilling engineering software was used to validate the RSS BHA configuration and ensure the required DLS for the well trajectory was achievable.

A PDC Drill Bit was chosen to achieve TD in a single run, with specialized cutter technology for specific applications that may require increased abrasion resistance or increased thoughness, with very low friction surface, that allows the formation chips to flow more freely, providing both improved ROP and greater drilling efficiency, at the time that a Taper Passive Gauge deliver maximum gauge contact, lowering resistance to steer by reducing torque, and leading to improve the ROP and extending Bit and directional tools life.

Using proprietary drilling engineering software and criteria, additional design checks were performed to ensure the drilling BHA is fit-for-purpose, including:

1. BHA stabilization optimized using industry guidelines, (Pastusek, 2018). Modeling results and local field experience concur on a slick drilling assembly with single string stabilizer.
2. Torque & drag analysis to model potential buckling risk, hookload and torque requirement for the hole section.
3. Hydraulics modeling to optimize hole cleaning for the well profile, sufficient flow rate to downhole tools and ensure operational ECD is within the drilling window.
4. Bit nozzles optimization to provide HSI > 1.5 for the 8-1/2in hole.
5. VME & Bending Stress of all drillstring components are within limits for all operations
6. Time Domain static and vibration analysis provided a Critical Speed Map to highlight the optimum drilling parameters to avoid downhole lateral, axial and torsional vibrations.
7. Driller's Roadmap designed to optimized ROP by formations.
8. Jar Placement optimization using stress-wave analysis to ensure the jar is placed in the "sweetspot" with sufficient DCs and/or HWDPs setup above and below the jar.



General				Connections		Dimensions			Length		
Item #	ItemDescription	Serial Number	Qty	Connection Type		Body OD	Body ID	Max OD	Item Length	Tot Length	Tot Acc Length
				Bottom	Top	in	in	in	m	m	m
17	G105 25.6# Drill Pipe		1	XT50	XT50	5.000	3.750	6.050	9.35	9.35	1733.57
16	G105 19.5# Drill Pipe		156	XT50	XT50	5.000	4.000	6.000	9.35	1458.60	1724.22
15	Sub		1	NC50	XT50	6.500	2.810	6.500	0.91	0.91	265.62
14	HWDP		3	NC50	NC50	5.000	3.000	6.630	9.03	27.09	264.71
13	Sub		1	NC50	XT39	6.750	2.810	6.750	0.91	0.91	237.62
12	Hydraulic Drilling Jar		1	NC50	NC50	6.500	2.750	6.500	10.06	10.06	236.70
11	Sub		1	XT39	NC50	6.500	2.810	6.500	0.91	0.91	226.64
10	HWDP		18	XT39	XT39	5.000	3.000	5.000	9.45	170.08	225.73
9	Sub		1	NC50	XT39	6.500	2.810	6.500	0.91	0.91	55.65
8	Drill Collar		3	4-1/2 IF	4-1/2 IF	6.500	2.810	6.500	9.00	27.00	54.74
7	Float Sub		1	4-1/2 IF	4-1/2 IF	6.750	2.810	6.750	0.50	0.50	27.74
6	String Stabilizer		1	4-1/2 IF	4-1/2 IF	6.750	2.250	8.380	2.13	2.13	27.23
5	PWD		1	4-1/2 IF	4-1/2 IF	6.750	2.000	7.380	5.42	5.42	25.10
4	LWD		1	4-1/2 IF	4-1/2 IF	6.750	2.000	7.380	8.99	8.99	19.68
3	MWD		1	4-1/2 IF	4-1/2 IF	6.750	2.000	7.130	3.75	3.75	10.70
2	New 'Push-The-Bit' RSS		1	4-1/2 REG	4-1/2 IF	6.750	1.000	8.500	6.66	6.66	6.95
1	PDC Bit		1	-	4-1/2 REG	8.500	3.000	8.500	0.29	0.29	0.29

Bit Information	
Type:	PDC Bit
Nozzles:	7
TFA :	0.74, in²
Blade Cnt:	7

Non-mag Spacing	
Az. Error:	0
Bp:	217.65, nT
Method:	Long Collar

Sensors	
Sensor	Offset (m)
NBI	2.12
NBG	2.23
DIR	8.55
GR	12.18
RES	15.11
PRESS	21.61

Stabilizers					
Description	Blade OD (in)	Mid Blade Offset (m)	JSA (%)	Wrap Angle (deg.)	Taper Angle (deg.)
STAB_2	8.38	26.17	25	330.00	30
STAB_1	8.25	3.19	35		30

Figure 5. BHA design used in Balam 3, Balam 9, Balam 31 and Balam 63 wells.

BHA design - Downhole sensors

To comply with the programmed DLS and to minimize wellbore tortousity, real time directional sensors were utilized. These near-bit sensors accurately measure the tendency of the inclination while drilling, allowing the directional driller to monitor and make timely steering corrections to avoid a micro-dogleg – a typical consequence of aggressive directional work. Micro-doglegs result in a tortuous wellbore that significantly increase the downhole torque & drag and risk of mechanical stuck pipe. The chosen Rotary Steerable System also aided in this effort due to its proportional steering capability which also greatly reduces micro-doglegs in the well providing a significant improvement in tortuosity. Using a proprietary firmware, the MWD tool was able to provide Real-Time Inclination, (DINC) and Azimuth (DAZM) while drilling.

The table above, **Figure 6** show us the value of the Near-Bit Inclination sensor, and the data in green, shows the extrapolated Dog Leg in 30 meters that Field Engineers can expect in the survey, according the trend of the NBI of the last 4 meters, 6 meters, 8 meters and 10 meters drilled.

Depth	NBI	4 m	6 m	8 m	10 m	Depth	NBI	4 m	6 m	8 m	10 m
3817	12.02	2.03	2.25	2.33	1.92	3824	11.59	2.33	2.65	2.29	2.40
3818	11.90	2.63	2.15	2.48	.27	3825	11.88	-.15	1.20	1.13	1.11
3819	11.88	2.10	2.05	2.21	2.28	3826	11.55	2.48	1.75	2.14	1.95
3820	11.74	2.63	2.55	2.21	2.46	3827	11.28	2.33	3.10	3.15	2.70
3821	11.69	2.48	2.35	2.25	2.34	3828	11.04	4.13	4.20	3.23	3.24
3822	11.55	2.63	2.70	2.63	2.34	3829	11.00	6.60	2.95	3.38	3.36
3823	11.48	3.00	2.70	2.55	2.43	3830	11.01	4.05	2.90	3.26	2.67
3824	11.40	2.55	2.50	2.59	2.55	3831	10.81	3.52	5.35	2.93	3.27
3825	11.27	3.15	3.05	2.81	2.67	3832	10.80	1.80	3.75	2.96	3.24
3826	11.19	2.70	2.75	2.66	2.70	3833	10.89	-.82	1.95	3.71	2.10

Figure 6. Example of inclination information in real time.

The accuracy of the Near-bit inclination sensor improves as the hole increases inclination. Therefore, when inclination is less than 5 degrees, the tool is less precise than with holes greater than 5 degrees of inclination. It can be said that as the inclination is being built, inclination and azimuth observed in real time becomes more stable and can be taken as a reference to calculate the Build Up Rate (BUR) and Turn Up Rate (TUR) of the drill string, **Figure 7**.

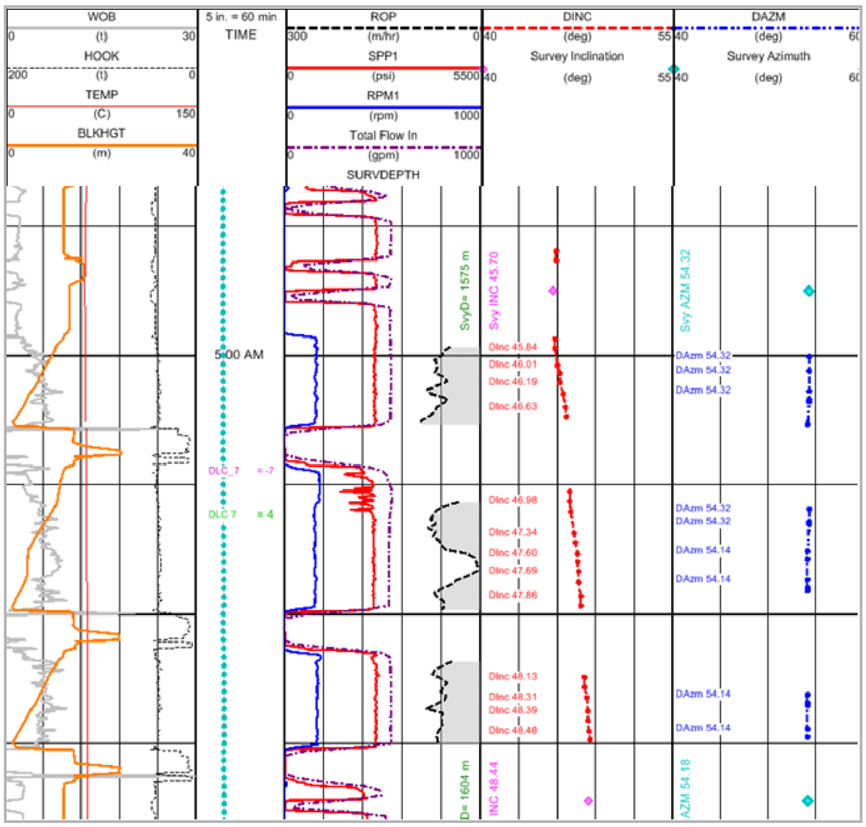


Figure 7. Example of results of DINC and DAZM vs. Official Survey.

Bi-Directional Downhole Tool Communication

In the offset wells, one of the significant invisible loss time was related to the programming times with a different “Push-The-Bit” RSS; recorded loss time of up to 10.45hrs per run, **Figure 8**. In Balam-3 & 63, a downlinking system to send commands automatically was utilized to reduce the loss time due to downlinking. This system diverts small percentage of the mud flow rate during the drilling process and associated negative pressure that serve as digitally coded telemetry signals. These signals are received and decoded by drilling tools placed downhole and interpreted as commands from the surface. The flow rate reductions are generated by tapping off a certain amount of the mud flow coming from the mud pump, routing it through the DLC and returning it via a bypass line directly into the mud tank, **Figure 9**.

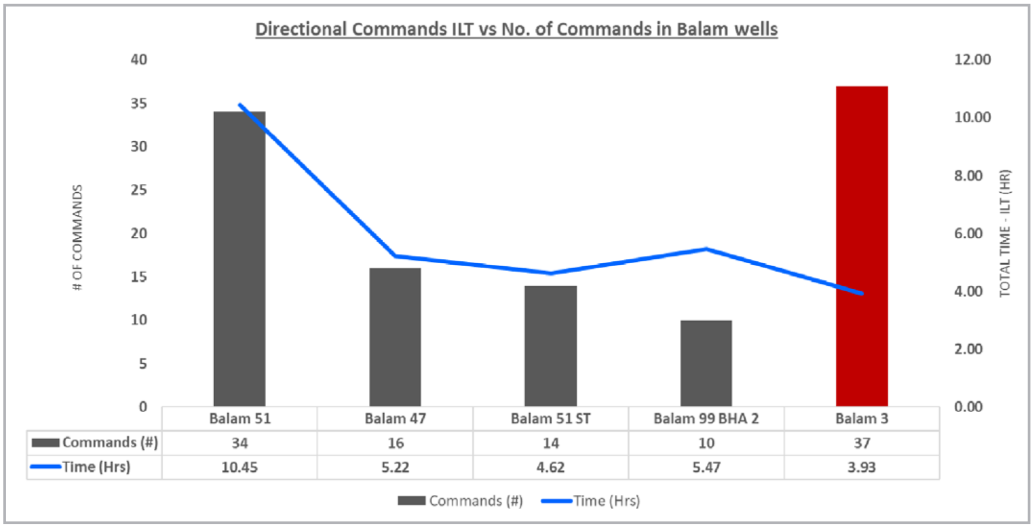


Figure 8. Invisible NPT in offset wells, Balam 3 used an automated system to downlink.

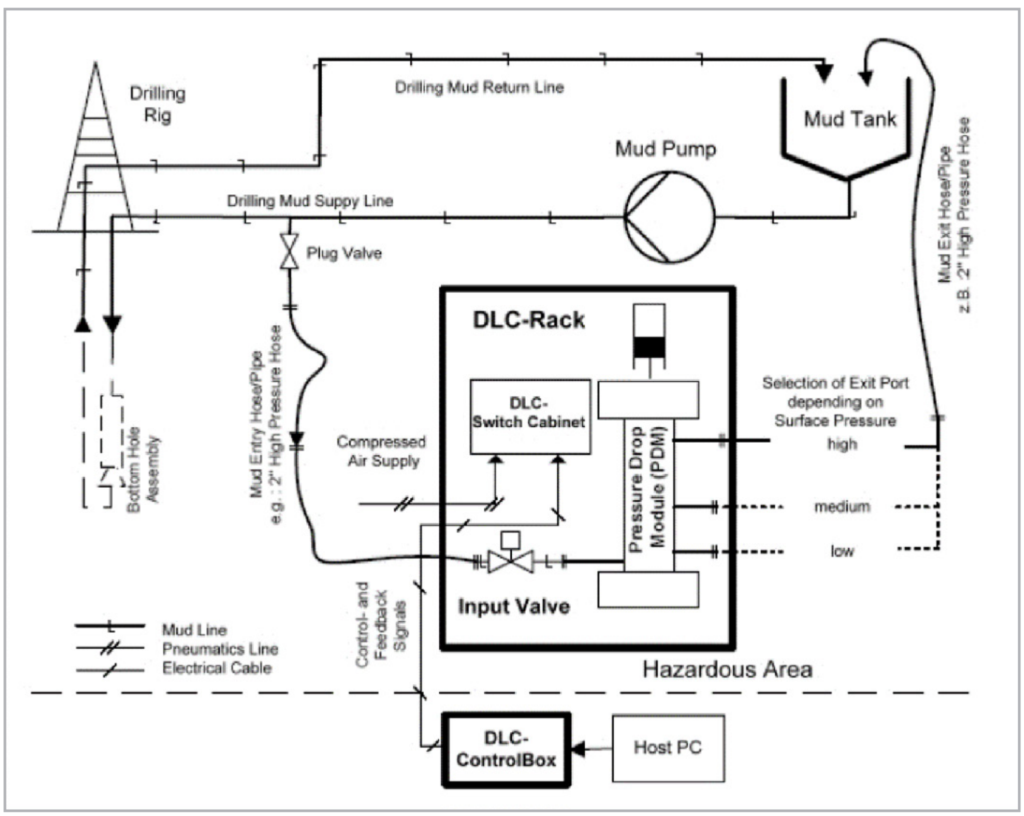


Figure 9. Diagram of DLC mud flow system, that helped to reduce invisible NPT.

Execute phase

During the execution phase, real-time data was transmitted from the rigsite via WITSML to a Real-Time Operation Center (RTOC) in Ciudad del Carmen, Campeche, the operator's offices and in Villahermosa, Tabasco, at the offices of the directional service provider to provide an environment where experts can continuously monitor drilling operations, 24 hours a day. The RTOC engineers proactively "listen-to-the-well", monitoring any trends of downhole dysfunctions, check on survey quality checks, planned drilling parameters are used in the hydraulic and T&D simulations were applied, as well as that the recommendations agreed with the operator were applied, among which the following stand out:

1. Do not build inclination in the BKS, KM, KI and JSK-T formations.
2. Maintain tangent in the anhydrite formation to avoid the generation of DL in the interspersed zone with the clay bodies.
3. Comply with the recommended parameters such as WOB, RPM and Flow Rate.
4. Timely prediction, identification and avoidance of downhole hazards
5. Ensures fit for purpose mitigation plans and techniques were implemented to prevent or mitigate NPT.

A communication protocol in the RTOC ensures efficient communication and allows for immediate corrective actions to be taken to avoid NPT or catastrophic events.

Presentation of data and results

In the evaluate phase, evaluation of KPIs for Balam-3 & Balam-63 wells vs other Balam offset wells was conducted together with the operator. The achievement in Balam-3 & Balam-63 wells are evident in **Figures 10 to 15** below.

In Balam 3 and Balam 63 wells, drilling operations were reduced by twelve (12) days and by seven (7) days in the Terrigenous formation. This improvement in drilling times represents a total cost savings for the operator of approximately $2.6 MM USD in rig time alone. Notwithstanding, the reduction in NPT in the Balam-3 & Balam-63 wells, are 47% less of NPT, and average of 24% of NPT of the total rig time, when compared against EK-Balam field average NPT of 45%.

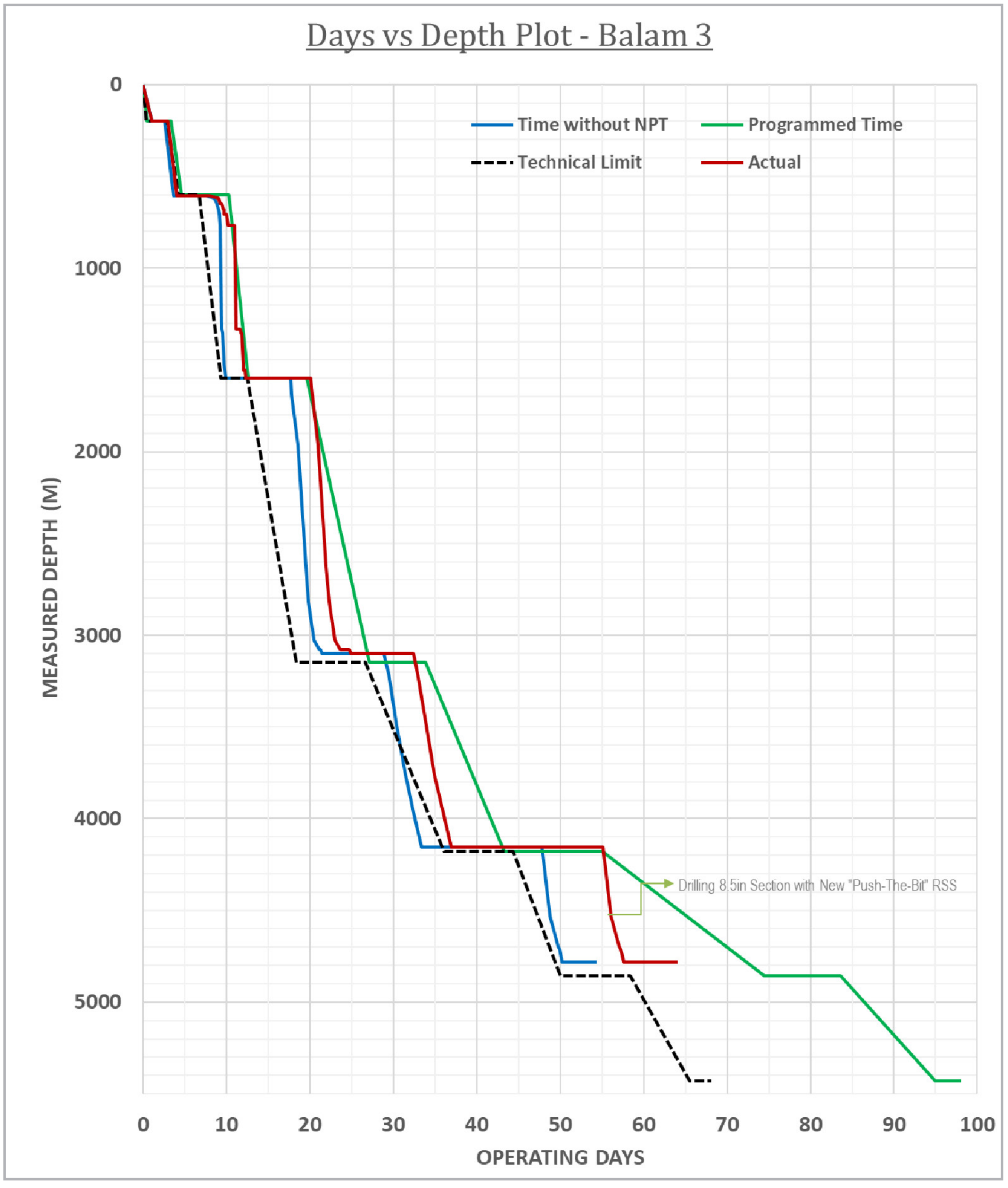


Figure 10. Balam 3 plot of technical limit vs programmed time vs actual time vs No NPT.

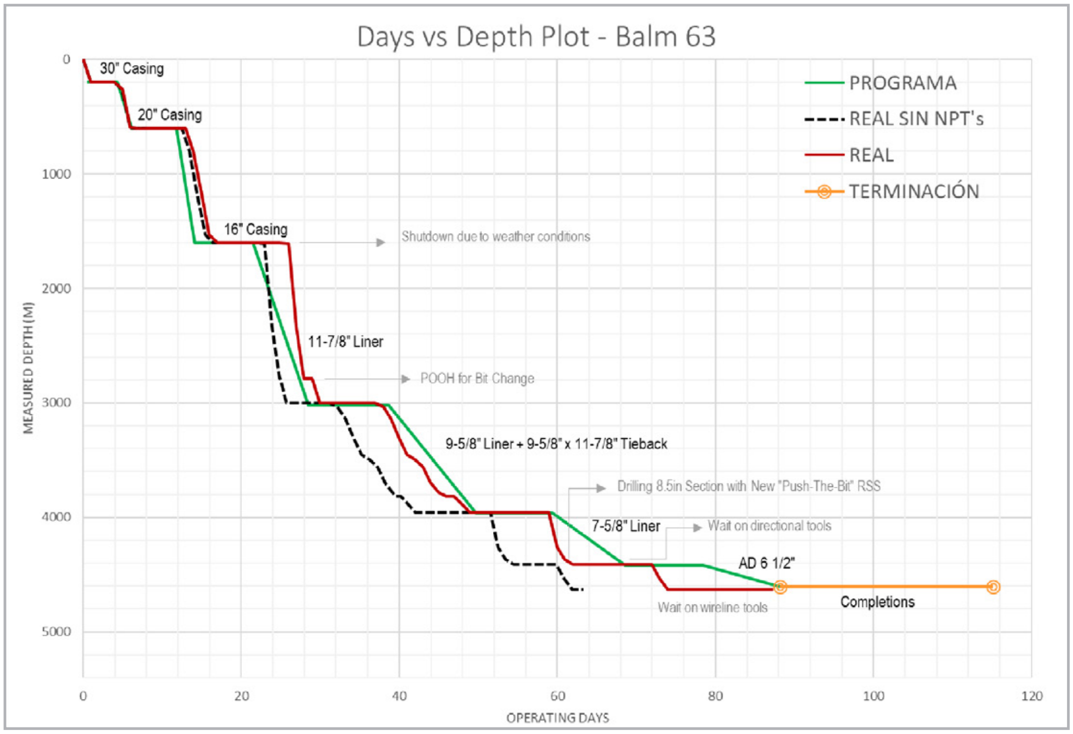


Figure 11. Balam 63 plot of technical limit vs programmed time vs actual time.

Due to the results obtained by following the process of drilling engineering, while maintaining a very close contact with the operator to know exactly the requirements, and using the latest technology in RSS "Push-The-Bit", taking it to the limit with the respective analysis of the behavior of the drill string and maintaining good levels of hole cleaning, it can be increased the efficiency of operations and performance during drilling process incrementally and repetitively, always pushing the limits to reach the technical limit and operator´s satisfaction.

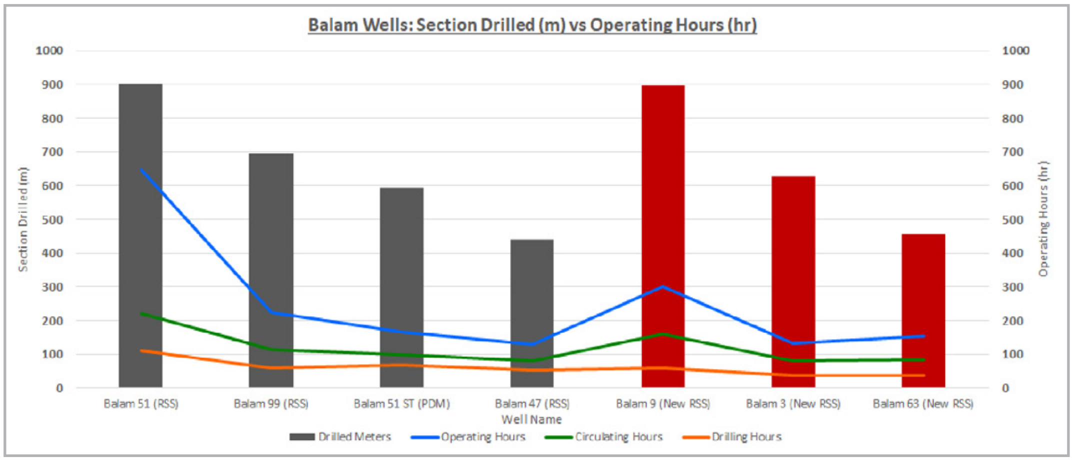


Figure 12. Depth drilled vs drilling hours vs operating hours of Balam wells.

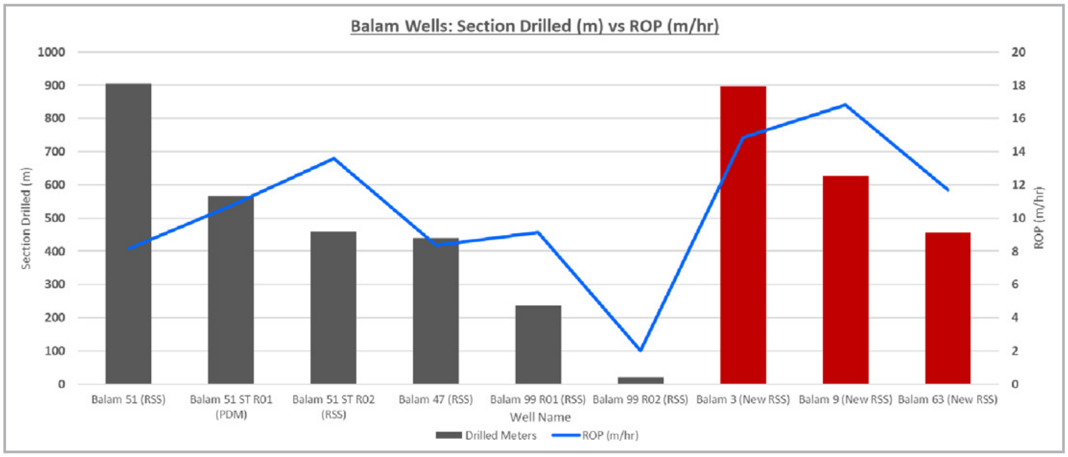


Figure 13. Depth drilled vs. ROP of Balam wells.

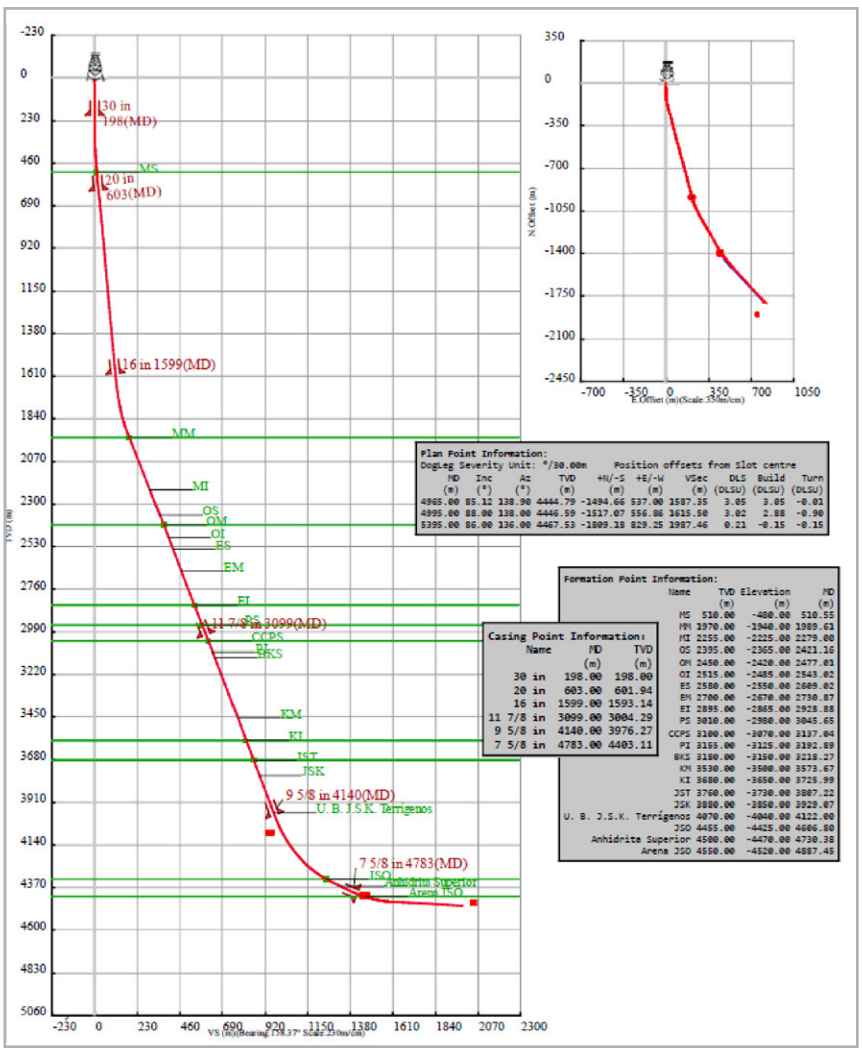


Figure 14. Plot of Balam 3 well.

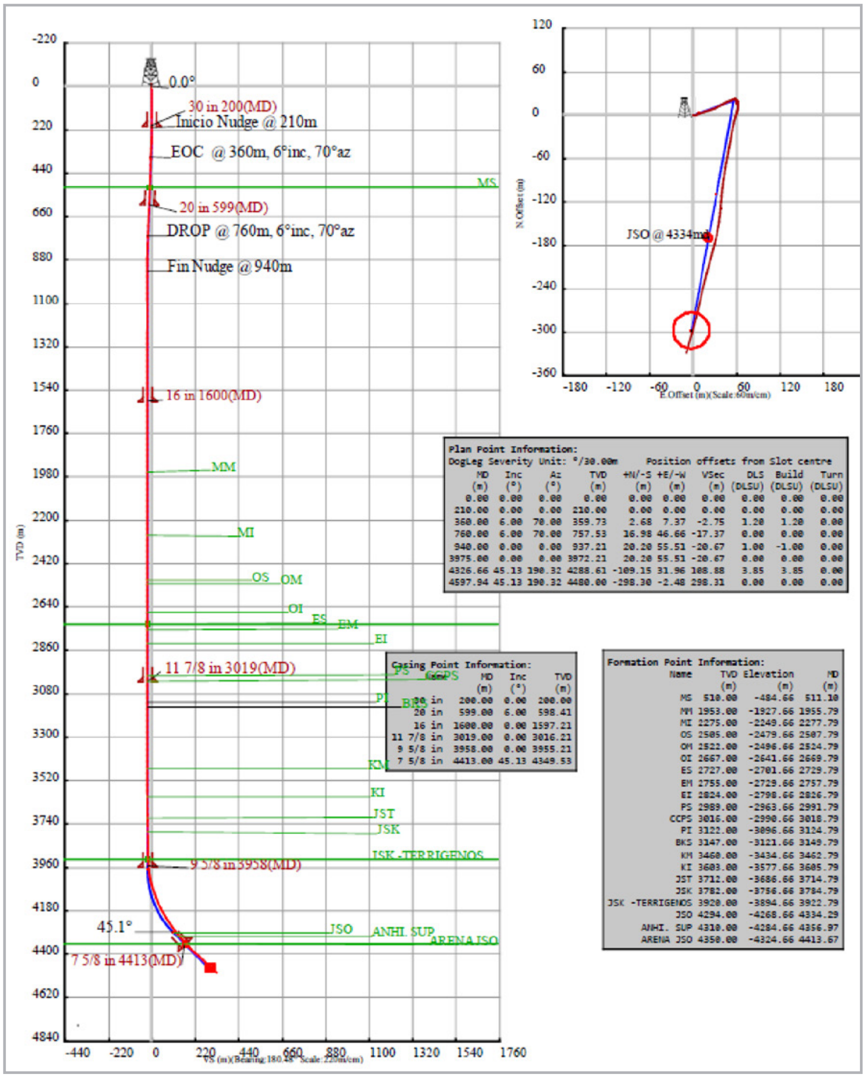


Figure 15. Plot of Balam 63 well.

Conclusions

In the optimization phase, we identify opportunities for further improvement such as the activities with the highest percentage of non-productive time during the drilling process, updating risk assessment to further lower the risk profile until ALARP. Capturing lessons learned and implementing best practices in the the well allowed us to improve the ROP up to 81.8%, reduce the Drilling Operating Hours up to 39.6% and reduce the rig operating costs to the operator by almost $2.5M USD in just two wells. In addition, all the drilling data and knowledge should be documented in a knowledge sharing database for efficient transferal of knowledge to other teams or projects. Continued discipline in the drilling engineering process will allow us to approach a true technical limit further improve drilling performance– the same process and methodology can be applied to other oil fields.

Nomenclature

ECD:	Equivalent Circulating Density
HSI:	Hydraulis Horsepower per Square Inch of bit area.
VME:	Von Misses Stress.
ILT:	Invisible Lost Time

DLC:	DownLink Commander
WITSML:	Wellsite Information Transfer Standard Markup Language

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Ingeniero en Tecnologías egresado de la Universidad Anáhuac, México. Tiene más de 12 años de experiencia en ingeniería de perforación y perforación direccional en pozos marinos y terrestres en México, Colombia, Argentina y Kuwait. Anteriormente, trabajó como perforador direccional y es experto en tecnología RSS. Ha participado en cursos técnicos en Houston, Bogotá, México y Abu Dhabi.

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