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“Follow your dreams. I am not saying
it’s going to be easy, but I am saying
it’s going to be worth it.”

(Moffat Machingura)

ABSTRACT

Sidetrack is a typical drilling technique in which a deviation is made from an already existing well from a position other than its end. Several openhole sidetracks have been performed over the last couple of years in Norway, and they have been both planned multilateral wellbores and unplanned technical sidetracks. The sidetrack of the well is achieved by time-drilling. Time-drilling is a lengthy operation that requires patience from the operators. Times up to 24 hours for this procedure are not uncommon, and sometimes the ledge created is not enough to kick off from a well successfully. The openhole sidetrack operation can be executed in different ways. Drillers may perform an assisted or an unassisted OHSDTR. An assisted operation uses a cement plug or a whipstock as support. An unassisted operation only uses the directional BHA to create the ledge. Data-driven decisions based on operations history contribute to improving performance and, consequently, reducing operators costs with drilling activities. Little effort has been made to track the performance of the different BHA types and drill bits used for unassisted openhole sidetracking. This thesis proposes the *Lesson Learned* of the drill bit features and BHA configuration influence in unassisted openhole sidetracking performance. In addition, it aims to examine how the findings align with directional drilling theory.

Keywords: Unassisted Openhole Sidetrack. Directional Drilling. Business Intelligence, Power BI.

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NOMENCLATURE

BHA	Bottomhole Assembly
BI	Business Intelligence
DD	Directional Drilling
DDR	Daily Drilling Report
E&P	Exploration and Production
NCS	Norwegian Continental Shelf
OHSDTR	Openhole Sidetrack
PBI	Power BI
PDC	Polycrystalline Diamond Compact
ROP	Rate of Penetration
RPM	Rotation per minute
RSS	Rotary Steerable System
SDTR	Sidetrack
WOB	Weight on Bit

1. INTRODUCTION

One can divide the petroleum industry into three main groups of activities: **Upstream -** which consists of Exploration and Production (E&P); **Midstream -** which includes transport and storage of crude oil; and, **Downstream -** which includes refining and distribution of products. Drilling is one of the activities of petroleum Exploration and Production, in which wells are constructed to allow conducting petroleum to the surface. This crude oil will later turn into products and energy that will meet our society demands. [1]

Figure 1.1 - Scheme of the petroleum industry activities groups

Source: Taken from [1]

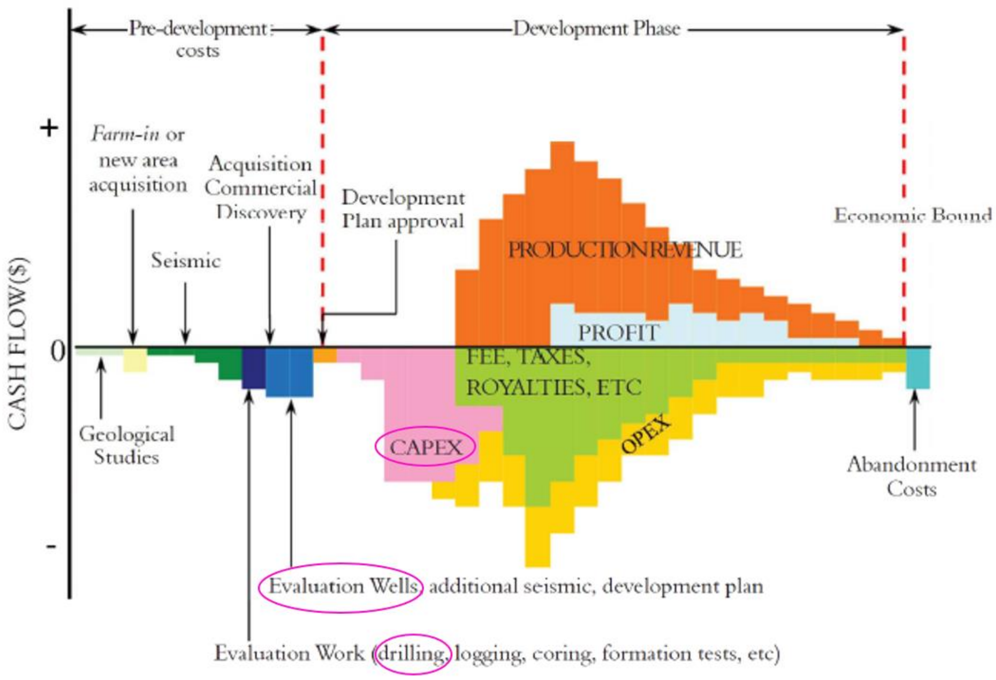
The main players involved in drilling activities are the **operators**, the **drilling contractors**, and the **service companies**. An operator is a petroleum, or energy, company that owns the mineral rights, leases, and permits to explore in a particular area. They plan the exploration and production program and specify the materials and labour needed for the operations. After a drilling plan is defined, the operators hire the drilling contractors and service companies. The drilling contractors are the companies that own the drilling rigs. Their function is to drill the wells, supplying the rig and the crew required for it. The service companies fill the supply gaps for the contractors and operators. These include many different products and services, such as drilling tools, software, training, logistics and others. [2]

Figure 1.2 - The main drilling players: Operators, Contractors and Service companies

Source: Own author.

Drilling requires considerable investment from operators. Cost reduction in this activity is a fundamental factor for the economic feasibility of a petroleum E&P project because it reduces an investment value that will only be compensated after petroleum production.

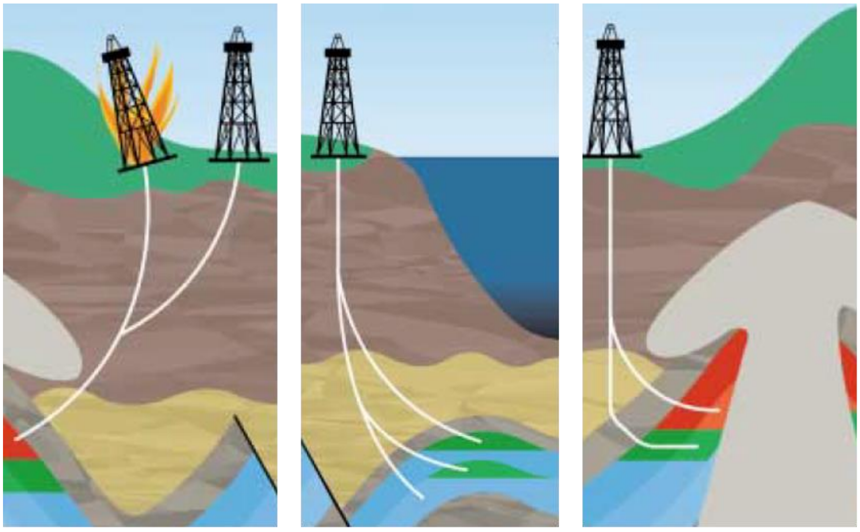
Figure 1.3 - Typical cash flow of an Operator in a petroleum project (highlighted the drilling activities)



Source: Taken from [3]

Directional drilling (DD) is a technique that started in the 1920s, which enabled wells to be deviated and this way allowed them to reach targets located in different coordinates than those of the wellhead. [4] Certain situations require advanced drilling technology. Local geology might dictate a complicated well trajectory, such as drilling around salt domes. Reservoir drainage might improve if a well is drilled horizontally to maximize wellbore exposure within the reservoir. One can drill a multilateral well to drain several reservoir sections. In emergencies, DD can be used to construct relief wells for blowouts. In addition, directional drilling can also be used in less dire situations, such as in sidetracking around an obstruction in a wellbore. Sidetracking means to drill a deviation from an existing wellbore from a position other than its end. [5] [6]

Figure 1.4 - Directional wells examples



a) Relief well b) Multilateral well c) Drilling around salt dome

Source: Taken from [5]

Drilling involves high costs with personnel and leasing the rig and equipment. The longer it takes, the more costly it is for the operators to construct a well. Reducing the operational time and increasing the probability of success of a procedure, therefore, reduces costs. Business intelligence (BI) comprises the processes and methods of collecting, storing, and analysing data from operations to optimise performance. Creating a comprehensive view of a business with BI can help operators and service companies make data-driven decisions that will improve drilling performance and reduce operational time. [7]

1.1 MOTIVATION

This thesis is essential for understanding the drill bit features and BHA configuration’s influence in unassisted openhole sidetracking performance. The longer an operation lasts, the more costly it is to drill a well. Reducing the operational time and increasing the probability of success of unassisted openhole sidetracking contributes to reducing operators' costs and, therefore, for the economic feasibility of E&P projects.

1.2 RESEARCH AIMS AND OBJECTIVES

This thesis proposes the *Lesson Learned* of the drill bit features and BHA configuration influence in unassisted openhole sidetracking performance in Norway. In addition, it intends to compare if the findings for unassisted openhole sidetrack align with directional drilling theory.

The following objectives must be achieved:

- Lesson Learned of the drill bit features and BHA configuration of the **best and worst performers** in unassisted openhole sidetracking.
- Lesson Learned of the unassisted openhole sidetracking **performance per well section**.
- Compare if the findings of this work align with the directional drilling theory.

1.3 STRUCTURE OF THE THESIS

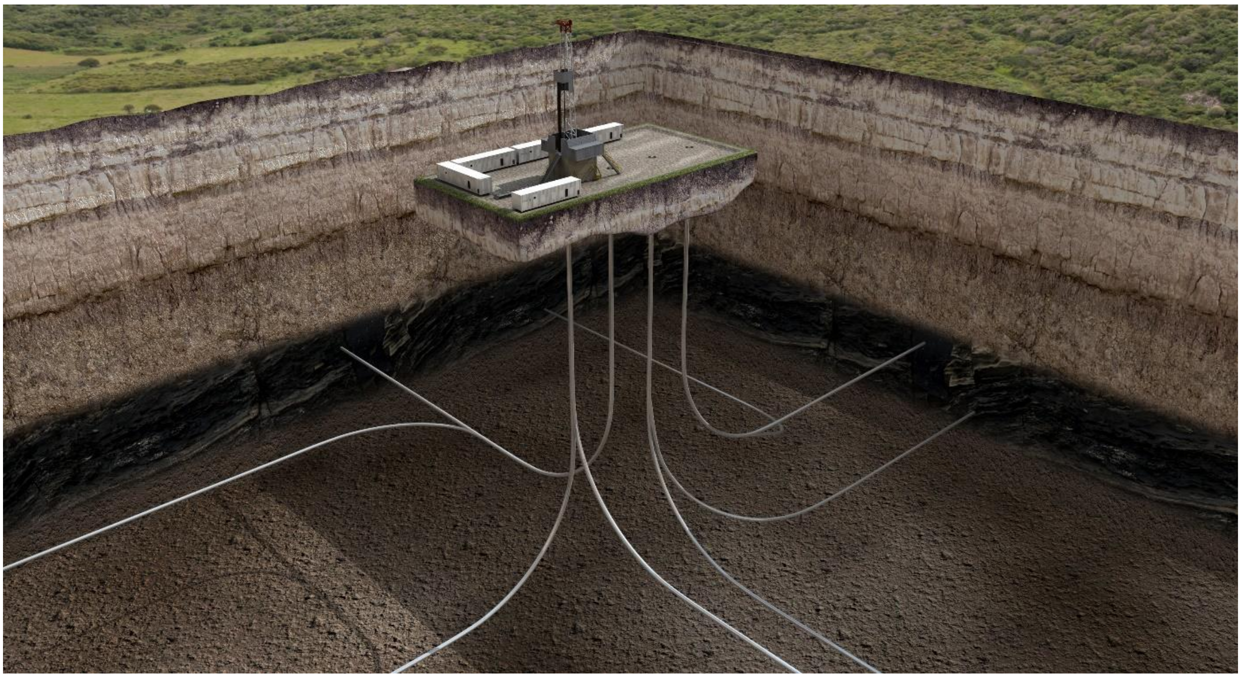
This text is divided into six chapters. **Chapter 1** introduces this thesis by presenting its context, motivation, and main objectives. **Chapter 2** provides the reader with a better understanding of the tools and procedures related to unassisted openhole sidetracking. **Chapter 3** explains the methodology used for data gathering and data analysis. **Chapter 4 and 5** show the results obtained with the data analysis and discuss them, comparing the findings to the theory. Finally, **Chapter 6** aims to conclude the research and suggest future work.

2. THEORETICAL BACKGROUND

2.1 SIDETRACK OPERATIONS

Sidetrack - deviating from an existing wellbore - is performed for a variety of reasons. Operators sidetrack as an alternative to abandoning a well when there is a need to detour around an obstruction inside the wellbore or unstable formations. Sometimes a SDTR is used to reposition a well's bottomhole location after failing to intercept a target. Increasingly, however, operators rely on sidetracking as a part of their production strategy. They deliberately deviate from a central wellbore to drill multilateral wells. Additionally, in unconventional reservoirs, operators SDTR to drill horizontally for maximum reservoir exposure. [6]

Figure 2.1 - Example of a Multilateral Well



Source: Taken from [8]

Drillers can perform the sidetrack technique in an open hole, well sections without casing. Or they can execute this operation in cased-hole, well sections with casing or production liner. [6]

The OHSDTR operation can be executed in different ways. Drillers may perform an assisted or an unassisted openhole sidetrack. An assisted operation uses a cement plug or a whipstock as support. An unassisted operation only uses the directional BHA to create the ledge in openhole sidetracking.

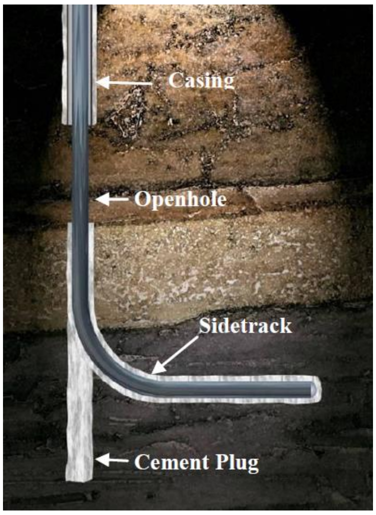
2.1.1 Assisted OHSDTR

In this section, a discussion on the assisted openhole sidetrack technologies is presented.

2.1.1.1 Sidetracking with a Cement Plug

The traditional method for OHSDTR is to set a cement plug followed by a directional BHA once the cement hardens.

Figure 2.2 - OHSDTR with a cement plug



Source: Taken from [9]

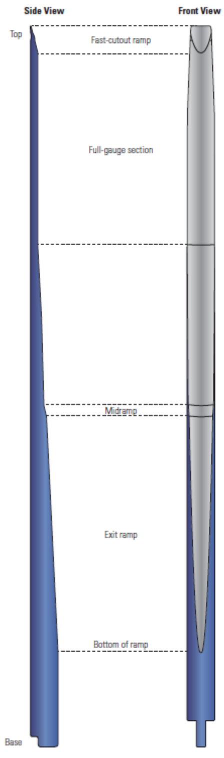
The success of the sidetrack operation will depend widely on the cement plug integrity. The set cement integrity depends on the formation's compressive strength, the downhole temperature and pressure, wellbore deviation, cement plug depth, cement quality, and cure time. The consequences of plug failure are extra trip time, a new cement plug, loss of drilling days and reconfiguration of drilling trajectory. [9]

In deepwater environments, characterised by high pressure and high temperature (HPHT), cement strength is usually not higher than that of the formation; the drill bit drills out the material of least resistance - in this case, the cement, rather than the formation. In highly deviated wells, cement plugs can become elongated along the slant section of the well; sometimes, the cement moves downhole along the low side of a deviated wellbore or spirals downward in vertical holes. In some cases, multiple cement plugs must be set before the operator obtains one that is sufficient for sidetracking. [6]

2.1.1.2 Sidetracking with a Whipstock

The whipstock technology was developed to overcome the drawbacks of the traditional OHSDTR with a cement plug. The whipstock is a steel ramp used to deflect the drill bit towards the wellbore wall, intending to help the driller initiate the sidetrack. As the bit travels down the sloping ramp, it starts to drill formation and build a new trajectory for the well. [6]

Figure 2.3 - Whipstock



Source: Taken from [6]

A disadvantage of drilling with a whipstock is that rotating the bit or BHA over the whipstock can damage the bit or cause downhole tools failure; this may require extra trips to change equipment before achieving a successful operation. [10]

The conventional process of sidetracking with a whipstock requires a trip to lower the tool and another for the directional BHA to start drilling. The disadvantage of this technology is in the extra trips. There are, however, different technologies for sidetracking with whipstock, as shown in [6] and [9]. Some of the new technologies only require one trip. These systems include a drill bit attached to the top of the whipstock. The driller can disengage the bit once the whipstock anchor is hydraulically set in the sidetrack's desired depth. [9]

Figure 2.4 - Single Trip Bit/Whip Combination

Source: Taken from [6]

2.1.2 Unassisted OHSDTR

The technology in this thesis, defined as unassisted openhole sidetrack, refers to the deviation made due to a combination of the bit type and the power source employed in directional drilling. For this sidetracking method, no cement plug or whipstock is used. The directional BHA is run in the well to time-drill the formation until a ledge is created.

This method of openhole sidetracking is the focus of this work. One can know more about the bit types and power sources in the following sections.

2.1.3 Time-drilling a ledge

For creating a ledge and kicking off a well, the driller must time-drill the first few meters to ease the well into its new trajectory. [6] Time-drilling means drilling with low weight on bit (WOB), low rate of penetration (ROP), low torque and low rotation (RPM). [4] Time-drilling is a lengthy operation that requires patience from the operator. Times up to 24 hours for this procedure are not uncommon, and sometimes the ledge created is not enough to kick off from a well successfully. [10]

2.2 DIRECTIONAL BHA: POWER SOURCES

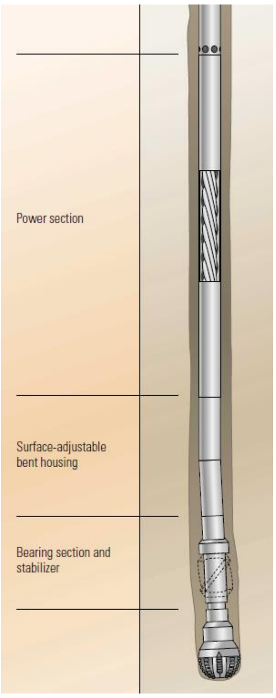
This section is presented to discuss the power systems used in directional drilling. The tools used for directional drilling are either based on the point-the-bit or the push-the-bit principle. [11]

2.2.1 Mud Motors

The mud motor is a point-the-bit system. In this type of system, the bit is oriented with a bend in the drill string, making it possible to point the drill bit in different directions. [11]

Mud motors were developed in the early 1960s to allow simultaneous control of wellbore azimuth and inclination. A typical steerable motor assembly consists of a power-generating section (through which drilling fluid is pumped to turn the drill bit), a bend section, a drive shaft and a bit. [5]

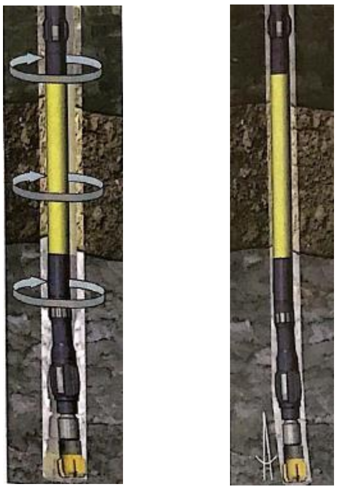
Figure 2.5 - Mud Motor Assembly



Source: Taken from [5]

Directional drilling with a mud motor is accomplished in two modes: **rotating** and **sliding**. In the rotating mode, the entire drill string rotates, the same as in ordinary rotary drilling. In this mode, the drill string tends to drill straight ahead. In the sliding mode, the drill string's rotation is paused so that the bend in the motor points in the new trajectory direction. [5] In other words, the sliding mode is used for trajectory corrections and orientation, and the rotary mode is used to keep the desired trajectory. [12]

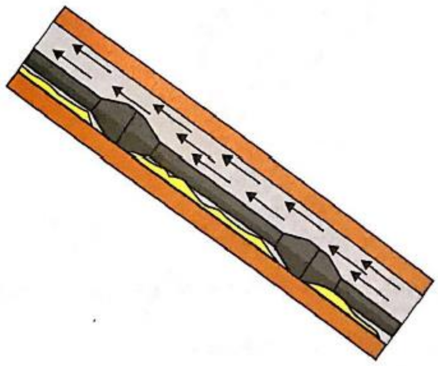
Figure 2.6 - Rotating mode and Sliding mode



Source: Taken from [12]

One of the challenges in using a mud motor is the tendency of the non-rotating drill string to become stuck. While using the sliding mode, the drill string lies on the borehole's low side, which may cause it to be stuck due to differential sticking or poor hole cleaning.[5]

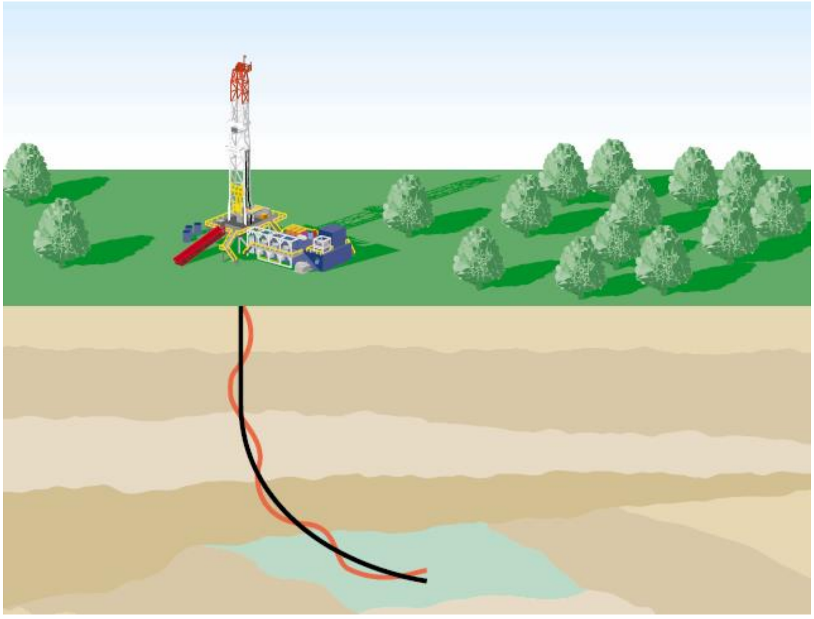
Figure 2.7 - Sliding Mode: drill string laying on the low side of the wellbore



Source: Taken from [12]

Switching from the sliding mode to the rotating mode while drilling with a mud motor typically results in a more irregular and longer path than planned. Higher wellbore tortuosity increases friction what can, for example, affect the ability to run casing to total depth. The use of a rotary steerable system eliminates the sliding mode and produces a smoother wellbore. [5]

Figure 2.8 - Well trajectories comparison. (red curve - Mud Motor, black curve - RSS)



Source: Taken from [5]

2.2.2 Rotary Steerable Systems

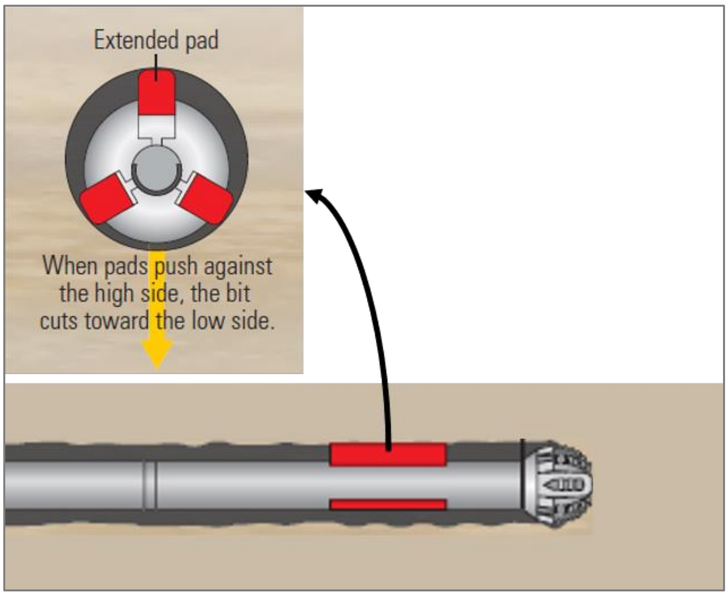
The introduction of rotary steerable systems in the late 1990s marked a significant advance in drilling technology. The most crucial aspect of an RSS is that it allows for continuous rotation of the drill string, eliminating the need to slide while directionally drilling as for the mud motors. [13]

Rotary steerable systems have evolved considerably since their introduction. Early versions utilized mud-actuated pads or stabilizers to create changes in direction. With a dependence on contact with the borehole wall for directional control, the performance of these tools can sometimes be affected by borehole washouts and rugosity. Later versions included designs that relied on a bend to produce changes in the tool face angle, reducing borehole environmental influences on tool performance. Therefore, two RSS concepts exist **push-the-bit** and **point-the-bit**. [13]

2.2.2.1 Push-the-bit RSS

A push-the-bit system pushes against the borehole wall to steer the drill string in the desired direction. This tool creates a side force at the drill bit, pushing external steering pads against the borehole wall. The pads are placed near the drill bit. If the trajectory needs to build angle, the pads will push the low side of the hole; to drop angle, the pads will push the high side. [13]

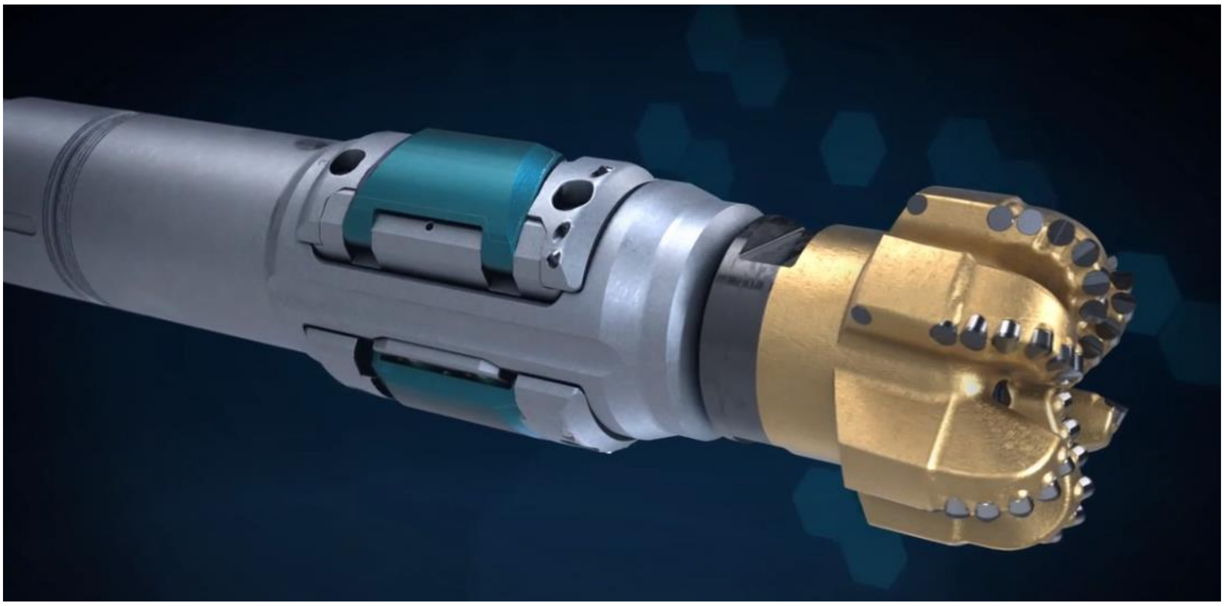
Figure 2.9 - Push-the-bit RSS: Pads explanation



Source: Taken from [13]

Push-the-bit systems usually have steering pads positioned on a rotating housing; however, some models have the steering pads positioned on a non-rotating housing. Examples of systems using steering pads on a rotating housing include the **PoweDrive Orbit** by Schlumberger and the **iCruise** by Halliburton. Systems using steering pads on a non-rotating housing include the **AutoTrak** by Baker Hughes. [14]

Figure 2.10 - Push-the-bit RSS: PowerDrive Orbit by Schlumberger

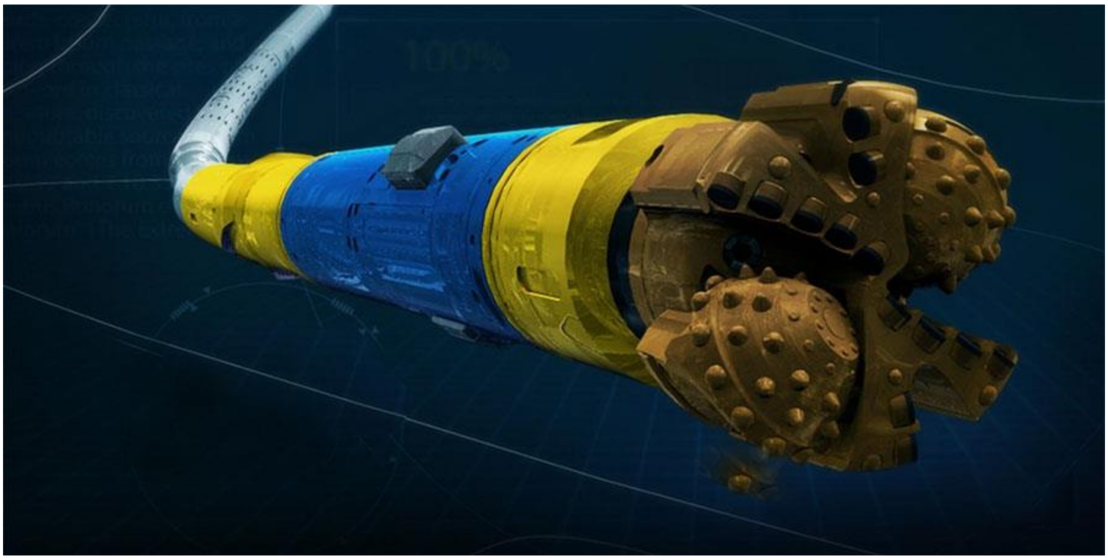


Source: Taken from [15]

Figure 2.11 - Push-the-bit RSS: iCruise by Halliburton

Source: Taken from [16]

Figure 2.12 - Push-the-bit RSS: AutoTrak by Baker Hughes



Source: Taken from [17]

Although the push-the-bit systems have good steerability, several problems are observed in practice. One major problem is that the intensive impact on the stretching pads mays cause violent vibrations, leading to high wellbore tortuosity. [18] Another drawback of this system is its dependence on contact with the borehole wall for directional control. The performance of these tools can sometimes be affected by washouts and rugosity. [13]

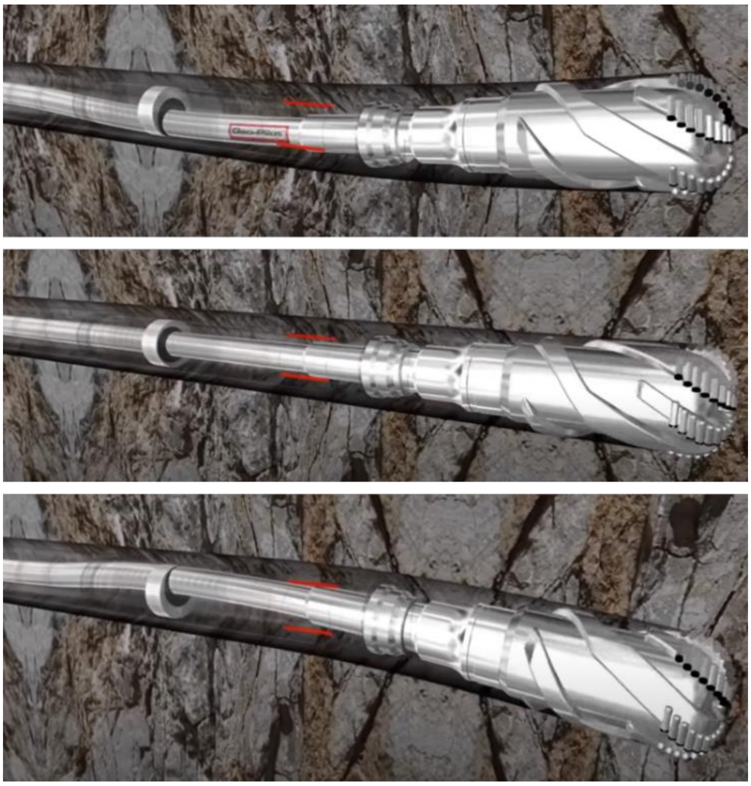
2.2.2.2 Point-the-bit RSS

The point-the-bit steering systems were proposed to overcome the drawbacks of the push-the-bit systems. A point-the-bit system uses an internal bend to offset the alignment between the tool and borehole to produce a directional response. Point-the-bit systems change well trajectory by orienting the bit to the desired path - the trajectory changes in the direction of the bend. The bend orientation is controlled by a motor that allows the tool face direction to remain constant, non-rotating, while the rest of the drill string rotates. [13]

As an example of a point-the-bit RSS, the Geo-Pilot can be mentioned. The **Geo-Pilot**, by Halliburton, is one of the industry's most proven point-the-bit rotary steerable system. In this RSS, the bit is pointed/oriented by flexing an internal driveshaft. The shaft is flexed using a pair of eccentric rings controlled by a clutch system, see figure 2.13. [19]

The main drawbacks of the point-the-bit systems are that they have a slower trajectory change response than the push-the-bit. Also, these systems have an inherent mechanical weakness in the bent or tilted driveshaft mechanism. [20]

Figure 2.13 - Point-the-bit RSS: Geo-pilot by Halliburton

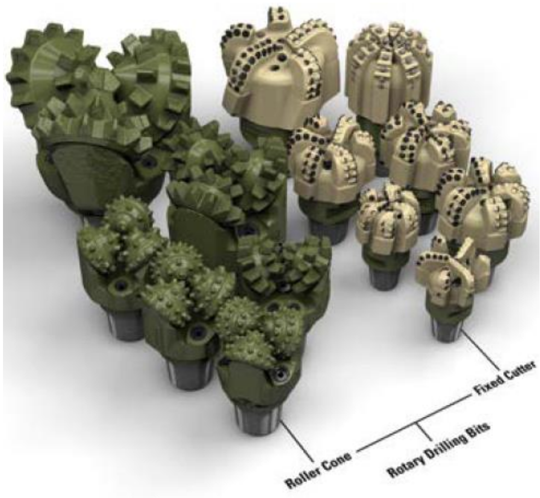


Source: Taken from [19]

2.3 DRILL BITS

Drill bits are classified according to their design as either **roller cone** or f**ixed cutter**. Roller cone bits drill by crushing the formation, and fixed cutter bits drill by shearing the formation. The tricone is an example of a roller cone bit, and the polycrystalline diamond compact (PDC) is an example of a fixed cutter bit. [21] [22]

Figure 2.14 - Drill Bits Classification: Roller Cone and Fixed Cutter



Source: Taken from [22]

2.3.1 Roller Cone Bits

Most **roller cone** bits have three metal cones that rotate independently as the bit drills. With the help of a certain WOB applied, the cutting structures on each cone will crush the rock as the cone rotates. [11][17]

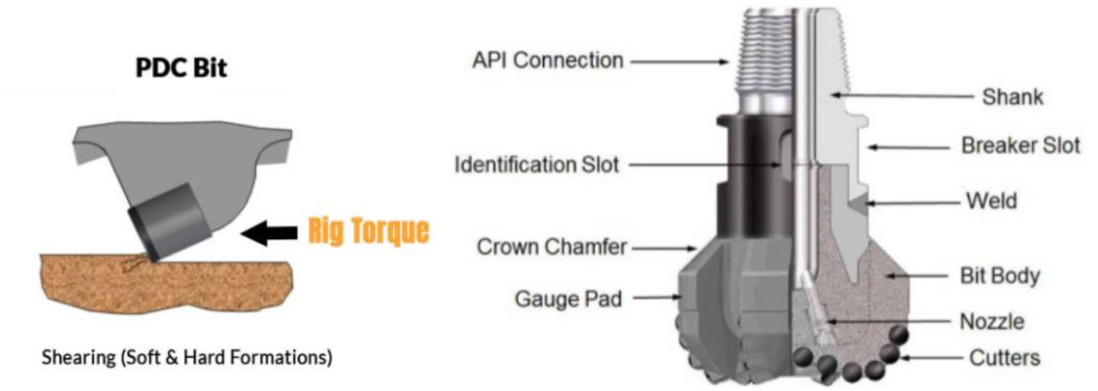
Figure 2.15 - Roller cone: Tricone Bit

Source: Taken from [22], [23]

2.3.2 Fixed Cutter Bits

Fixed cutter bits have no moving parts or bearings. The cutters are permanently mounted onto blades, which are integral to the structure of the bit. The cutters drill by shearing the formation. [22]

Figure 2.16 - Fixed cutter: PDC Bit



Source: Taken from [23]

2.3.3 Bit types comparison

A couple of advantages of roller cones are that they are less expensive than PDC bits and produce less torque. The latter is a massive benefit in larger well sizes, for example, top holes and surface sections. [10]

Tricone bits can be better than PDC bits for drilling soft formations. In very soft/gummy formations, the cuttings may stick to the blades of a PDC bit, reducing the ROP and consequently drilling effectiveness.[21]

Figure 2.17 - PDC bit with cuttings stuck to its blades

Source: Taken from [24]

An advantage of PDC bits over tricones is that they do not have any rolling parts. Since one can make PDC bits from one solid piece of steel, there is less chance of bit breakage. Tricone bits may lose cones in the well, which may cause a need for a fishing operation leading to additional trips and loss of rig time. [21]

Figure 2.18 - Example of wear caused in Tricone bits

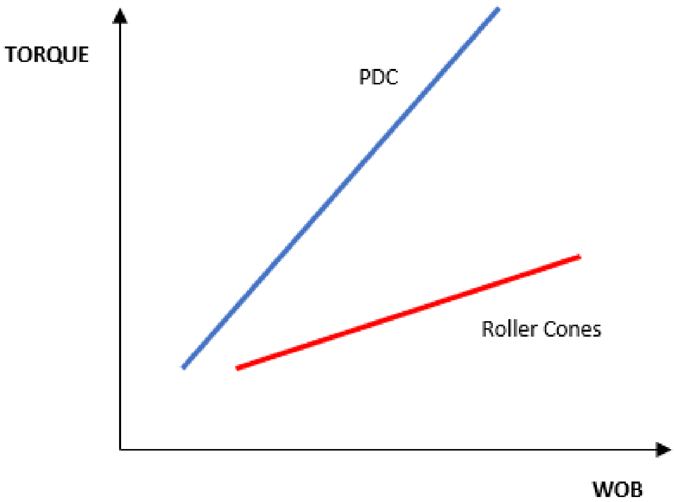
a) Tricone bit (12 ¼) at the beggining of operation

b) Tricone bit (12 ¼) after wear with three missing cones

Source: Taken from [25]

Comparing roller cones and PDC bits, the first is **less aggressive** than the second, which means they are **easier to steer**. For PDC bits, small changes in WOB cause significant variations in torque. High torque while drilling can easily change the well trajectory in an unwanted way. PDC bit design has, however, been continuously improved to increase the steerability of this type of bit. For example, one may place non-aggressive cutters in the bit to reduce torque sensitivity to WOB changes. [11]

Figure 2.19 - Roller Cone vs PDC bits: Torque sensitivity to WOB changes



Source: Taken from [11]

PDC bits can achieve **higher ROPs** than roller cone bits under optimal circumstances. In addition, they have a longer lifespan which means they do not need to be replaced as often as tricone bits. For formations in which the correct PDC bit is selected, drilling is faster and more **durable -** using a single bit for drilling an extended section of a well brings costs per foot down. [23]

2.3.4 Additional information on PDC bits

As one will see in the case study, most of the unassisted openhole sidetracks performed were operated by using PDC bits, see figure 4.21. For that reason, the author wrote this section to provide the reader with more information about this drill bit type.

2.3.4.1 Directional characteristics of PDC bits

The increased use of rotary steerable tools has required further consideration into the design of PDC bits in order to improve the drilling performance that these systems can offer. The deviation mechanism is different according to the RSS configuration. For a push-the-bit system, the side force of the pads controls the deviation. For a point-the-bit, the deviation is controlled by the bit tilt. The drill bit used must be compatible with the directional system to achieve the maximum attainable dogleg. The drill bits must possess sufficient lateral cutting ability and be stable during rotation, to minimise downhole vibrations that could damage the bit or cause premature tool failure. [26] [27] [28]

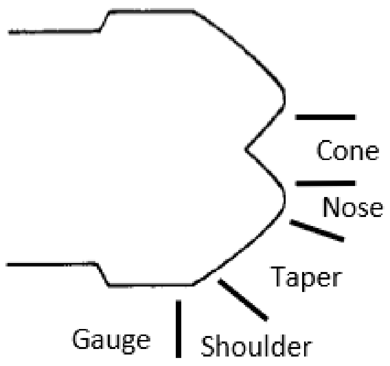
For a drill bit to be successful, it must have three attributes: **stability**, **durability** and **steerability**. These attributes propose the following:

- *Stability* implies that the bit design should not induce significant vibration downhole, which could cause premature failure of the drilling tools. In general, high levels of lateral vibration (bit whirl) will lead to damage and eventual fatigue failure of the weakest point of the drill string. [26]
- *Durability* refers to the drill bit being able to endure drilling different formations, hard and soft, and preventing the damage caused by them. PDC bits are known to perform best in soft to medium-hard, non-abrasive formations. The driller must consider beforehand the type of formation crossed for selecting the right drill bit for the operation. [21] [26]

➢ *Steerability* corresponds to the ability of the bit, submitted to lateral and axial forces, to initiate a lateral deviation. Generally, the harder the formation drilled is, the less steerable the bit is. In the same way, the higher the side force applied by the RSS system, the more steerable the bit. [27]

Each component of a drill bit plays a significant role in its steerability. In a simplified manner, a PDC bit cutting structure is composed of: *cone*, *nose*, *taper*, *shoulder* and *gauge*. [11]

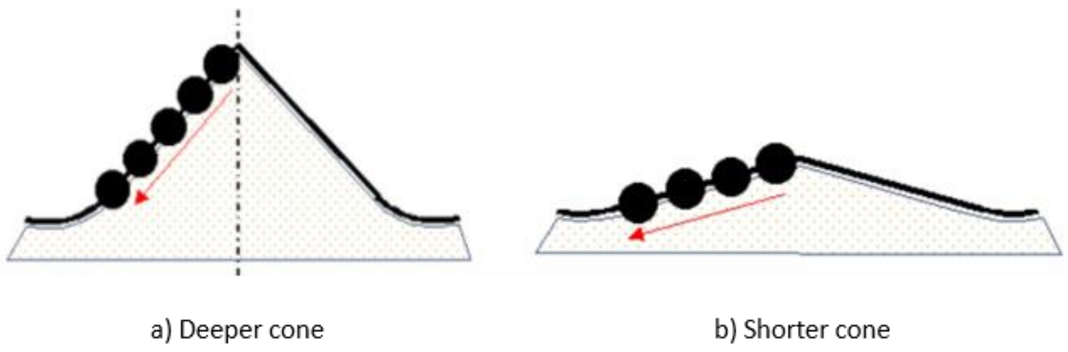
Figure 2.20 - PDC bits: Cutting structure



Source: Own author.

PDCs with **deep cones** provide a cone-shaped borehole that counteracts lateral bit movement. Bits with this profile have high stability and low steerability; they tend to drill straight ahead. On the other hand, PDCs with **shallow cones** have a flatter profile. The cutters are positioned nearly in the same plane what adds to lateral cutting ability causing the bit to be more steerable. [29]

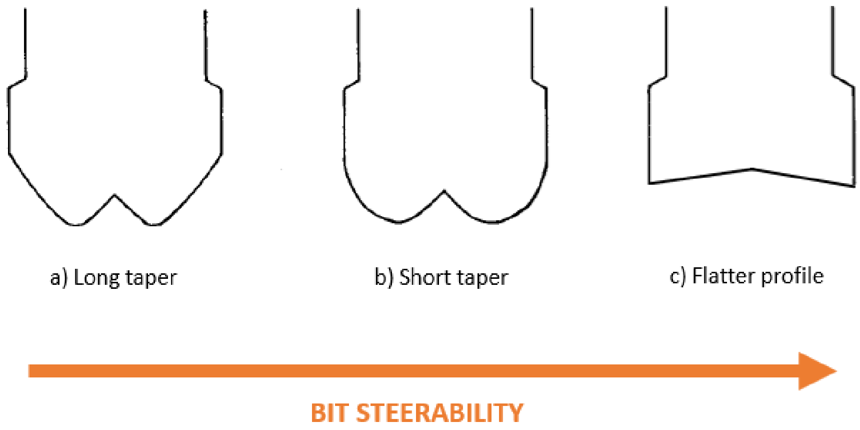
Figure 2.21 - PDC bits: deep cones & shallow cones



Source: Taken from [29]

The overall profile length affects the potential dogleg attainable by a particular design. Shorter profiles result in less contact with the wellbore, and thus a reduced force is required by the bit to tilt and initiate a lateral deviation. [26]

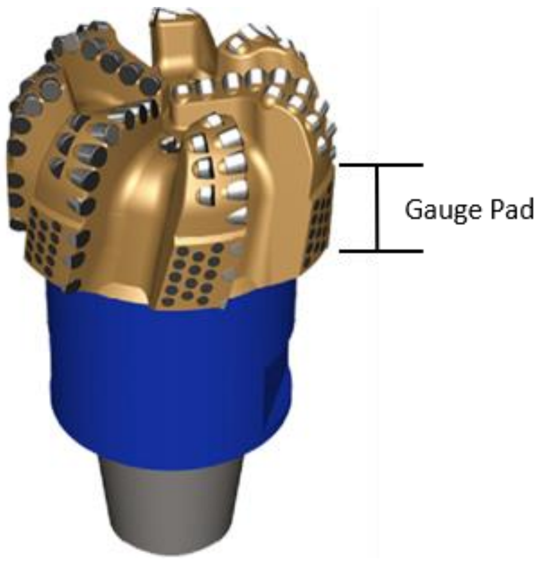
Figure 2.22 - PDC bits: Effect of bit profile on steerability



Source: Own author.

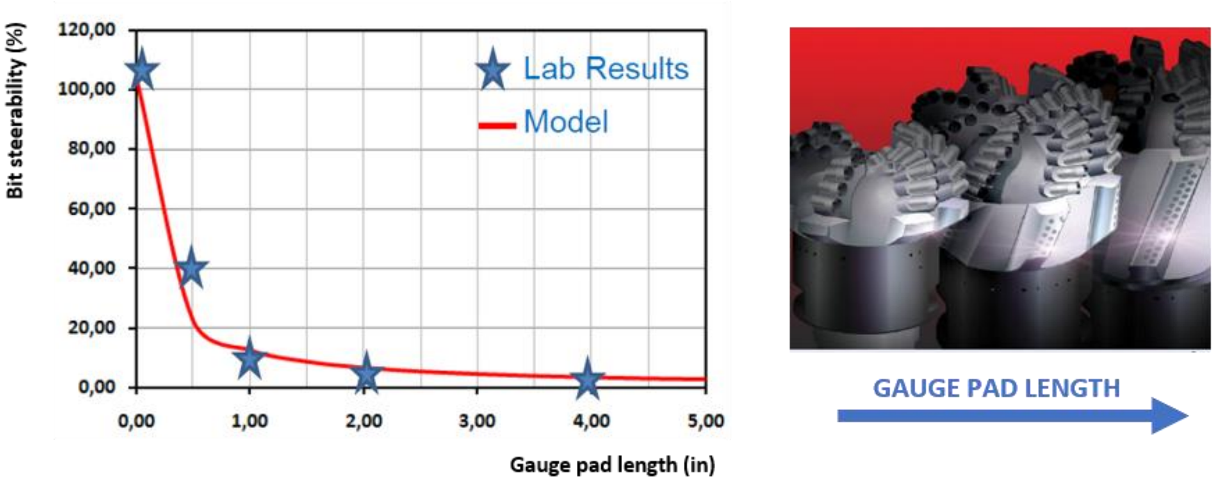
Experimental results describe the gauge pad length effect on steerability. The relation is that the shorter the gauge pad, the more steerable the bit. A bit with a shorter gauge pad is more easily tilted, requiring less force to attain a lateral deviation. [26][27][30]

Figure 2.23 - PDC bits: Gauge pad



Source: Own author.

Figure 2.24 - PDC bits: Effect of gauge pad length on steerability



Source: Taken from [30]

The best choice of bit design will depend on the application. For example, if a driller wants to perform a lateral deviation in the wellbore, a pancake bit would be a strong candidate. This drill bit has a flat profile, and the gauge pads are short. This bit is slow and fragile, but it is suitable for lateral deviation due to its high steerability.[10]

Figure 2.25 - PDC bits: Pancake drill bit

Source: Image shared by the supervisor.

If the application would be to drill a straight section of the well, a long bit with a deep cone could be used. This bit would be difficult to tilt and fit for drilling straight ahead. The conical shape of the formation drilled prevents the bit from changing direction. [10]

Figure 2.26 - PDC bit: Long and deep coned bit

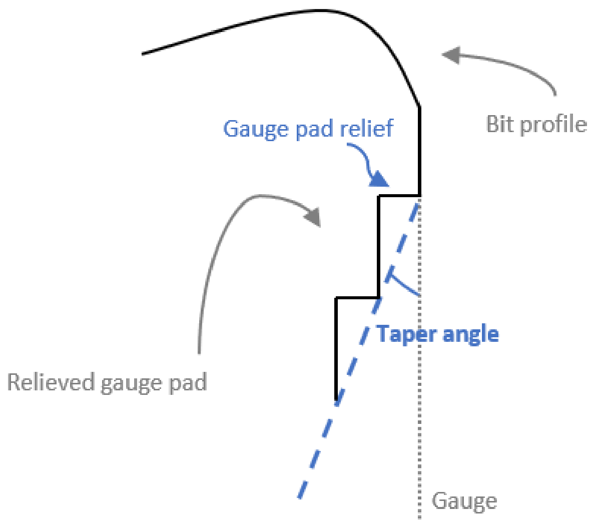
Source: Image shared by the supervisor.

The bit design optimization process focuses on increasing bit lateral stability and reducing the aggressiveness of the gauge pads without sacrificing steerability. [31] It is vital to keep in mind that the directional behaviour of a whole drilling system can not be explained solely by that of the bit. A bit with a high side-cutting ability does not necessarily produce a high build rate. This rate depends on the side force and weight applied on the bit, the bit tilt angle, and the rock formation. [32]

2.3.4.2 Relieved Gauge Pad Bits

With longer gauge pads, the bit gains stability; however, it loses steerability. As an attempt to improve borehole quality whilst preserving steerability, PDC bits with relieved gauge pads were developed. These gauge pads can be divided into steps, as can be seen in the figure below. [10]

Figure 2.27 - PDC bits: Stepped gauge pad bit scheme



Source: Own author.

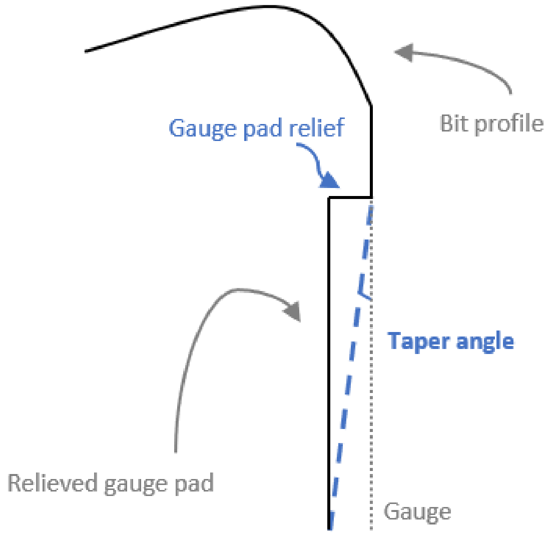
Simulations show that increasing the taper angle of the gauge pad increases the steerability of the bit. The relief follows the same logic: the more relief, the more steerable the bit. The improvement in steerability happens because, with more relief and a higher taper angle, the bit has less contact with the wellbore. If there is less contact with the borehole walls, less force is required for the bit to move laterally. The challenge in designing PDC bits with relieved gauge pads is not crossing the inflexion point, in which the higher relief starts increasing wellbore tortuosity. [10]

Figure 2.28 - PDC bits: Stepped gauge pad bit

Source: Image shared by the supervisor.

Another design possibility for the relieved bits is having only one step in the gauge pad, as seen in figure 2.29 and 2.30.[10]

Figure 2.29 - PDC bits: One-step gauge pad bit scheme



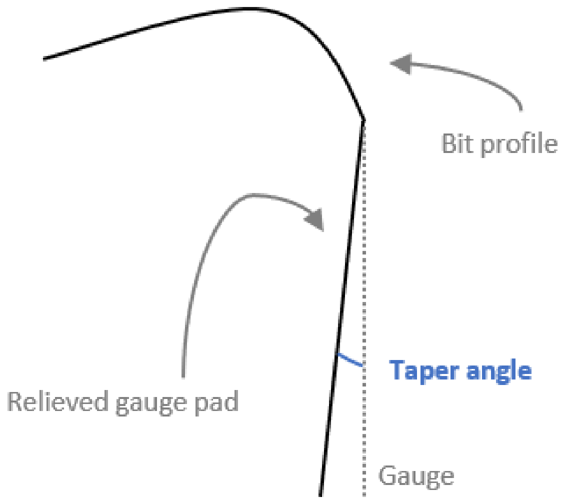
Source: Own author.

Figure 2.30 - PDC bits: One-step gauge pad bit

Source: Image shared by the supervisor.

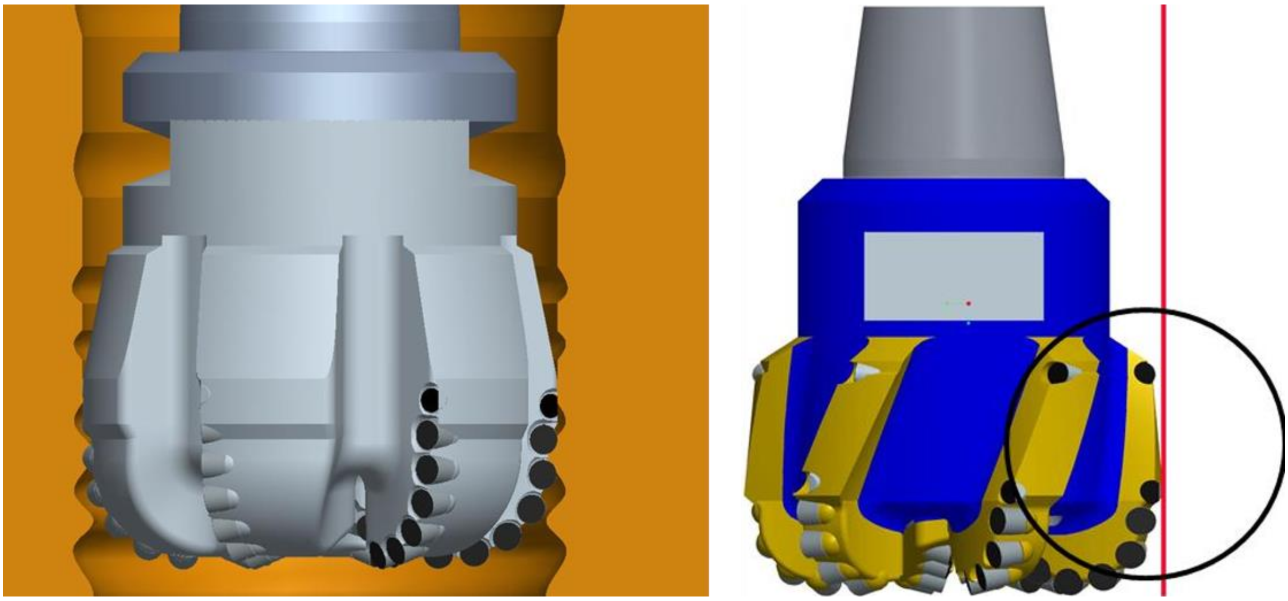
Manufacturers also construct PDC bits with a true taper. Instead of the gauge pads being divided into steps, they have a conic shape, as seen in the scheme below. [10]

Figure 2.31 - PDC bits: Tapered bit scheme



Source: Own author.

Figure 2.32 – PDC bits: Tapered bit



Source: Image shared by the supervisor.

3. METHODOLOGY

3.1 RESEARCH SETTING & SAMPLE

The sample used in the analysis included 52 unassisted OHSDTRs performed in offshore wells, in Norway, between 2007 and 2020.

The information about the operations resulted from a lengthy examination of several drilling reports from four different operators: Aker BP, BP, Conoco Phillips and Equinor. Halliburton Norway provided the drilling reports for this work. Since the service company gathered these reports, most operations in this analysis were completed by them.

Figure 3.1 - Research setting: offshore wells drilled in Norway

Source: Taken from [33]

3.2 METHOD USED

The methodology of this study covered three phases: **data-gathering**, **data filtering** and **data analysis**. Data-gathering consisted of a lengthy process of manually examining several drilling reports. The information specific for the unassisted openhole sidetrack operation found in the reports was filtered and summarised in an Excel spreadsheet in the data filtering stage. In the data analysis phase, the excel spreadsheet was used as a database for the Business Intelligence tool Power BI. Five different dashboards were built to assist with the analysis.

3.2.1 Data gathering and filtering

Data-gathering consisted of a lengthy process of manually examining several drilling reports. Later the information specific for the unassisted openhole sidetrack operation found in the reports was filtered and summarised in an Excel spreadsheet.

The data gathering and data filtering phases were performed simultaneously. The entire process demanded approximately five months, and it happened in two phases - the first one when the drilling reports were provided for examination. The second, when a filtered excel spreadsheet was ready with the reports' data, Halliburton added some more information about the PDC drill bit characteristics to provide more parameters to the analysis.

By examining the reports, these data were being gathered:

- The **date** that the unassisted OHSDTR was performed.
- The **operator** that owned the well.
- The **field** in which the well is located.
- The **well name**.
- The **bit size**, **model**, **serial number**, and **manufacturer**.
- The name of the directional BHA, **power source**, used for the operation.
- The **sidetrack category**: if the OHSDTR was planned or unplanned. This information came from the well name. It was unplanned if it had a "T" indicating a technical/unplanned sidetrack, for example, 2/8-G10-BT3.
- The **sidetrack outcome**: if the unassisted OHSDTR operation was successful or not. The outcome was most of the times specified in the operations description section of the report. See the example of a successful OHSDTR in figure 3.2.
- The number of hours it took to perform the operation (**duration**). This data came from the operations summary. Figure 3.3 shows an example of an unsuccessful OHSDTR that had 14 hours of duration.

Figure 3.2 - Data gathering: Checking reports for OHSDTR outcome.

Comments:	Spent only 3 hrs from initiating Time drilling to seperation from pilot hole to reservoir (K-5A) hole was confirmed. A very good Bit run with instantanous ROP up to 65 m/hr. From 5144m MD ROP were limited to optimize LWD data towards TD. At 6243m MD drilling stopped due to no signals from MWD and TD was therefore called at 6301m MD.

Source: Own author.

Figure 3.3 - Data gathering: Checking reports for OHSDTR operational time.

Operations Summary

From / Op. Depth (m)	Hrs	Unit	Task	Activity	Code	Operation
11:15 4239	8.25	RIG	DRILL	DRL	P	Initiated ledge foundation for open hole side track from 4186 m to 4191 m with 1500 lpm/91 bar/100 rpm/20-35 kNm - max gas in mud return 0,9 % - seepage losses 1,0-1,6 m3/hrs - reduced addition of G-seal fine to 1 sack/hr
19:30 4239	3.00	RIG	DRILL	DRL	P	Timedrilled from 4190,6 m to 4192,3 m with 1450 lpm/81-84 bar/100 rpm/ 11-37 kNm/1,10 s.g EMW - seepage losses: 1,2 m3/hrs - downlinked ribs-off
22:30 4239	1.50	RIG	DRILL	DRL	P	Bit slipped over top of ledge. Pulled back 4192,3 m to 4191,8 m and tried to create new ledge with 1462 lpm/74-80 bar/ 100-130 rpm/15-31 kNm. - seepage losses: 1,4 m3/hrs
00:00 4239	1.25	RIG	DRILL	DRL	P	Cont. to to create new ledge with 1462 lpm/65-73 bar/ 100-130 rpm/15-31 kNm/2-3 ton WOB - inspected all surface lines and equipment due to decreasing pressure trend - found decreasing trend on BCPM revolutions from 3000 rpm to 2200 rpm (from 22:30 hrs to 01:15) - not able to communicate with MWD tools - pump pressure reduction from 84 bar to 65 bar (33%) last 5,5 hrs.
01:15 4239	0.25	RIG	DRILL	DRL	P	Evaluated situation with Sr.DSV. Decided to POOH and L/D with 8 1/2" ATK BHA.

Source: Own author.

Figure 3.4 - Data gathering: Checking reports for drill bit and BHA information.

6.0 Bit Data

Run no	Bit size	Bit no	BHA no	Bit type	IADC code	Manufacturer	Serial no	Nozzles (n/32") no x n	no x n	no x n	no x n	TFA in2
12	8 1/2"		16	FMF3651Z		Halliburton	11211361	5 x 14	1 x 13			0,882

6.2 Bottom Hole Assembly

Run no: 16

Conveyance: DP **Run Type:** Drilling run #12 **BHA description:** 8.5" Geopilot Sidetrack T3

String component	Supplier	Quantity	OD inch	ID inch	Length m	Acc length m	Comment
BIT	Halliburton		8,500	3,000	0,38	0,38	
GEOPILOT XL	Halliburton		7,625	1,713	9,88	10,26	w/GeoPilot Flex

Source: Own author.

The results obtained with the examination of the drilling reports are available in Appendix A: Unassisted OHSDTR database

3.2.1.1 Data limitations

At the end of the examination process, 52 unassisted OHSDTRs were detected. This analysis limitations include:

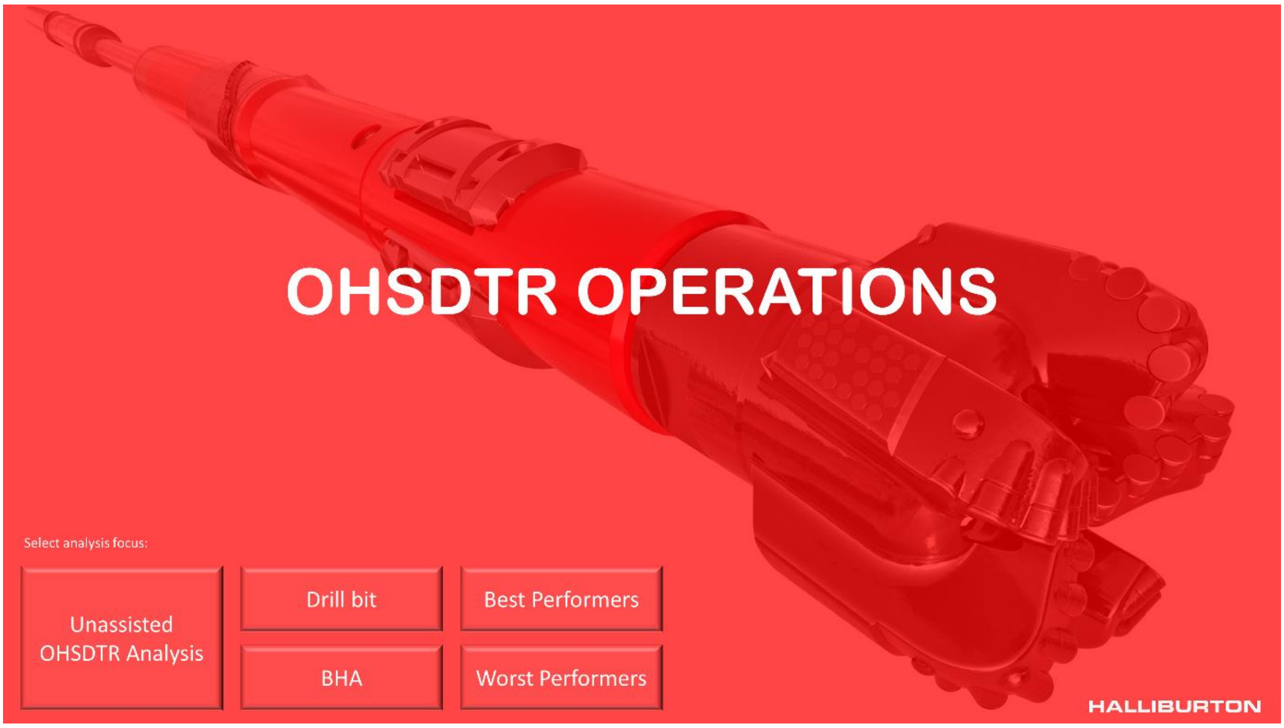
- The drilling reports investigation process had to be done manually due to the lack of a standard on the operations reporting. The manual investigation may have been a source of error.
- Halliburton had difficulties in gathering more operational reports. The findings for the unassisted OHSDTR operation may be an exclusive representation of the population of this analysis.
- There were problems with having more parameters analysed due to missing information in the reports. For example, since the formation type data was missing, its effect on the unassisted OHSDTR performance could not be analysed.

3.2.2 Data analysis techniques

Drilling operations involve high costs, and the longer they take, the more costly they become. Therefore, decreasing operational time and increasing the probability of success of an operation reduces costs. Business intelligence (BI) comprises the processes and methods of collecting, storing, and analysing data from operations to optimise performance. [7] Creating a comprehensive view of a business with BI can help operators and service companies make **data-driven decisions** that will improve drilling performance, reduce operational time and costs.

For the study of the drill bit features and BHA configuration influence in unassisted openhole sidetracking performance, the Business Intelligence tool *Power BI* (PBI) was used. Five different dashboards were built to assist with the analysis. The data analysis phase demanded approximately 1 month.

Figure 3.5 - Menu of the Power BI dashboard used in this case study



Source: Own author.

Before building the dashboards, some KPIs had to be defined. A Key Performance Indicator (KPI) is a measurable value that demonstrates a company's performance against key business objectives. [34] Drilling activities intend to construct the wells safely and efficiently while reducing costs. Following the logic that the longer the operation, the more costly the well, the best performer in unassisted OHSDTR will be fast and successful. On the other hand, the worst performer will be the sidetrack that takes a long time to drill and is unsuccessful. This study aims to evaluate unassisted openhole sidetracking performance; that way, the selected KPIs were:

- The average duration of the operation (hours).
- The success rate (%):

$$Success\ Rate\ (\%) = \frac{(Successful\ operations)}{(Total\ operations)}$$

Power BI allows applying filters to the calculations; the reader will see in the results section that, for example, the KPI **average duration of the operation** was calculated, considering the entire sample or just the successful or the failed operations. This information is interesting to learn how long a successful unassisted OHSDTR lasts on average. In addition, if it fails, how long does it take on average for the operators and service companies to consider the operation unsuccessful.

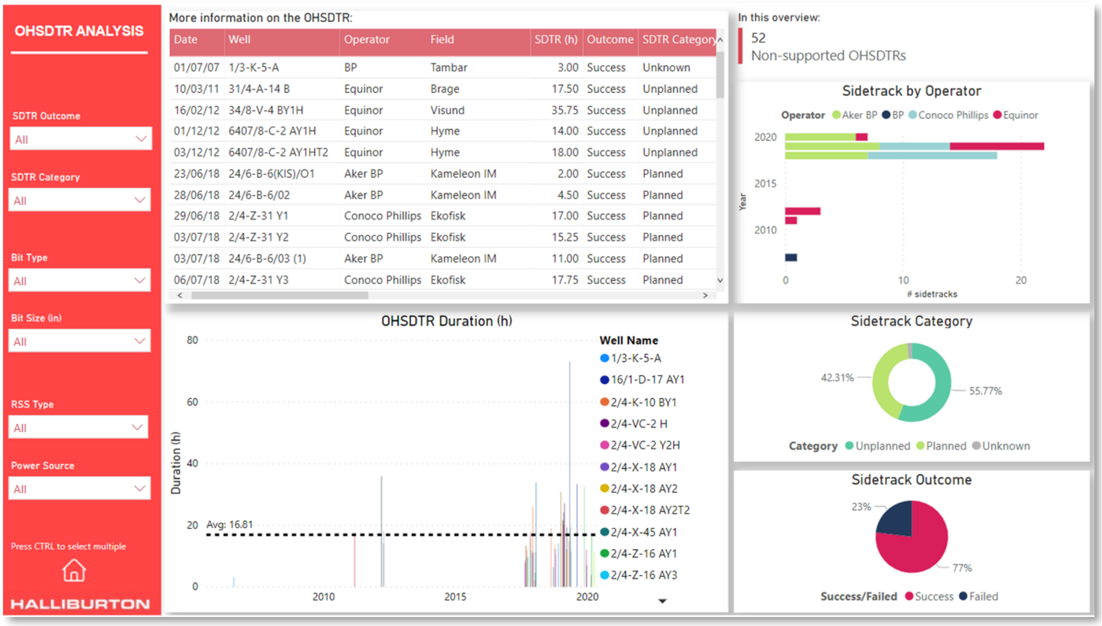
As mentioned in the data gathering and filtering section, the Power BI dashboard was built using data sourced from Excel. The database included 52 unassisted OHSDTRs performed in offshore wells in Norway. The PBI analysis environment was divided into five dashboards:

- Unassisted OHSDTR general analysis.
- Drill bit analysis.
- BHA configuration analysis.
- Best performers.
- Worst performers.

3.2.2.1 Unassisted OHSDTR general analysis

The **unassisted OHSDTR dashboard** contained a general evaluation of the sample characteristics. The dashboard overviewed the sidetracks category, outcome, operators, timeline, and average duration of the operations.

Figure 3.6 - Unassisted OHSDTR dashboard

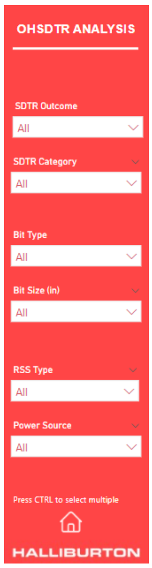


Source: Own author.

The left-hand side of this dashboard accommodated the filters:

- **Sidetrack outcome**: Failed, Success.
- **Sidetrack category**: Planned, Unplanned, Unknown.
- **Bit type**: Roller cone, PDC.
- **Bit size**: 12.25 in, 9.5 in, 8.5 in, 6.5 in, 6.0 in.
- **RSS type**: Point-the-bit, Push-the-bit, Point-the-bit – Mud motor, Other.
- **Power source**: AutoTrak, Geo-Pilot Dirigo, Geo-pilot Hybrid, Geo-Pilot XL, iCruise, Mud Motor, NB stabilizer, PowerDrive Orbit.

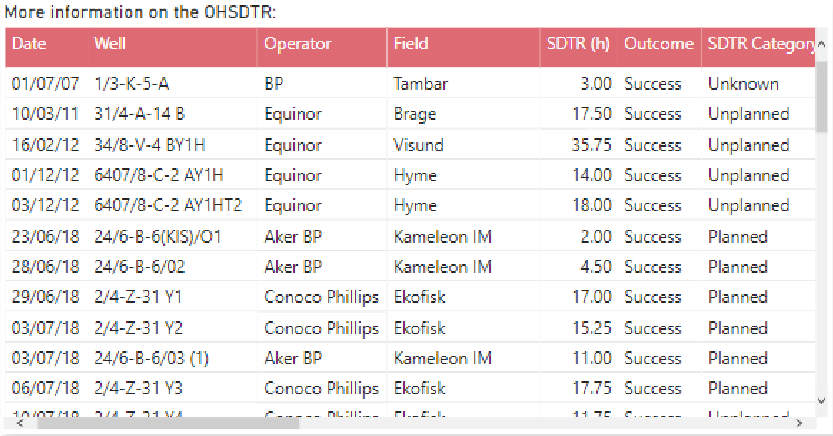
Figure 3.7 - Unassisted OHSDTR dashboard: Filters



Source: Own author.

In the middle-above chart, a table with detailed information on the sidetracks is presented. The table included: date, well name, operator, field, SDTR duration, SDTR outcome, SDTR category, bit size, bit type, bit manufacturer, bit model, bit length, gauge pad length, taper angle, gauge pad relief, bit serial number, RSS type and power source.

Figure 3.8 - Unassisted OHSDTR dashboard: Table with detailed information.



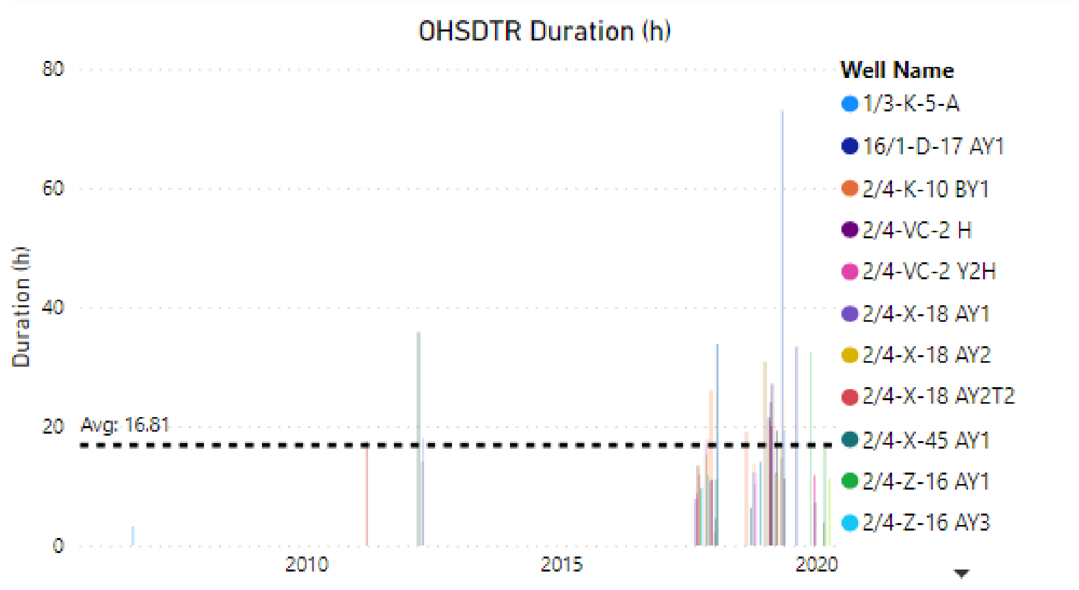
More information on the OHSDTR:

Date	Well	Operator	Field	SDTR (h)	Outcome	SDTR Categor
01/07/07	1/3-K-5-A	BP	Tambar	3.00	Success	Unknown
10/03/11	31/4-A-14 B	Equinor	Brage	17.50	Success	Unplanned
16/02/12	34/8-V-4 BY1H	Equinor	Visund	35.75	Success	Unplanned
01/12/12	6407/8-C-2 AY1H	Equinor	Hyme	14.00	Success	Unplanned
03/12/12	6407/8-C-2 AY1HT2	Equinor	Hyme	18.00	Success	Unplanned
23/06/18	24/6-B-6(KIS)/O1	Aker BP	Kameleon IM	2.00	Success	Planned
28/06/18	24/6-B-6/02	Aker BP	Kameleon IM	4.50	Success	Planned
29/06/18	2/4-Z-31 Y1	Conoco Phillips	Ekofisk	17.00	Success	Planned
03/07/18	2/4-Z-31 Y2	Conoco Phillips	Ekofisk	15.25	Success	Planned
03/07/18	24/6-B-6/03 (1)	Aker BP	Kameleon IM	11.00	Success	Planned
06/07/18	2/4-Z-31 Y3	Conoco Phillips	Ekofisk	17.75	Success	Planned

Source: Own author.

The middle-below diagram showed the timeline of the unassisted OHSDTRs performed and their duration. The dashed line accounted for the average duration of all operations shown in the graph. On the right-centre of the chart, a legend with the name of the well in which the sidetrack was drilled is displayed.

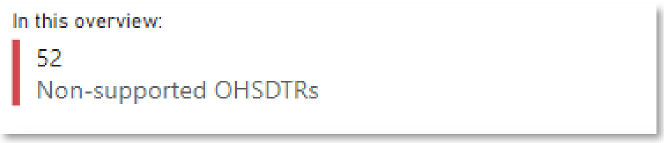
Figure 3.9 - Unassisted OHSDTR dashboard: Sidetracks timeline and duration chart



Source: Own author.

In the right-above part of the dashboard, a counter is presented. Its objective is to show the user how many operations are fitting the selected filters.

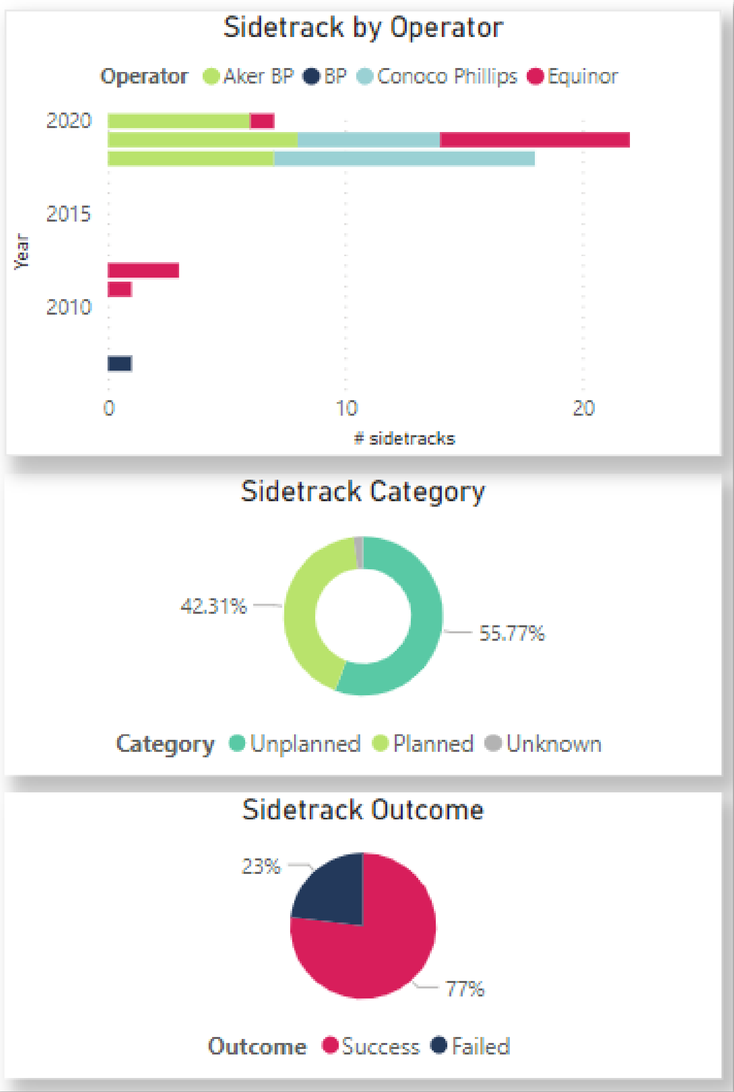
Figure 3.10 - Unassisted OHSDTR dashboard: operations counter



Source: Own author.

On the right-lower side, three diagrams are displayed: one accounting for the number of sidetracks per operator, one showing the category distribution and one the outcome of the operations.

Figure 3.11 - Unassisted OHSDTR dashboard: other diagrams



Source: Own author.

3.2.2.2 Drill bit dashboard

The **drill bit dashboard** was divided into two parts: drill bit general analysis and PDC bit characteristics analysis.

The *drill bit general analysis* dashboard contained a general evaluation of the drill bits used in the unassisted OHSDTR operations. It included an overview of the success rate and average duration of the operation per bit size.

Figure 3.12 - Drill bit dashboard

Source: Own author.

The left-hand side of this dashboard accommodated the filters:

- **Sidetrack outcome**: Failed, Success.
- **Sidetrack category**: Planned, Unplanned, Unknown.
- **Bit type**: Roller cone, PDC.
- **Bit size**: 12.25 in, 9.5 in, 8.5 in, 6.5 in, 6.0 in.
- **Bit model**: There are several bit model codes in the sample, see figure 3.13.
- **RSS type**: Point-the-bit, Push-the-bit, Point-the-bit – Mud motor, Other.
- **Power source**: AutoTrak, Geo-Pilot Dirigo, Geo-pilot Hybrid, Geo-Pilot XL, iCruise, Mud Motor, NB stabilizer, PowerDrive Orbit.

Figure 3.13 - Bit model codes in the analysed sample

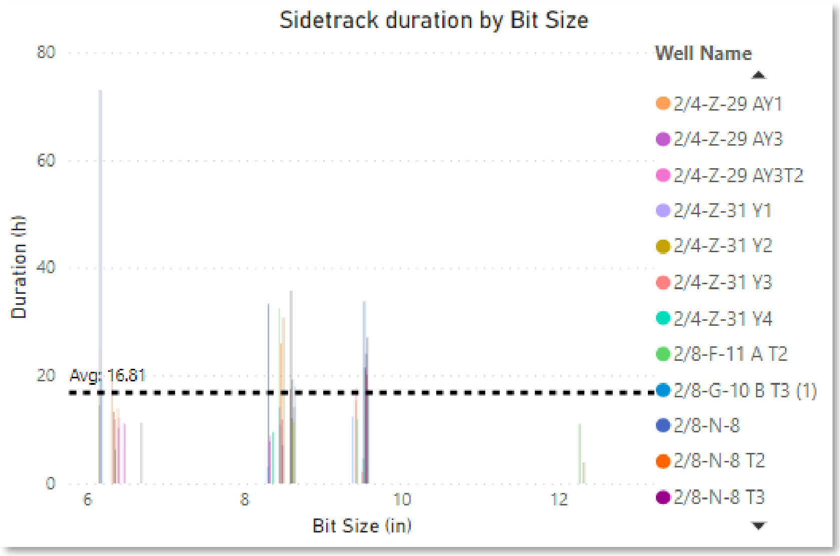
Bit Type	Bit Model
PDC	GT64H
PDC	VibX7332
PDC	FMF3651Z
PDC	FMF3653Z
PDC	GTD54DK
PDC	GTD54WK
PDC	GTD55DK
PDC	GTD55DKOs
PDC	GTD55Ds
PDC	GTD55DWMOs
PDC	GTD55WMOs
PDC	GTD64
PDC	GTD64H
PDC	GTD64Ks
PDC	GTD64MKOs
PDC	GTD75
PDC	GTD75c
PDC	GTD75HO
PDC	GTE54D
PDC	GTi55WMHOs
PDC	GTi75HO
Roller Cone	Insert bit
Roller Cone	Milled tooth
Roller Cone	QHC1GRC
PDC	SFE65CH
PDC	XZ616

Source: Own author.

In the middle-above chart, a table with detailed information on the sidetracks is presented. The table included: date, well name, operator, field, SDTR duration, SDTR outcome, SDTR category, bit size, bit type, bit manufacturer, bit model, bit length, gauge pad length, taper angle, gauge pad relief, bit serial number, RSS type and power source.

The middle-below diagram showed the unassisted OHSDTRs performed and their duration per bit size. The dashed line accounted for the average duration of all operations shown in the graph. On the right-centre of the chart, a legend with the name of the well in which the sidetrack was drilled is displayed.

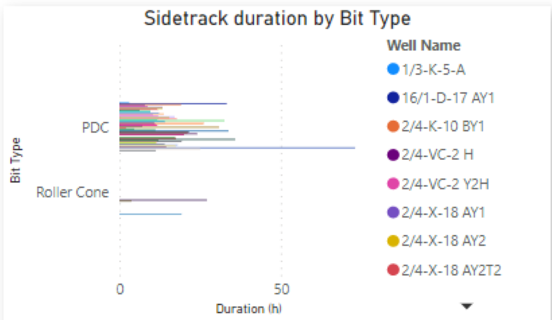
Figure 3.14 - Drill bit dashboard: Sidetrack duration by bit size



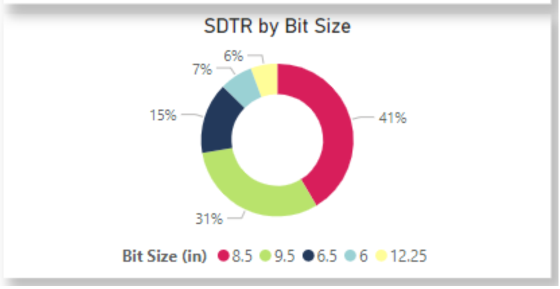
Source: Own author.

On the right-hand side of the dashboard, three charts are displayed. Above, one graph displaying the number of sidetracks per bit type (roller cone or PDC). In the middle, a table presents the sidetrack count, average duration, and success rate for each bit size. Below, one pie chart shows the sidetrack distribution per bit size.

Figure 3.15 - Drill bit dashboard: other diagrams



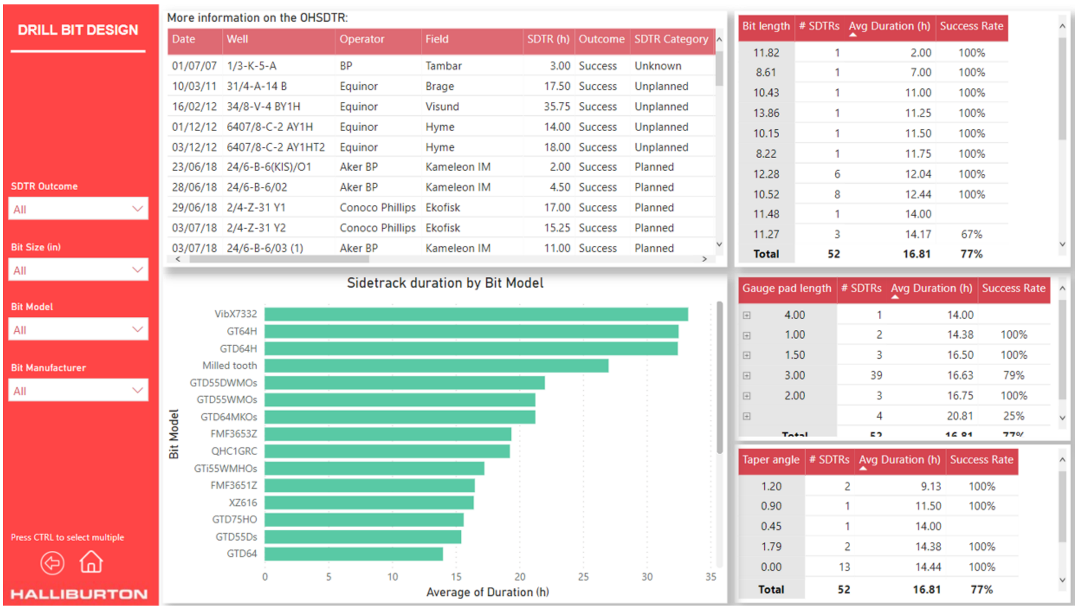
Bit Size (in)	# SDTRs	Avg Duration (h)	Success Rate
12.25	2	7.38	50%
9.50	14	17.50	71%
8.50	21	16.37	90%
6.50	10	12.18	100%
6.00	5	29.80	
Total	**52**	**16.81**	**77%**



Source: Own author.

The second part of the drill bit dashboard consisted of a more specific analysis of the *PDC bits characteristics*. In this view, the influence of bit length, gauge pad length, gauge pad relief, and taper angle on the operation's average duration and success rate were analysed. The goal of these examinations was to learn if the same known rules for bit steerability in directional drilling are also valid for unassisted OHSDTR operations, even though there is no restriction in front of the drill bit. Additionally, the operational average time of the OHSDTR per bit model was investigated as an internal analysis for Halliburton.

Figure 3.16 - PDC bit characteristics dashboard



Source: Own author.

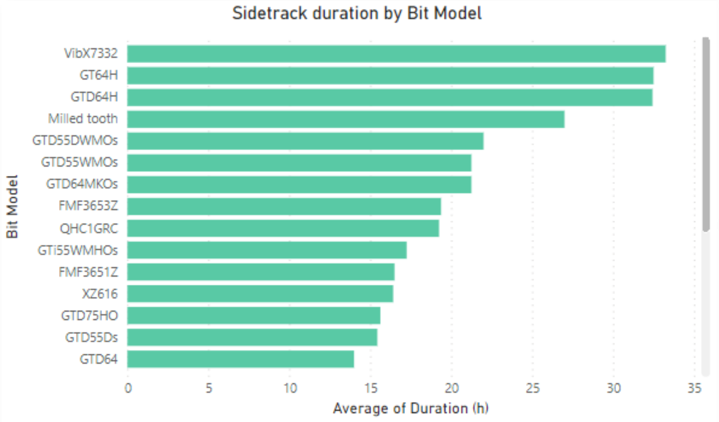
The left-hand side of this dashboard accommodated the filters: sidetrack outcome, bit size, bit model and bit manufacturer.

- **Sidetrack outcome**: Failed, Success.
- **Bit size**: 12.25 in, 9.5 in, 8.5 in, 6.5 in, 6.0 in.
- **Bit model**: There are several bit model codes in the sample, see figure 3.13.
- **Bit Manufacturer**: HDBS, SLB, SMITH, (Blank).

In the middle-above chart, a table with detailed information on the sidetracks is presented. The table included: date, well name, operator, field, SDTR duration, SDTR outcome, SDTR category, bit size, bit type, bit manufacturer, bit model, bit length, gauge pad length, taper angle, gauge pad relief, bit serial number, RSS type and power source.

The middle-below diagram shows the average duration of the unassisted openhole sidetrack operation per bit model.

Figure 3.17 - PDC bit characteristics dashboard: Sidetrack duration by bit model



Source: Own author.

On the right-hand side of the dashboard, three tables are presented showing the sidetracks count, average duration and success rate for each bit length, gauge pad length, gauge pad relief, and taper angle.

Figure 3.18 - PDC bit characteristics dashboard: Other diagrams

Bit length	# SDTRs	Avg Duration (h)	Success Rate
15.28	2	19.38	100%
14.90	6	19.33	67%
14.69	2	16.00	100%
14.08	3	25.00	100%
13.86	1	11.25	100%
13.76	5	29.45	20%
13.00	1	17.00	100%
12.28	6	12.04	100%
11.82	1	2.00	100%
11.48	1	14.00	
Total	**52**	**16.81**	**77%**

Gauge pad length	Gauge pad relief (off radius)	# SDTRs	Avg
⊟ 4.00	0.02	1	
	Total	**1**	
⊟ 3.00		3	
	0.00	8	
	0.02	26	
	0.02	2	

Taper angle	# SDTRs	Avg Duration (h)	Success Rate
1.79	2	14.38	100%
1.20	2	9.13	100%
0.90	1	11.50	100%
0.60	26	18.52	73%
0.45	1	14.00	
Total	**52**	**16.81**	**77%**

Source: Own author.

Figure 3.19 - PDC bit characteristics dashboard: gauge pad length/relief table in focus

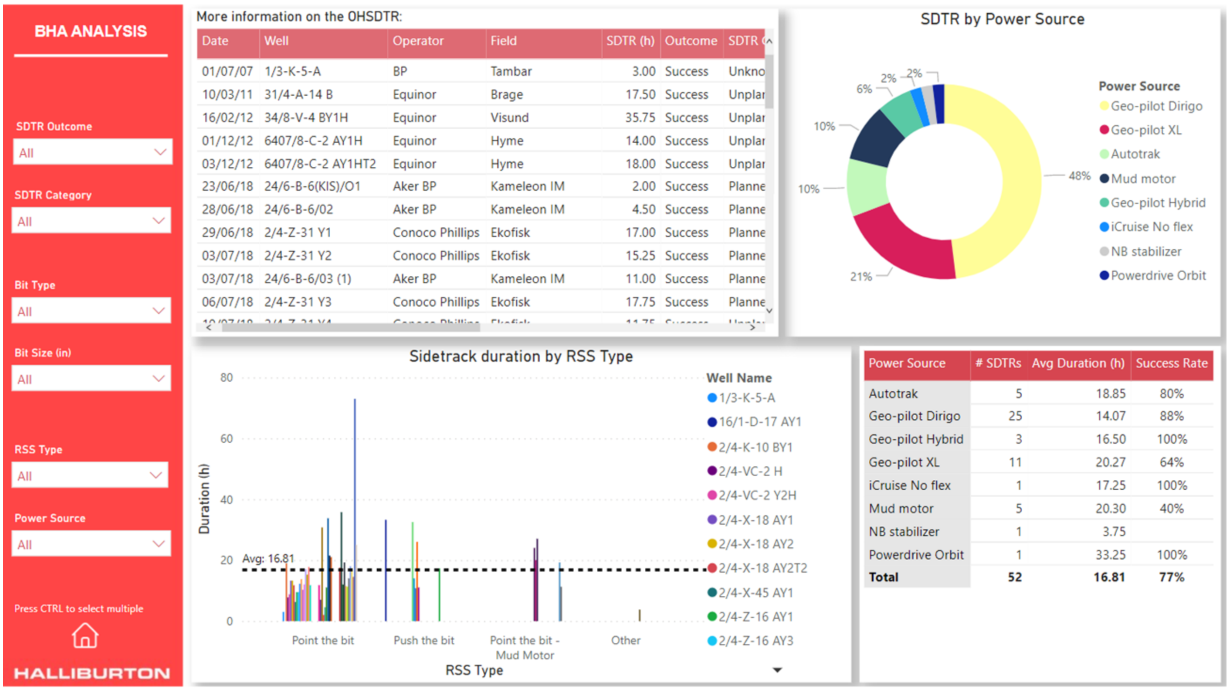
Gauge pad length	Gauge pad relief (off radius)	# SDTRs	Avg Duration (h)	Success Rate
4.00	0.02	1	14.00	
	Total	**1**	**14.00**	
3.00		**39**	**16.63**	**79%**
2.00		**3**	**16.75**	**100%**
1.50		**3**	**16.50**	**100%**
1.00		**2**	**14.38**	**100%**
		4	**20.81**	**25%**
Total		**52**	**16.81**	**77%**

Source: Own author.

3.2.2.3 BHA configuration analysis

The **BHA configuration dashboard** evaluated the power sources used for unassisted openhole sidetracking. The dashboard overviewed the most used power sources for this kind of operation and the average time for each type of directional BHA (point-the-bit RSS, push-the-bit RSS and mud motor). It also included a summary of the success rate and average duration of the operation per power source.

Figure 3.20 - BHA configuration dashboard



Source: Own author.

The left-hand side of this dashboard accommodated the filters:

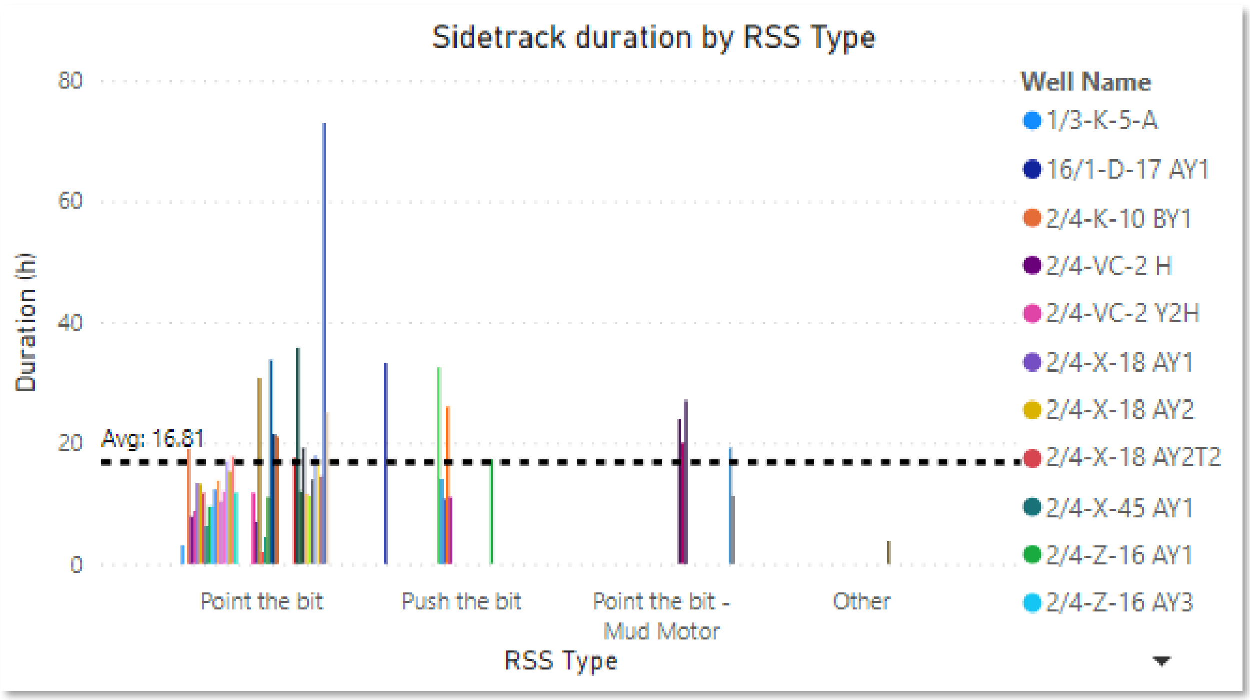
- **Sidetrack outcome**: Failed, Success.
- **Sidetrack category**: Planned, Unplanned, Unknown.

- **Bit type**: Roller cone, PDC.
- **Bit size**: 12.25 in, 9.5 in, 8.5 in, 6.5 in, 6.0 in.
- **Bit model**: There are several bit model codes in the sample, see figure 3.13.
- **RSS type**: Point-the-bit, Push-the-bit, Point-the-bit – Mud motor, Other.
- **Power source**: AutoTrak, Geo-Pilot Dirigo, Geo-pilot Hybrid, Geo-Pilot XL, iCruise, Mud Motor, NB stabilizer, PowerDrive Orbit.

In the middle-above chart, a table with detailed information on the sidetracks is presented. The table included: date, well name, operator, field, SDTR duration, SDTR outcome, SDTR category, bit size, bit type, bit manufacturer, bit model, bit length, gauge pad length, taper angle, gauge pad relief, bit serial number, RSS type and power source.

The middle-below diagram shows the unassisted OHSDTRs performed and their duration per RSS type. The dashed line accounted for the average duration of all operations shown in the graph. On the right-centre of the chart, a legend with the name of the well in which the sidetrack was drilled is displayed.

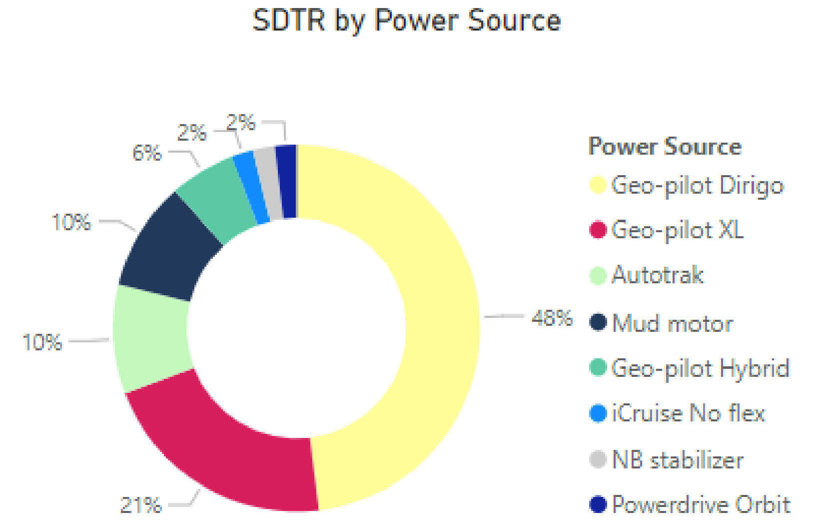
Figure 3.21 - BHA configuration dashboard: Sidetrack duration by RSS type



Source: Own author.

On the right-hand side of the dashboard, two charts are shown. Above, one pie chart displaying the share of sidetracks per power source. Below, one table presenting the sidetrack count, average duration, and success rate for each power source.

Figure 3.22 - BHA configuration dashboard: Other diagrams



Power Source	# SDTRs	Avg Duration (h)	Success Rate
Autotrak	5	18.85	80%
Geo-pilot Dirigo	25	14.07	88%
Geo-pilot Hybrid	3	16.50	100%
Geo-pilot XL	11	20.27	64%
iCruise No flex	1	17.25	100%
Mud motor	5	20.30	40%
NB stabilizer	1	3.75	
Powerdrive Orbit	1	33.25	100%
Total	**52**	**16.81**	**77%**

Source: Own author.

3.2.2.4 Best Performers

The **best performers dashboard** presented the features of the Top 10 successful unassisted openhole sidetrack operations. In this analysis, two filters were applied to the 52 unassisted OHSDTRs. The first filter refined the sample for only successful operations. The second picked the ten faster sidetracks between the successful unassisted openhole sidetracks.

Figure 3.23 - Best performers dashboard

Top 10 Successful SDTRs:

Date	Well	Operator	Field	SDTR (h)	Outcome	SDTR Category	Bit Size (in)	Bit Type	Bit Manufacturer	RSS Type	Power Source
01/07/07	1/3-K-5-A	BP	Tambar	3.00	Success	Unknown	8.50	PDC	HDBS	Point the bit	Geo-pilot Dirigo
23/06/18	24/6-B-6(KIS)/O1	Aker BP	Kameleon IM	2.00	Success	Planned	9.50	PDC	HDBS	Point the bit	Geo-pilot Dirigo
28/06/18	24/6-B-6/02	Aker BP	Kameleon IM	4.50	Success	Planned	9.50	PDC	SMITH	Point the bit	Geo-pilot Dirigo
21/11/18	2/4-Z-16 AY1	Conoco Phillips	Ekofisk	9.50	Success	Planned	8.50	PDC	HDBS	Point the bit	Geo-pilot Dirigo
24/11/18	2/4-Z-16 AY3	Conoco Phillips	Ekofisk	9.50	Success	Planned	8.50	PDC	HDBS	Point the bit	Geo-pilot Dirigo
26/11/18	2/4-VC-2 H	Conoco Phillips	Ekofisk	7.75	Success	Planned	8.50	PDC	HDBS	Point the bit	Geo-pilot XL
28/11/18	2/4-VC-2 Y2H	Conoco Phillips	Ekofisk	8.75	Success	Planned	8.50	PDC	HDBS	Point the bit	Geo-pilot XL
04/03/19	2/4-X-45 AY1	Conoco Phillips	Ekofisk	6.25	Success	Planned	6.50	PDC	HDBS	Point the bit	Geo-pilot Dirigo
22/04/19	2/4-Z-29 AY3	Conoco Phillips	Ekofisk	10.25	Success	Unplanned	6.50	PDC	HDBS	Point the bit	Geo-pilot Dirigo
28/02/20	2/8-V-2-Y2	Aker BP	Valhall Flank West	7.00	Success	Planned	8.50	PDC		Point the bit	Geo-pilot Hybrid

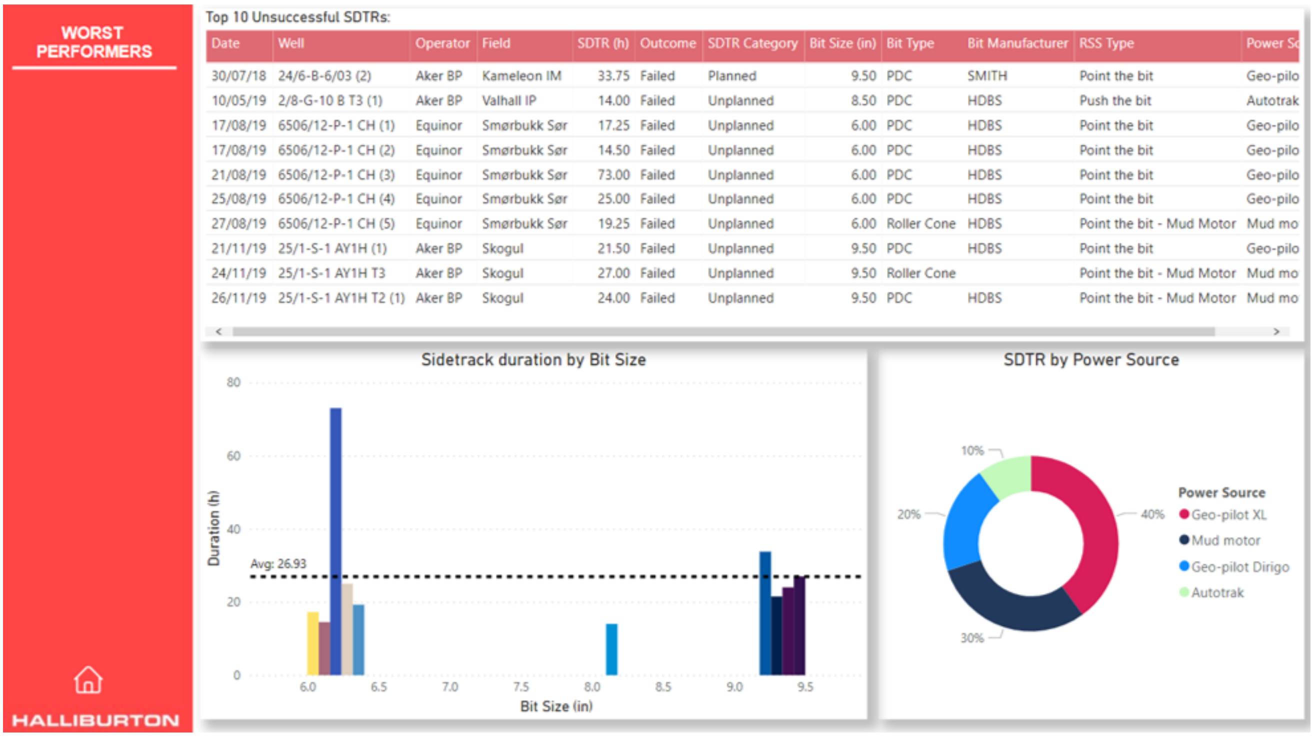
Source: Own author.

A table with detailed information on the ten best performers is presented in the middle-above diagram. The left-lower side shows a bar graph containing the ten best performance sidetrack duration per bit size. The dashed line calculates the average duration of the best performer's operations. The right-lower side displays a pie chart including the share of each power source among the best performers.

3.2.2.5 Worst Performers

The **worst performers dashboard** presented the features of the Top 10 unsuccessful unassisted openhole sidetrack operations. In this analysis, two filters were applied to the 52 unassisted OHSDTRs. The first filter refined the sample for only unsuccessful operations. The second picked the ten sidetracks with greater duration time between the unsuccessful unassisted openhole sidetrack operations.

Figure 3.24 - Worst performers dashboard



Date	Well	Operator	Field	SDTR (h)	Outcome	SDTR Category	Bit Size (in)	Bit Type	Bit Manufacturer	RSS Type	Power S
30/07/18	24/6-B-6/03 (2)	Aker BP	Kameleon IM	33.75	Failed	Planned	9.50	PDC	SMITH	Point the bit	Geo-pilo
10/05/19	2/8-G-10 B T3 (1)	Aker BP	Valhall IP	14.00	Failed	Unplanned	8.50	PDC	HDBS	Push the bit	Autotrak
17/08/19	6506/12-P-1 CH (1)	Equinor	Smørbukk Sør	17.25	Failed	Unplanned	6.00	PDC	HDBS	Point the bit	Geo-pilo
17/08/19	6506/12-P-1 CH (2)	Equinor	Smørbukk Sør	14.50	Failed	Unplanned	6.00	PDC	HDBS	Point the bit	Geo-pilo
21/08/19	6506/12-P-1 CH (3)	Equinor	Smørbukk Sør	73.00	Failed	Unplanned	6.00	PDC	HDBS	Point the bit	Geo-pilo
25/08/19	6506/12-P-1 CH (4)	Equinor	Smørbukk Sør	25.00	Failed	Unplanned	6.00	PDC	HDBS	Point the bit	Geo-pilo
27/08/19	6506/12-P-1 CH (5)	Equinor	Smørbukk Sør	19.25	Failed	Unplanned	6.00	Roller Cone	HDBS	Point the bit - Mud Motor	Mud mo
21/11/19	25/1-S-1 AY1H (1)	Aker BP	Skogul	21.50	Failed	Unplanned	9.50	PDC	HDBS	Point the bit	Geo-pilo
24/11/19	25/1-S-1 AY1H T3	Aker BP	Skogul	27.00	Failed	Unplanned	9.50	Roller Cone		Point the bit - Mud Motor	Mud mo
26/11/19	25/1-S-1 AY1H T2 (1)	Aker BP	Skogul	24.00	Failed	Unplanned	9.50	PDC	HDBS	Point the bit - Mud Motor	Mud mo

Source: Own author.

A table with detailed information on the ten worst performers is presented in the middle-above diagram. The left-lower side shows a bar graph containing the ten worst performance sidetrack duration per bit size. The dashed line calculates the average duration of the worst performer’s operations. The right-lower side displays a pie chart including the share of each power source among the worst performers.

4. RESULTS

This thesis proposes the *Lesson Learned* of the drill bit features and BHA configuration influence in unassisted openhole sidetracking performance in Norway. The sample used in the analysis included 52 unassisted OHSDTRs performed in offshore wells between 2007 and 2020.

This section is divided in four parts:

1) **General Remarks**: the results obtained from the general analysis are presented. The findings are displayed focused on the operation, the power source and the drill bit.

2) **Remarks per well section**: the results from the analysis are presented for each drill bit size: 12.25 in, 9.5 in, 8.5 in, 6.5 in and 6 in.

3) **Best performers**: the features of the Top 10 successful sidetrack operations are presented. In this analysis, two filters were applied to the sample. The first filter refined the sample for only successful operations. The second picked the ten faster sidetracks between those.

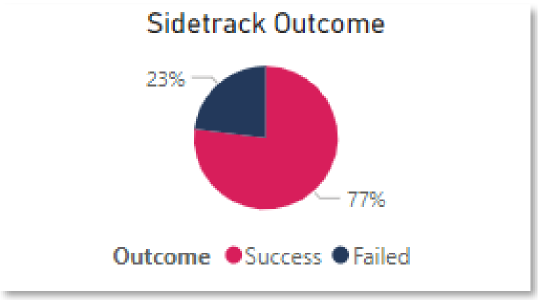
4) **Worst performers:** the features of the Top 10 unsuccessful sidetrack operations are presented. In this analysis, two filters were applied to the sample. The first filter refined the sample for only unsuccessful operations. The second picked the ten sidetracks with greater duration time between those.

4.1 GENERAL REMARKS

4.1.1 Unassisted OHSDTR

Regarding the operation outcome, the majority of the unassisted openhole sidetracks were **successful**.

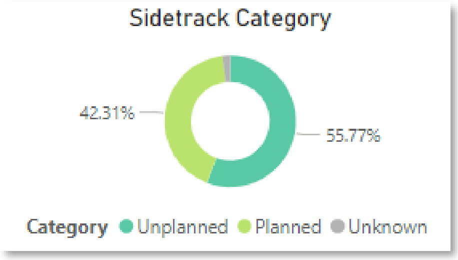
Figure 4.1 - General remarks: Sidetrack Outcome



Source: Own author.

Concerning the category, most unassisted openhole sidetracks were **unplanned**.

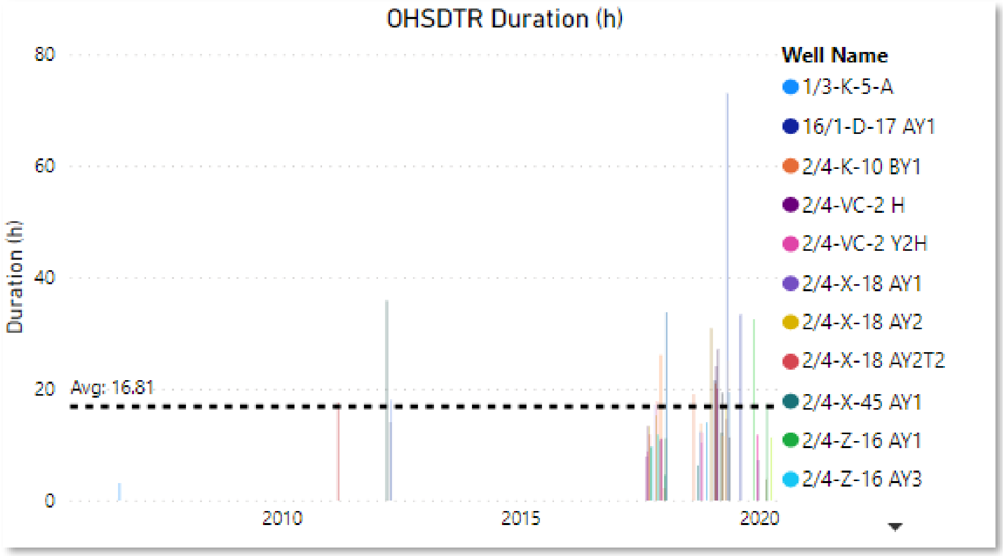
Figure 4.2 - General remarks: Sidetrack Category



Source: Own author.

Considering the entire sample, the **average time** of the unassisted openhole sidetrack was 16.81 hours.

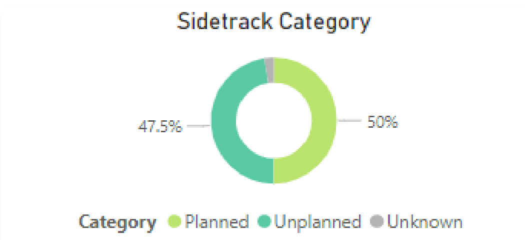
Figure 4.3 - General remarks: Average duration of the OHSDTR



Source: Own author.

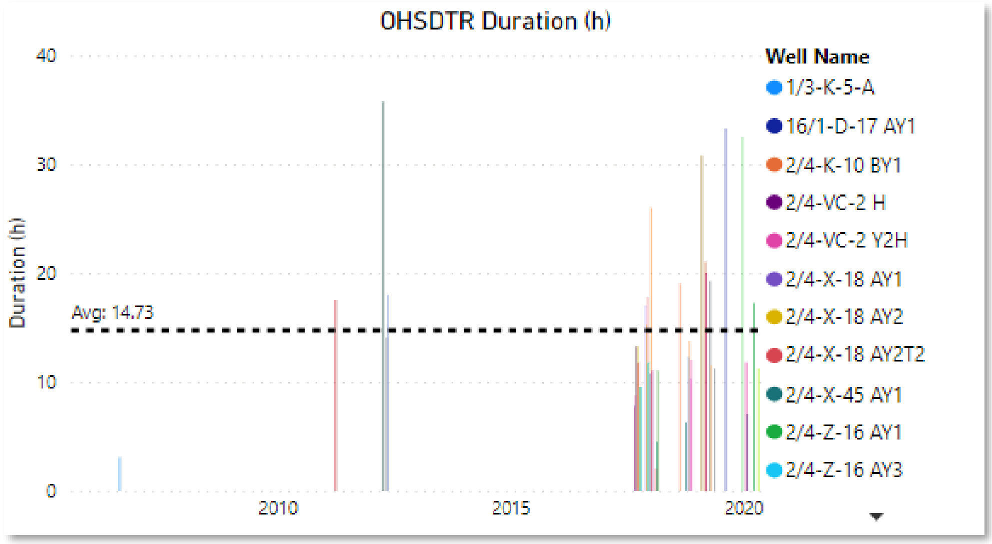
The **successful** operations had a majority of **planned** OHSDTRs and an **average time** of 14.73 hours.

Figure 4.4 - General remarks: Category of the successful OHSDTRs



Source: Own author.

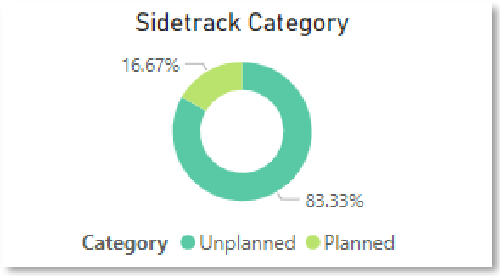
Figure 4.5 - General remarks: Average duration of the successful OHSDTRs



Source: Own author.

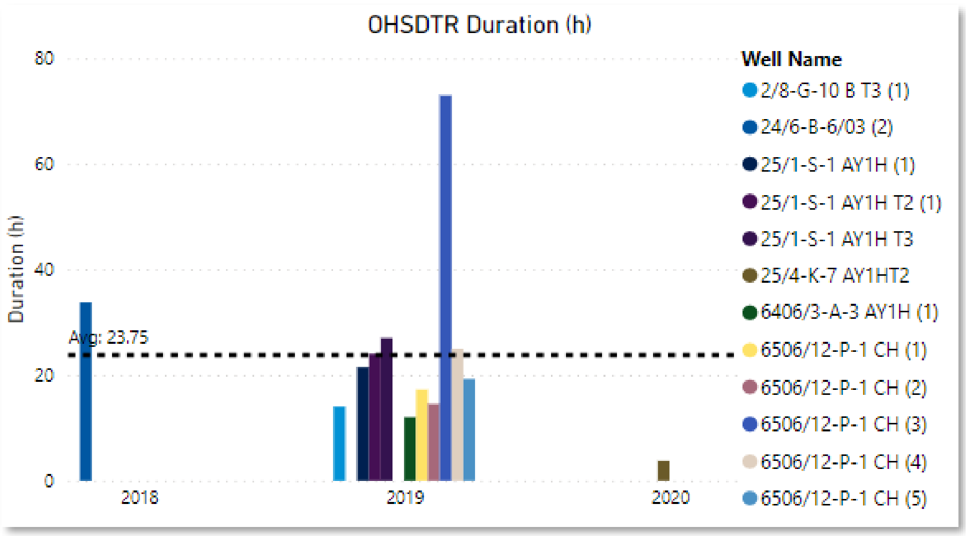
The **failed** operations had a majority of **unplanned** OHSDTRs and an **average time** of 23.75 hours.

Figure 4.6 - General remarks: Category of the unsuccessful OHSDTRs



Source: Own author.

Figure 4.7 - General remarks: Average duration of the unsuccessful OHSDTRs

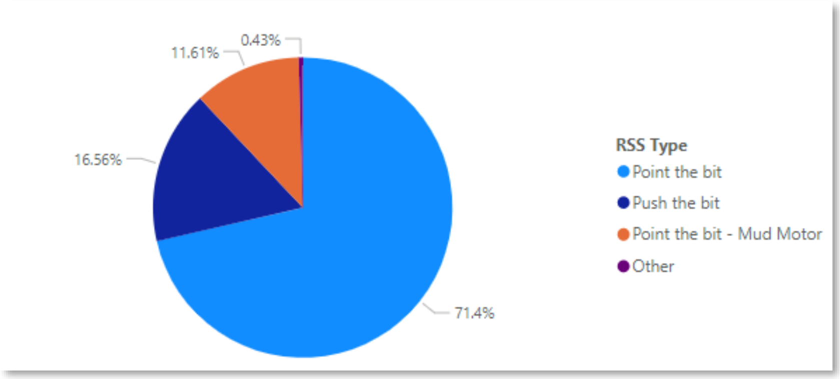


Source: Own author.

4.1.2 BHA Configuration

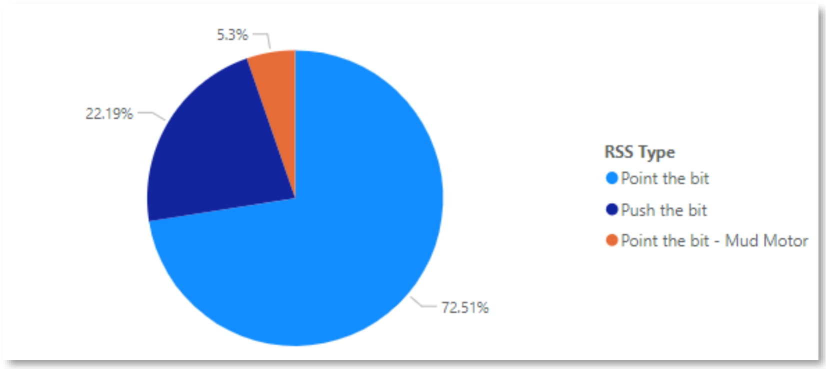
The unassisted openhole sidetracks were performed using mostly point-the-bit RSS systems, followed by push-the-bit RSS and then mud motor. Both the **successful** and **unsuccessful** operations mainly used the **point-the bit RSS**.

Figure 4.8 - Sidetrack by RSS type: All sample



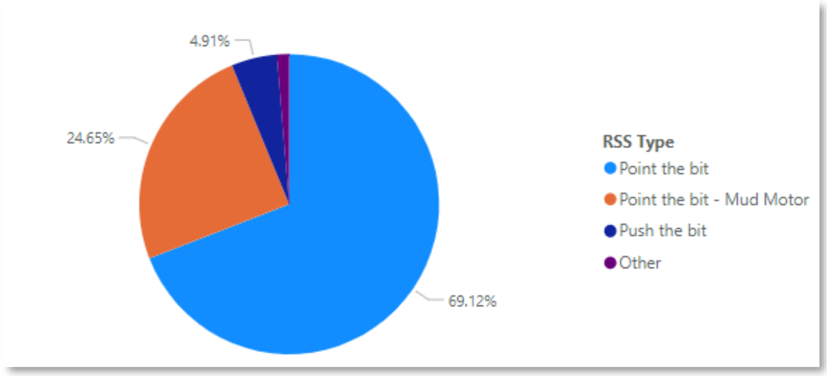
Source: Own author.

Figure 4.9 - Sidetrack by RSS type: Successful Sidetracks



Source: Own author.

Figure 4.10 - Sidetrack by RSS type: Unsuccessful Sidetracks



Source: Own author.

Point-the-bit RSS

The OHSDTRs performed with **point-the-bit RSS** had a **success rate** of 82%, and most sidetracks were **planned**.

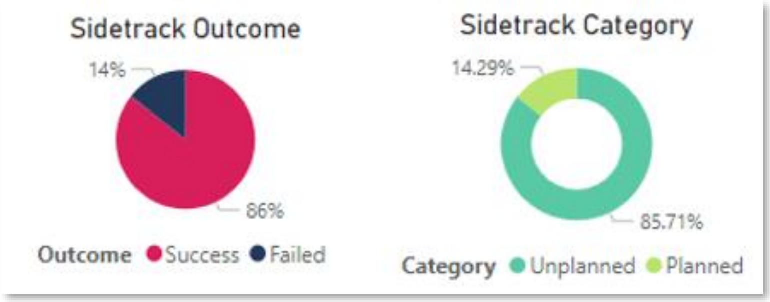
Figure 4.11 - Point-the-bit RSS findings overview

Source: Own author.

Push-the-bit RSS

The OHSDTRs performed with **push-the-bit RSS** had a **success rate** of 86%, and most sidetracks were **unplanned**.

Figure 4.12 - Push-the-bit RSS findings overview



Source: Own author.

Mud motor

The OHSDTRs performed with **mud motor** had a **success rate** of 40%, and all sidetracks were **unplanned**.

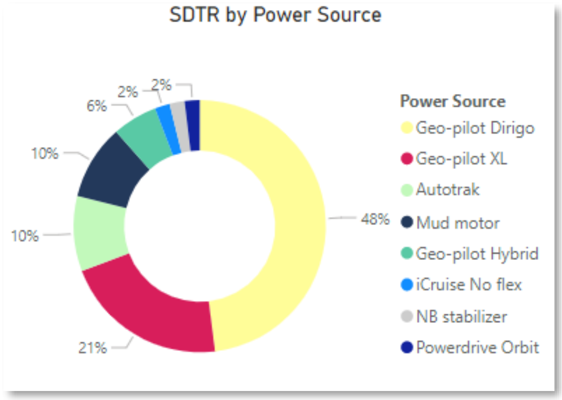
Figure 4.13 - Mud motor findings overview

Source: Own author.

Power sources

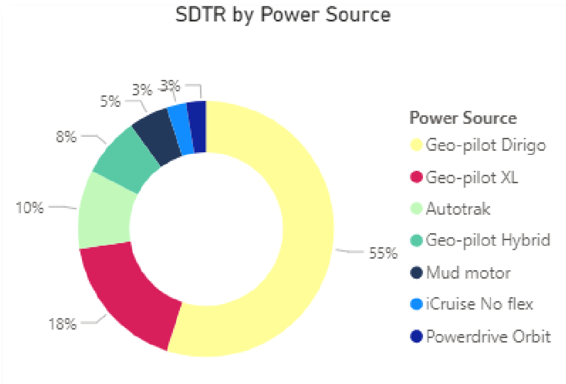
Most of the unassisted OHSDTR attempts were executed with the **Geo-pilot Dirigo**, followed by **Geo-pilot XL**, and then **Autotrak** and **mud motor**. The **successful** operations mainly used the **Geo-pilot Dirigo**. The **unsuccessful** operations mainly used the **Geo-pilot XL**.

Figure 4.14 - Sidetrack by Power Source: All sample



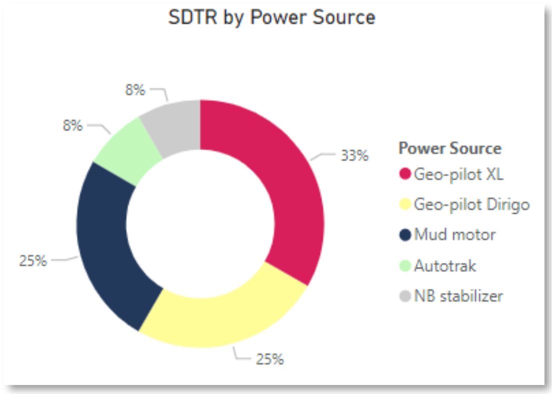
Source: Own author.

Figure 4.15 - Sidetrack by Power Source: Successful Sidetracks



Source: Own author.

Figure 4.16 - Sidetrack by Power Source: Unsuccessful Sidetracks



Source: Own author.

The **success rate** and **average time** of the unassisted openhole sidetracks for each **power source**, considering the entire sample, are shown in the figure below:

Figure 4.17 - Success rate and average duration of the unassisted OHSDTR for each power source

Power Source	RSS Type	# SDTRs	Avg Duration (h)	Success Rate
Autotrak	Push the bit	5	18.85	80%
Geo-pilot Dirigo	Point the bit	25	14.07	88%
Geo-pilot Hybrid	Point the bit	3	16.50	100%
Geo-pilot XL	Point the bit	11	20.27	64%
iCruise No flex	Push the bit	1	17.25	100%
Mud motor	Point the bit - Mud Motor	5	20.30	40%
NB stabilizer	Other	1	3.75	
Powerdrive Orbit	Push the bit	1	33.25	100%
Total	**Other**	**52**	**16.81**	**77%**

Source: Own author.

The **success rate** and **average time** of the unassisted openhole sidetracks by **directional BHA type,** considering the entire sample, are shown in the figure below:

Figure 4.18 - Success rate and average duration of the unassisted OHSDTR for each directional BHA type

RSS Type	# SDTRs	Avg Duration (h)	Success Rate
Point the bit	39	16.01	82%
Push the bit	7	20.68	86%
Point the bit - Mud Motor	5	20.30	40%
Other	1	3.75	
Total	**52**	**16.81**	**77%**

Source: Own author.

The **average time** of the **successful** unassisted openhole sidetracks by **directional BHA type** is shown in the figure below:

Figure 4.19 - Average duration of the successful unassisted OHSDTR for each directional BHA type

RSS Type	# SDTRs	Avg Duration (h)
Point the bit	32	13.35
Push the bit	6	21.79
Point the bit - Mud Motor	2	15.63
Total	**40**	**14.73**

Source: Own author.

The **average time** of the **unsuccessful** unassisted openhole sidetracks by **directional BHA type** is shown in the figure below:

Figure 4.20 - Average duration of the unsuccessful unassisted OHSDTR for each directional BHA type

RSS Type	# SDTRs	Avg Duration (h)
Point the bit	7	28.14
Point the bit - Mud Motor	3	23.42
Other	1	3.75
Push the bit	1	14.00
Total	**12**	**23.75**

Source: Own author.

4.1.3 Drill bits

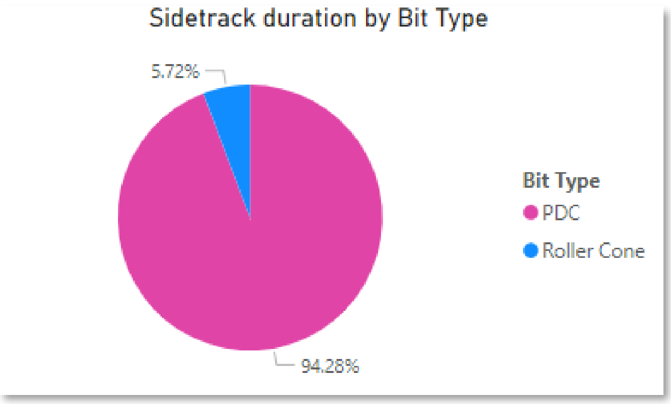
Roller cone bits

All the operations using roller cone bits were **unsuccessful**. All the unassisted openhole sidetracks performed using a **roller cone** were **unplanned**.

PDC bits

Most of the unassisted openhole sidetracks were performed using **PDC bits**.

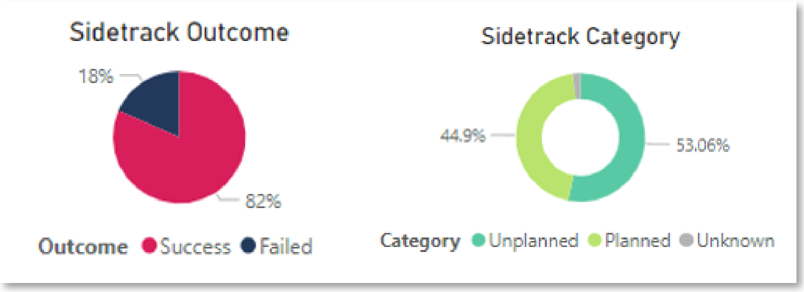
Figure 4.21 - Sidetrack by Bit type



Source: Own author.

The OHSDTRs performed with PDC bits had a **success rate** of 82%. The majority of the sidetracks performed by these bits were **unplanned**.

Figure 4.22 - PDC bits results overview



Source: Own author.

PDC bit characteristics - Bit Length

From the analysis of the PDC bit length effect on the average duration and success rate, it was difficult to notice a trend in the table values.

Figure 4.23 - PDC bit length effect on average duration and success rate.

Bit length	# SDTRs	Avg Duration (h)	Success Rate
	4	20.81	25%
8.22	1	11.75	100%
8.61	1	7.00	100%
9.89	3	16.42	67%
10.15	1	11.50	100%
10.43	1	11.00	100%
10.52	8	12.44	100%
11.27	3	14.17	67%
11.30	2	16.50	100%
11.48	1	14.00	
11.82	1	2.00	100%
12.28	6	12.04	100%
13.00	1	17.00	100%
13.76	5	29.45	20%
13.86	1	11.25	100%
14.08	3	25.00	100%
14.69	2	16.00	100%
14.90	6	19.33	67%
15.28	2	19.38	100%
Total	**52**	**16.81**	**77%**

Bit length	# SDTRs	Avg Duration (h)	Success Rate
11.82	1	2.00	100%
8.61	1	7.00	100%
10.43	1	11.00	100%
13.86	1	11.25	100%
10.15	1	11.50	100%
8.22	1	11.75	100%
12.28	6	12.04	100%
10.52	8	12.44	100%
11.48	1	14.00	
11.27	3	14.17	67%
14.69	2	16.00	100%
9.89	3	16.42	67%
11.30	2	16.50	100%
13.00	1	17.00	100%
14.90	6	19.33	67%
15.28	2	19.38	100%
	4	20.81	25%
14.08	3	25.00	100%
13.76	5	29.45	20%
Total	**52**	**16.81**	**77%**

Bit length	# SDTRs	Avg Duration (h)	Success Rate
8.22	1	11.75	100%
8.61	1	7.00	100%
10.15	1	11.50	100%
10.43	1	11.00	100%
10.52	8	12.44	100%
11.30	2	16.50	100%
11.82	1	2.00	100%
12.28	6	12.04	100%
13.00	1	17.00	100%
13.86	1	11.25	100%
14.08	3	25.00	100%
14.69	2	16.00	100%
15.28	2	19.38	100%
9.89	3	16.42	67%
11.27	3	14.17	67%
14.90	6	19.33	67%
	4	20.81	25%
13.76	5	29.45	20%
11.48	1	14.00	
Total	**52**	**16.81**	**77%**

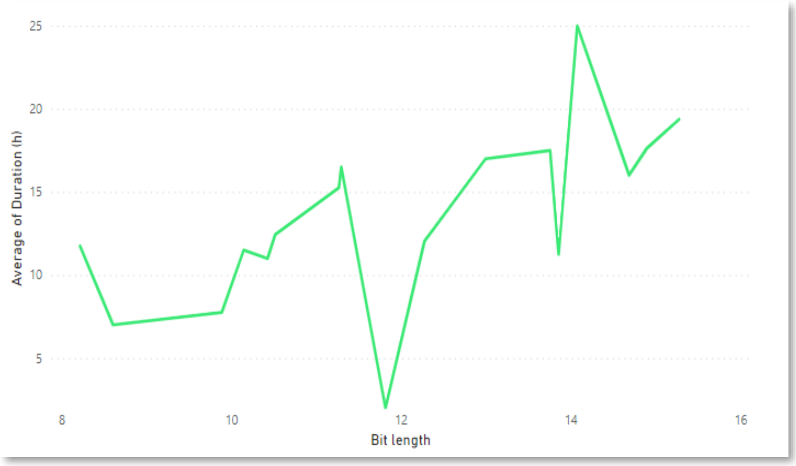
Source: Own author.

The author created extra plots to try and observe a relation between the bit length, average duration and success rate. The discussion about these results will be presented in chapter 5.

Figure 4.24 - PDC Bit Length vs Average Duration of the OHSDTR: All operations

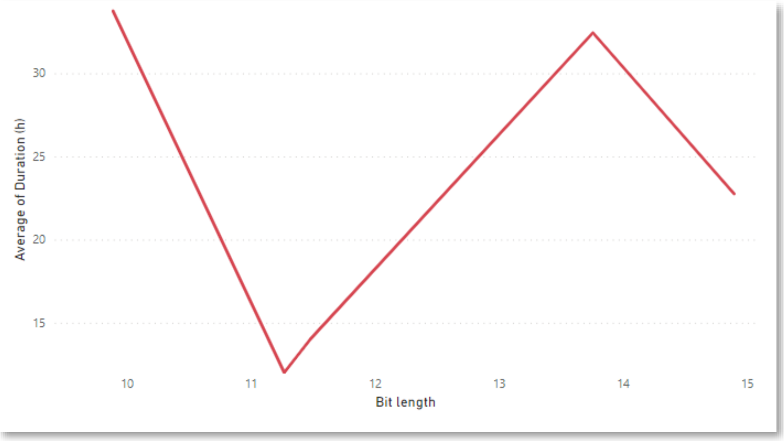
Source: Own author.

Figure 4.25 - PDC Bit Length vs Average Duration of the OHSDTR: Successful operations



Source: Own author.

Figure 4.26 - PDC Bit Length vs Average Duration of the OHSDTR: Failed operations



Source: Own author.

Figure 4.27 - PDC Bit Length vs Success Rate

Source: Own author.

PDC bit characteristics – Taper angle

From the analysis of the taper angle effect on the average duration and success rate, it was also difficult to notice a trend in the values.

Figure 4.28 - Taper angle effect on average duration and success rate.

Taper angle	# SDTRs	Avg Duration (h)	Success Rate
	7	18.93	43%
0.00	13	14.44	100%
0.45	1	14.00	
0.60	26	18.52	73%
0.90	1	11.50	100%
1.20	2	9.13	100%
1.79	2	14.38	100%
Total	**52**	**16.81**	**77%**

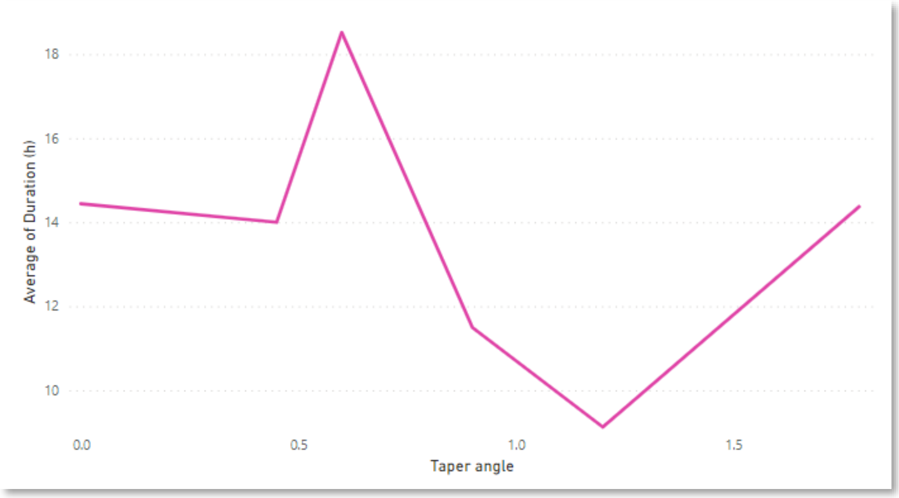
Taper angle	# SDTRs	Avg Duration (h)	Success Rate
1.20	2	9.13	100%
0.90	1	11.50	100%
0.45	1	14.00	
1.79	2	14.38	100%
0.00	13	14.44	100%
0.60	26	18.52	73%
	7	18.93	43%
Total	**52**	**16.81**	**77%**

Taper angle	# SDTRs	Avg Duration (h)	Success Rate
0.00	13	14.44	100%
0.90	1	11.50	100%
1.20	2	9.13	100%
1.79	2	14.38	100%
0.60	26	18.52	73%
	7	18.93	43%
0.45	1	14.00	
Total	**52**	**16.81**	**77%**

Source: Own author.

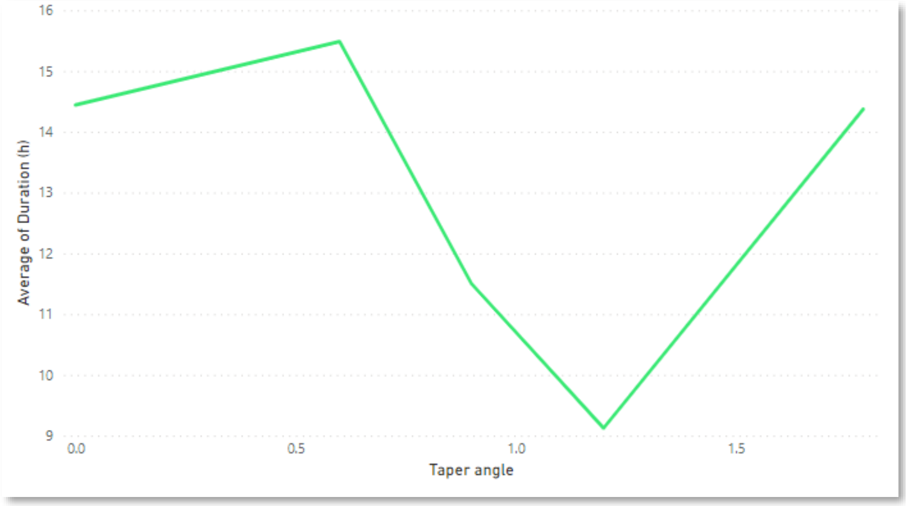
The author created extra plots to try and observe a relation between the taper angle, average duration and success rate. The discussion about these results will be presented in chapter 5.

Figure 4.29 - PDC Taper Angle vs Average Duration of the OHSDTR: All operations



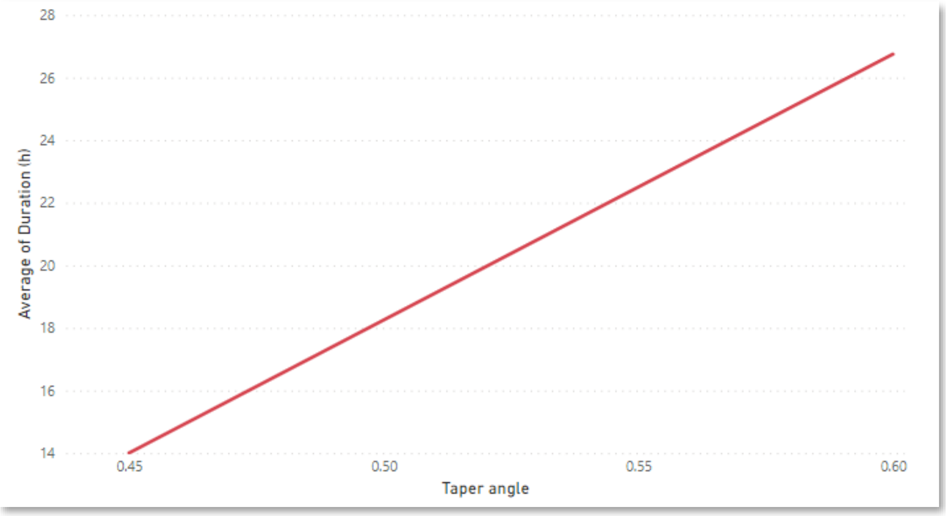
Source: Own author.

Figure 4.30 - PDC Taper Angle vs Average Duration of the OHSDTR: Successful operations



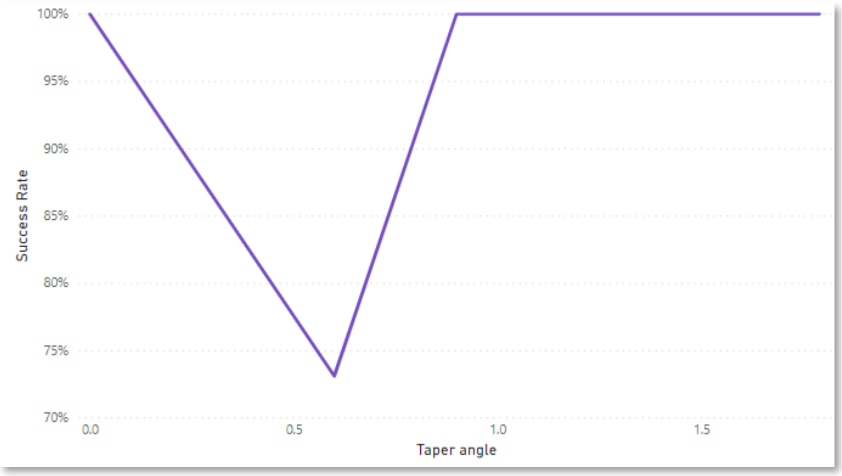
Source: Own author.

Figure 4.31 - PDC Taper Angle vs Average Duration of the OHSDTR: Failed operations



Source: Own author.

Figure 4.32 - PDC Taper Angle vs Success Rate



Source: Own author.

PDC bit characteristics – Gauge Pad Length

From the analysis of the gauge pad length effect on the average duration and success rate, it was not easy to notice a pattern in the table values.

Figure 4.33 - Gauge pad length effect on average duration and success rate.

Gauge pad length	# SDTRs	Avg Duration (h)	Success Rate
	4	20.81	25%
1.00	2	14.38	100%
1.50	3	16.50	100%
2.00	3	16.75	100%
3.00	39	16.63	79%
4.00	1	14.00	
Total	**52**	**16.81**	**77%**

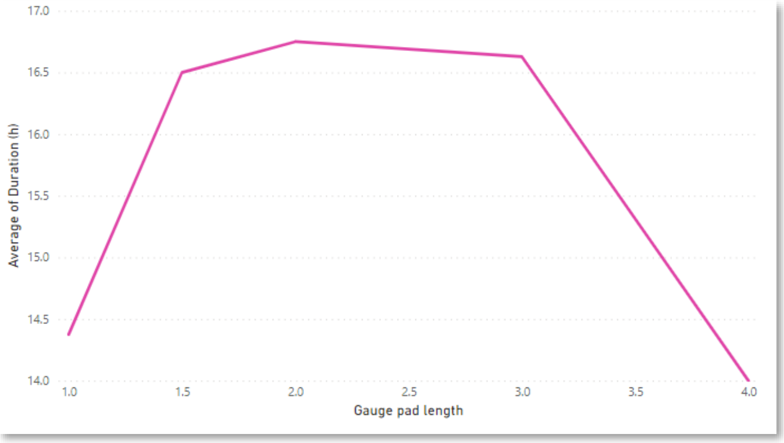
Gauge pad length	# SDTRs	Avg Duration (h)	Success Rate
4.00	1	14.00	
1.00	2	14.38	100%
1.50	3	16.50	100%
3.00	39	16.63	79%
2.00	3	16.75	100%
	4	20.81	25%
Total	**52**	**16.81**	**77%**

Gauge pad length	# SDTRs	Avg Duration (h)	Success Rate
1.00	2	14.38	100%
1.50	3	16.50	100%
2.00	3	16.75	100%
3.00	39	16.63	79%
	4	20.81	25%
4.00	1	14.00	
Total	**52**	**16.81**	**77%**

Source: Own author.

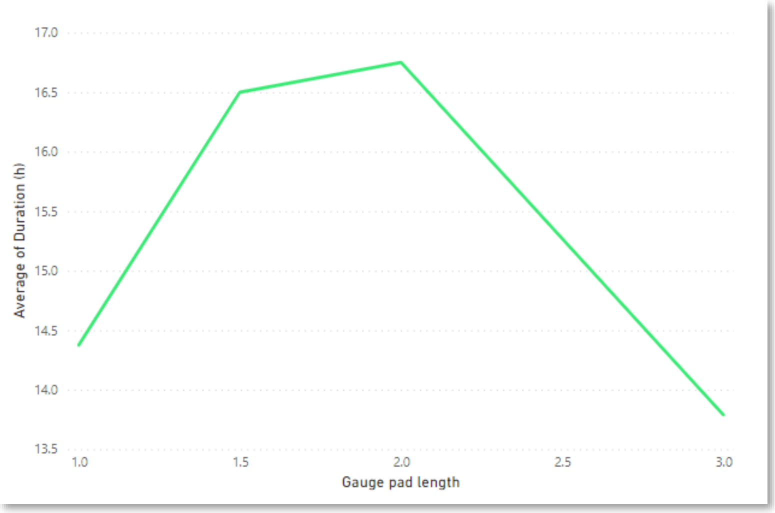
The author created extra plots to try and observe a relation between the gauge pad length, average duration and success rate. The discussion about these results will be presented in chapter 5.

Figure 4.34 - PDC Gauge Pad Length vs Average Duration of the OHSDTR: All operations



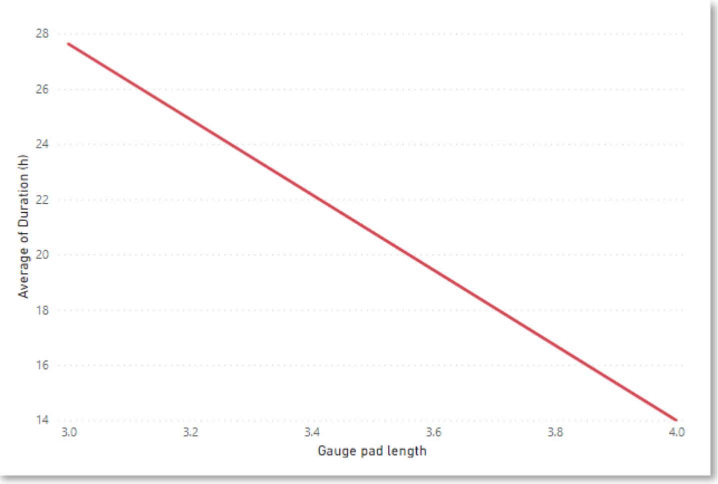
Source: Own author.

Figure 4.35 - PDC Gauge Pad Length vs Average Duration of the OHSDTR: Successful operations



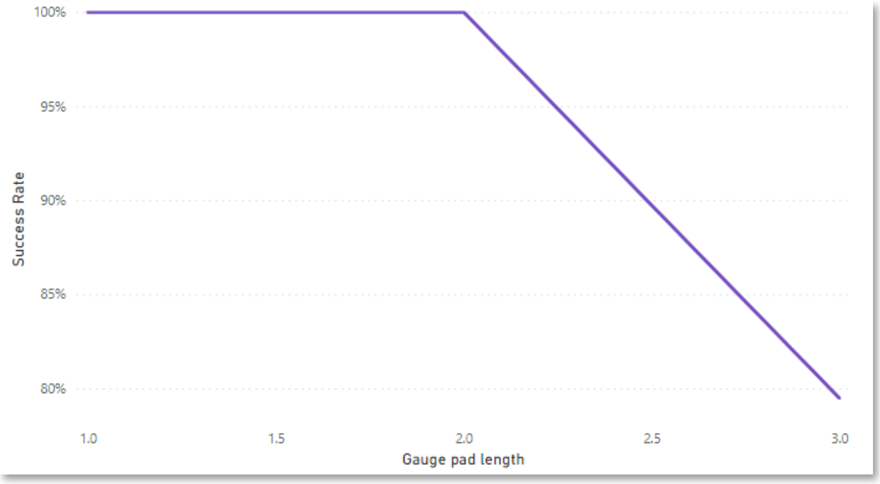
Source: Own author.

Figure 4.36 - PDC Gauge Pad Length vs Average Duration of the OHSDTR: Failed operations



Source: Own author.

Figure 4.37 - PDC Gauge Pad Length vs Success Rate



Source: Own author.

PDC bit characteristics – Gauge Pad Relief

From the analysis of the gauge pad relief effect on the average duration and success rate, it was once again difficult to notice a pattern in the values.

Figure 4.38 - Gauge pad relief effect on average duration and success rate.

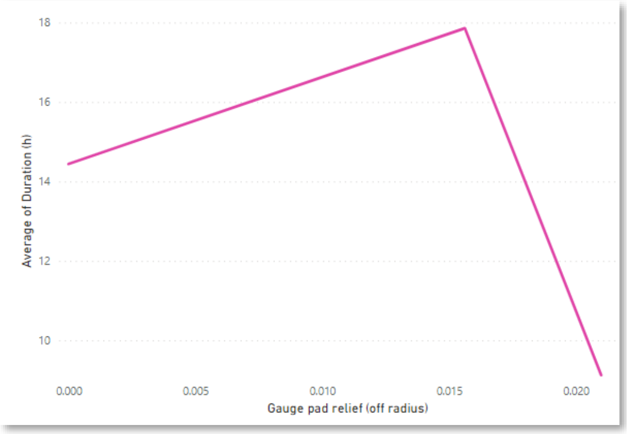
Gauge pad relief (off radius)	# SDTRs	Avg Duration (h)	Success Rate
	7	18.93	43%
0.0000	13	14.44	100%
0.0156	30	17.86	73%
0.0210	2	9.13	100%
Total	**52**	**16.81**	**77%**

Gauge pad relief (off radius)	# SDTRs	Avg Duration (h)	Success Rate
0.0210	2	9.13	100%
0.0000	13	14.44	100%
0.0156	30	17.86	73%
	7	18.93	43%
Total	**52**	**16.81**	**77%**

Source: Own author.

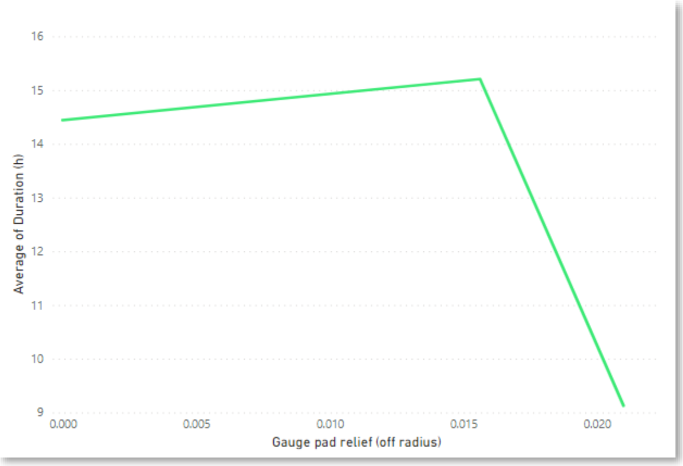
The author created extra plots to try and observe a relation between the gauge pad relief, average duration and success rate. The discussion about these results will be presented in chapter 5.

Figure 4.39 - PDC Gauge Pad Relief vs Average Duration of the OHSDTR: All operations



Source: Own author.

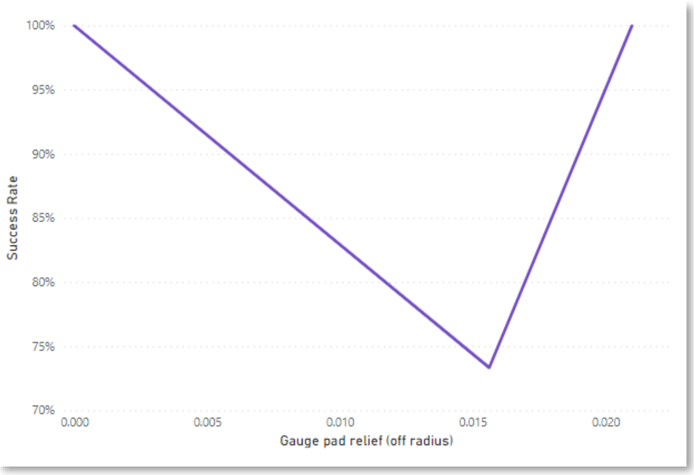
Figure 4.40 - PDC Gauge Pad Relief vs Average Duration of the OHSDTR: Successful operations



Source: Own author.

The plot of the gauge pad relief effect on the average duration showed that all **failed operations** used a relieved gauge pad bit with a 0.0156 inches relief.

Figure 4.41 - PDC Gauge Pad Relief vs Success Rate



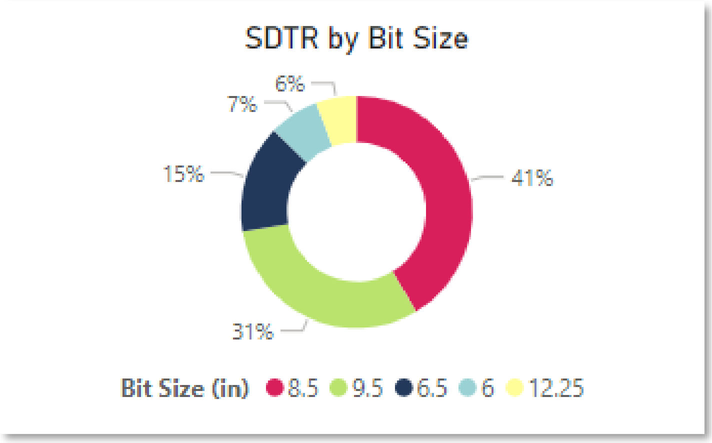
Source: Own author.

4.2 REMARKS PER WELL SECTION

For the Lesson Learned of unassisted openhole sidetracking **performance per well section**, the results from the analysis are here presented for each drill bit size.

From the unassisted OHSDTRs performed, most of them were drilled with an 8.5 or a 9.5 inches bit.

Figure 4.42 - Sidetrack by Bit size



Source: Own author.

The **success rate** and **average time** of the unassisted openhole sidetracks by bit size**,** considering the entire sample, are shown in the figure below:

Figure 4.43 - Success rate and average duration of the unassisted OHSDTR for each bit size

Bit Size (in)	# SDTRs	Avg Duration (h)	Success Rate
12.25	2	7.38	50%
9.50	14	17.50	71%
8.50	21	16.37	90%
6.50	10	12.18	100%
6.00	5	29.80	
Total	**52**	**16.81**	**77%**

Source: Own author.

The **average time** of the **successful** unassisted openhole sidetracks by **bit size** is shown in the figure below:

Figure 4.44 - Average duration of the successful unassisted OHSDTR for each bit size

Bit Size (in)	# SDTRs	Avg Duration (h)
12.25	1	11.00
9.50	10	13.88
8.50	19	16.72
6.50	10	12.18
Total	**40**	**14.73**

Source: Own author.

The **average time** of the **unsuccessful** unassisted openhole sidetracks by **bit size** is shown in the figure below:

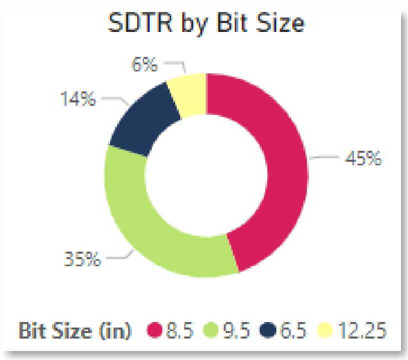
Figure 4.45 - Average duration of the unsuccessful unassisted OHSDTR for each bit size

Bit Size (in)	# SDTRs	Avg Duration (h)
12.25	1	3.75
9.50	4	26.56
8.50	2	13.00
6.00	5	29.80
Total	**12**	**23.75**

Source: Own author.

From the **planned** OHSDTRs performed, most of them were drilled with an 8.5 or a 9.5 inches bit.

Figure 4.46 - Planned Sidetracks by Bit size



Source: Own author.

The **success rate** and **average time** of the planned sidetracks by bit size are shown in the figure below:

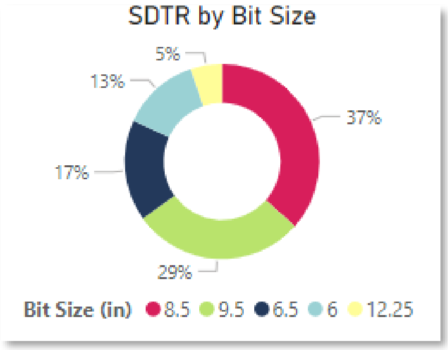
Figure 4.47 - Success rate and average duration of the planned unassisted OHSDTR by bit size

Bit Size (in)	# SDTRs	Avg Duration (h)	Success Rate
12.25	1	11.00	100%
9.50	7	14.64	86%
8.50	10	12.98	90%
6.50	4	13.06	100%
Total	**22**	**13.43**	**91%**

Source: Own author.

From the **unplanned** OHSDTRs performed, most of them were drilled with an 8.5 or a 9.5 inches bit. All sidetracks drilled with the 6 inches bit were unplanned.

Figure 4.48 - Unplanned Sidetracks by Bit size



Source: Own author.

The **success rate** and **average time** of the unplanned sidetracks by bit size are shown in the figure below:

Figure 4.49 - Success rate and average duration of the unplanned unassisted OHSDTR by bit size

Bit Size (in)	# SDTRs	Avg Duration (h)	Success Rate
12.25	1	3.75	
9.50	7	20.36	57%
8.50	10	21.10	90%
6.50	6	11.58	100%
6.00	5	29.80	
Total	**29**	**19.85**	**66%**

Source: Own author.

4.3 BEST PERFORMERS

Here the features of the Top 10 successful unassisted openhole sidetrack operations are presented. In this analysis, two filters were applied to the sample. The first filter refined the sample for only successful operations. The second picked the ten faster operations between the successful unassisted openhole sidetracks.

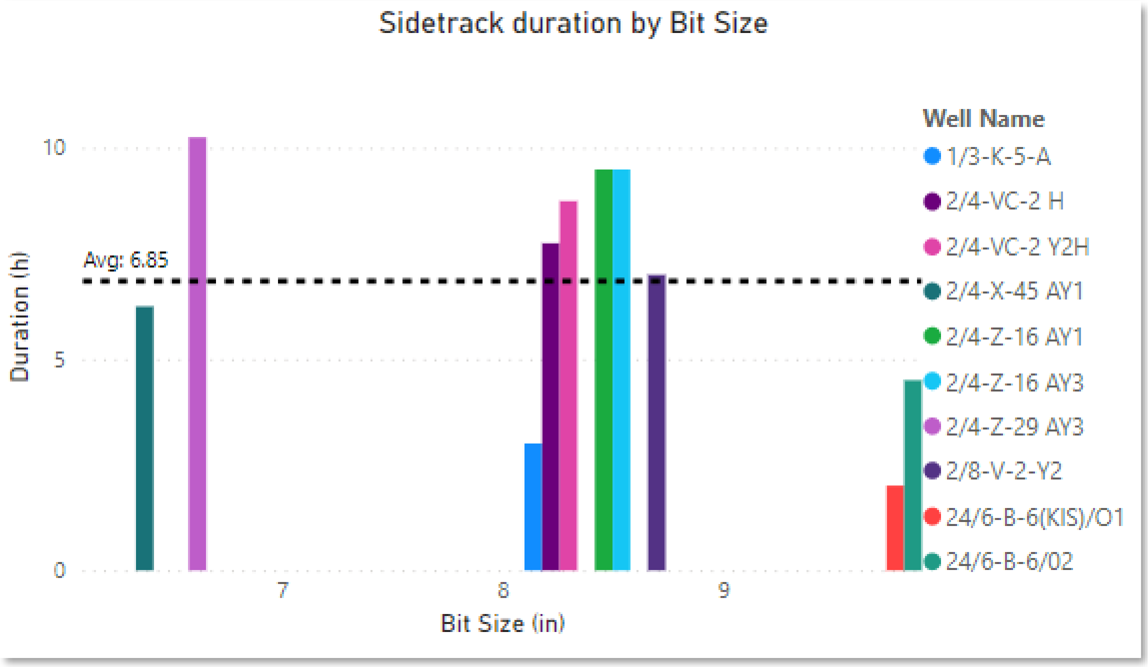
The best performers had an average operational time of 6.85 hours. All of them used PDC bits and point-the-bit RSS.

Figure 4.50 - Features of the Top 10 successful unassisted openhole sidetrack operations

Date	Well	Operator	Field	SDTR (h)	Outcome	SDTR Category	Bit Size (in)	Bit Type	Bit Manufacturer	RSS Type	Power Source
23/06/18	24/6-B-6(KIS)/O1	Aker BP	Kameleon IM	2.00	Success	Planned	9.50	PDC	HDBS	Point the bit	Geo-pilot Dirigo
01/07/07	1/3-K-5-A	BP	Tambar	3.00	Success	Unknown	8.50	PDC	HDBS	Point the bit	Geo-pilot Dirigo
28/06/18	24/6-B-6/02	Aker BP	Kameleon IM	4.50	Success	Planned	9.50	PDC	SMITH	Point the bit	Geo-pilot Dirigo
04/03/19	2/4-X-45 AY1	Conoco Phillips	Ekofisk	6.25	Success	Planned	6.50	PDC	HDBS	Point the bit	Geo-pilot Dirigo
28/02/20	2/8-V-2-Y2	Aker BP	Valhall Flank West	7.00	Success	Planned	8.50	PDC		Point the bit	Geo-pilot Hybrid
26/11/18	2/4-VC-2 H	Conoco Phillips	Ekofisk	7.75	Success	Planned	8.50	PDC	HDBS	Point the bit	Geo-pilot XL
28/11/18	2/4-VC-2 Y2H	Conoco Phillips	Ekofisk	8.75	Success	Planned	8.50	PDC	HDBS	Point the bit	Geo-pilot XL
21/11/18	2/4-Z-16 AY1	Conoco Phillips	Ekofisk	9.50	Success	Planned	8.50	PDC	HDBS	Point the bit	Geo-pilot Dirigo
24/11/18	2/4-Z-16 AY3	Conoco Phillips	Ekofisk	9.50	Success	Planned	8.50	PDC	HDBS	Point the bit	Geo-pilot Dirigo
22/04/19	2/4-Z-29 AY3	Conoco Phillips	Ekofisk	10.25	Success	Unplanned	6.50	PDC	HDBS	Point the bit	Geo-pilot Dirigo

Source: Own author.

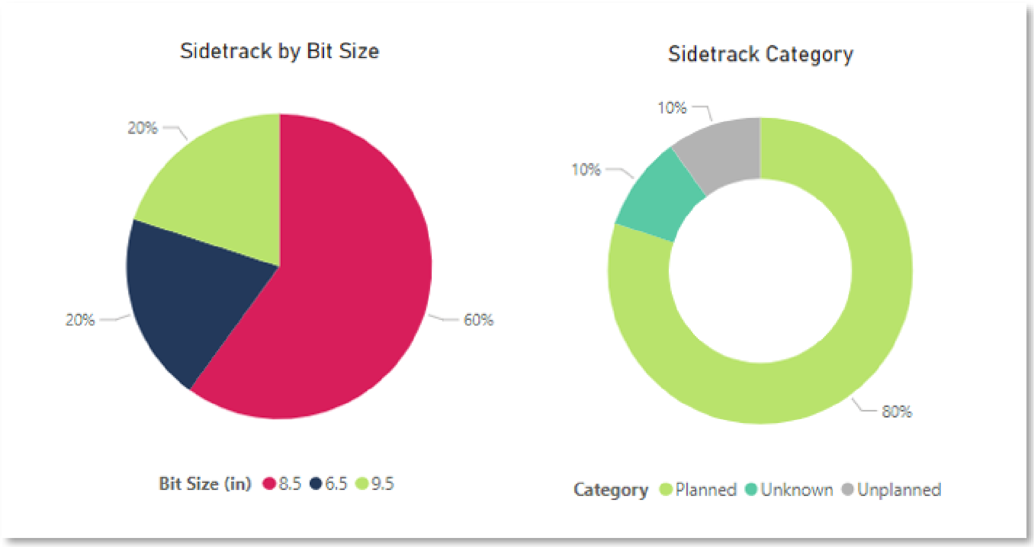
Figure 4.51 - Best performers: Sidetrack duration by bit size.



Source: Own author.

The majority of the sidetracks in this group (60%) were drilled with the 8.5 inches drill bit. Concerning the category, a clear preponderance consisted of planned sidetracks (80%).

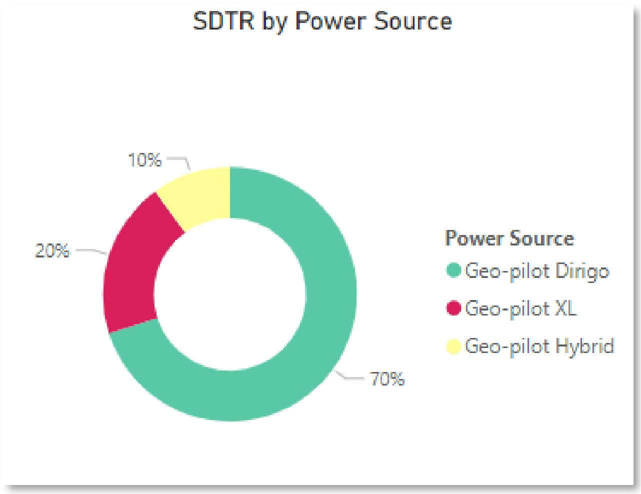
Figure 4.52 - Best performers: sidetrack by bit size and category



Source: Own author.

A significant number of the best performers used the Geo-pilot Dirigo as a power source (70%).

Figure 4.53 - Best performers: Sidetrack by Power Source



Source: Own author.

4.4 WORST PERFORMERS

Here the features of the Top 10 unsuccessful unassisted openhole sidetrack operations are presented. In this analysis, two filters were applied to the sample. The first filter refined the sample for only unsuccessful operations. The second picked the ten operations with greater duration time between the unsuccessful unassisted openhole sidetrack operations.

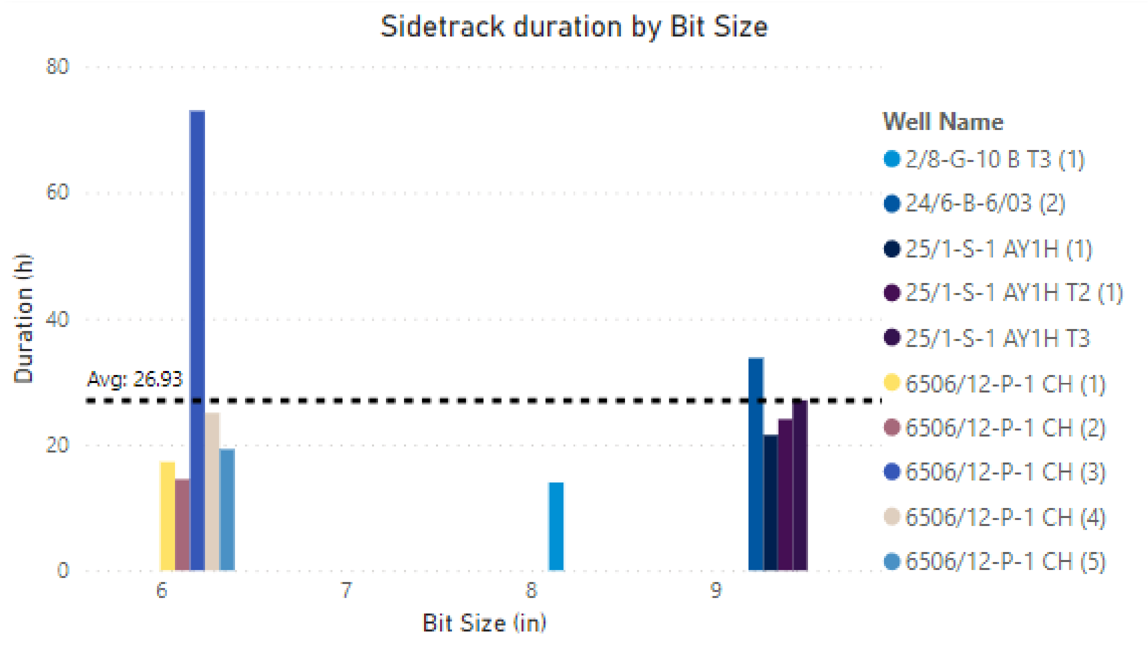
The worst performers had an average operational time of 26.93 hours. Roller cone bits, mud motors, and the geo-pilot XL are noteworthy in the worst performance list.

Figure 4.54 - Features of the Top 10 unsuccessful unassisted openhole sidetrack operations

Date	Well	Operator	Field	SDTR (h)	Outcome	SDTR Category	Bit Size (in)	Bit Type	Bit Manufacturer	RSS Type	Power Source
21/08/19	6506/12-P-1 CH (3)	Equinor	Smørbukk Sør	73.00	Failed	Unplanned	6.00	PDC	HDBS	Point the bit	Geo-pilot XL
30/07/18	24/6-B-6/03 (2)	Aker BP	Kameleon IM	33.75	Failed	Planned	9.50	PDC	SMITH	Point the bit	Geo-pilot Dirigo
24/11/19	25/1-S-1 AY1H T3	Aker BP	Skogul	27.00	Failed	Unplanned	9.50	Roller Cone		Point the bit - Mud Motor	Mud motor
25/08/19	6506/12-P-1 CH (4)	Equinor	Smørbukk Sør	25.00	Failed	Unplanned	6.00	PDC	HDBS	Point the bit	Geo-pilot XL
26/11/19	25/1-S-1 AY1H T2 (1)	Aker BP	Skogul	24.00	Failed	Unplanned	9.50	PDC	HDBS	Point the bit - Mud Motor	Mud motor
21/11/19	25/1-S-1 AY1H (1)	Aker BP	Skogul	21.50	Failed	Unplanned	9.50	PDC	HDBS	Point the bit	Geo-pilot Dirigo
27/08/19	6506/12-P-1 CH (5)	Equinor	Smørbukk Sør	19.25	Failed	Unplanned	6.00	Roller Cone	HDBS	Point the bit - Mud Motor	Mud motor
17/08/19	6506/12-P-1 CH (1)	Equinor	Smørbukk Sør	17.25	Failed	Unplanned	6.00	PDC	HDBS	Point the bit	Geo-pilot XL
17/08/19	6506/12-P-1 CH (2)	Equinor	Smørbukk Sør	14.50	Failed	Unplanned	6.00	PDC	HDBS	Point the bit	Geo-pilot XL
10/05/19	2/8-G-10 B T3 (1)	Aker BP	Valhall IP	14.00	Failed	Unplanned	8.50	PDC	HDBS	Push the bit	Autotrak

Source: Own author.

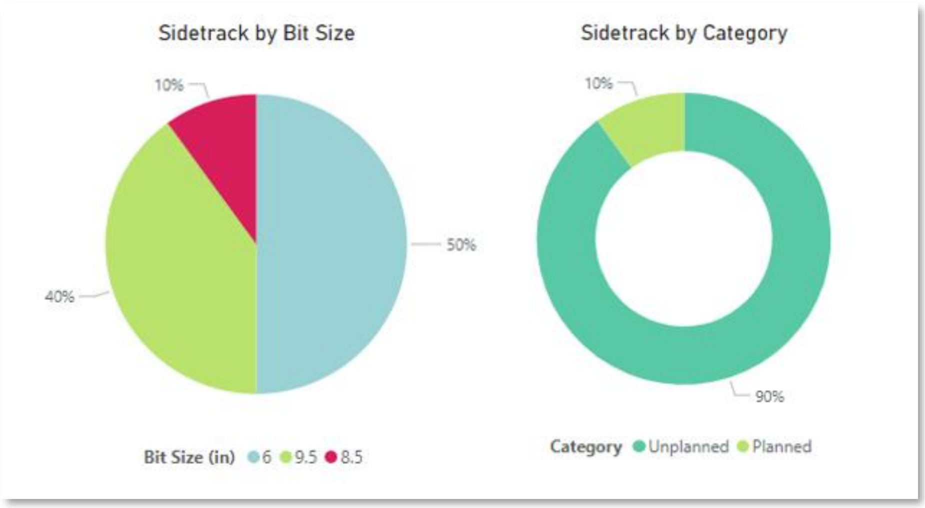
Figure 4.55 - Worst performers: Sidetrack duration by bit size.



Source: Own author.

Half of the sidetracks in this group were drilled with the 6 inches drill bit. Concerning the category, one can see a clear dominance of unplanned sidetracks (90%).

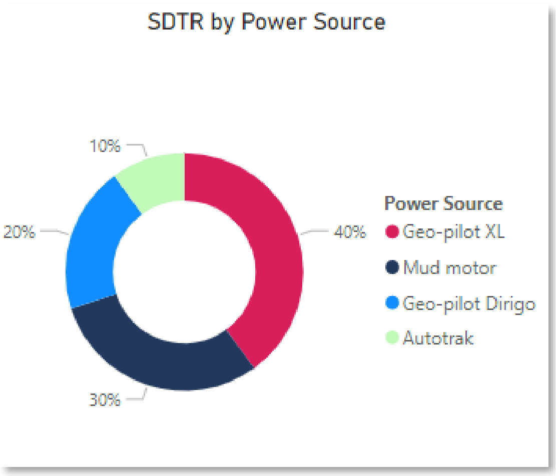
Figure 4.56 - Worst performers: sidetrack by bit size and category



Source: Own author.

A significant number of the worst performers used the Geo-pilot XL (40%) or a mud motor (30%) as a power source.

Figure 4.57 - Worst performers: Sidetrack by Power Source



Source: Own author.

5. DISCUSSION

Data-driven decisions based on operations history contribute to reducing operators costs during drilling activities and, therefore, to the economic feasibility of E&P projects. The *Lesson Learned* of the drill bit features and BHA configuration influence in unassisted openhole sidetracking performance is proposed in this thesis.

The study sample comprised 52 unassisted openhole sidetracks performed in offshore wells in Norway between 2007 and 2020. One can know more about how the sample was obtained in chapter 3.

Drilling operations involve high costs, and the longer they take, the more costly they become. This study defines the performance of openhole sidetracking based on two KPIs, the average duration of the operation and its success rate. The best performer operation is fast and successful, and the worst takes a long time and is unsuccessful.

5.1 DATA ANALYSIS

In this section, a discussion is presented for the reader to understand better the results shown in chapter 4. The discussion will follow the sequence:

- **General Remarks**
- **Remarks per well section**
- **Best performers**
- **Worst performers**

5.1.1 General remarks

5.1.1.1 Unassisted OHSDTR

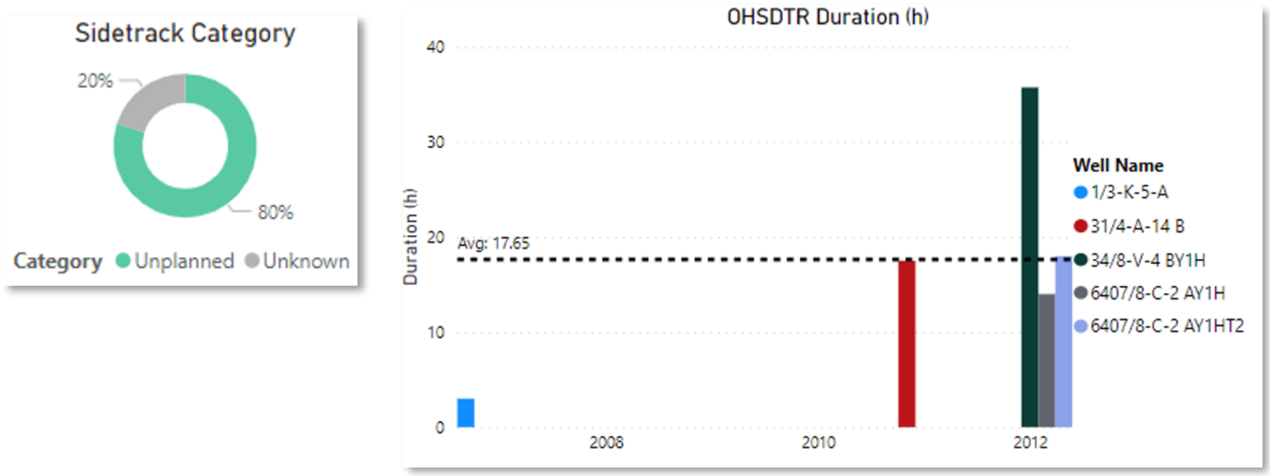
From the 52 unassisted OHSDTRs, most of the operations were successful (fig. 4.1). Most of the sidetracks were unplanned (fig. 4.2), which means that technical sidetracks due to an operational unforeseen, for example, junk in the hole or missing the target formation, are the majority in the sample.

It is possible to observe from the results a relation between the sidetrack category and the operational outcome. The planned sidetracks like those drilled for constructing multilateral wells are a slight majority (50%) within the successful sidetracks from the sample (fig. 4.4). On the other hand, the unplanned sidetracks were the clear majority (83.3%) within the failed operations (fig. 4.6). The lower success rate for the unplanned sidetracks may be due to more limited planning in the well trajectory. In these operations, the initially planned course has to be changed due to the operational unforeseen.

From the average operational time analysis, one can see that when the operation is successful, its average time is around 14.73 hours (fig. 4.5). Even though some successful operations took over 30 hours (fig. 4.5), one could notice a trend in the operators considering the procedure unsuccessful after approximately 24 hours (fig. 4.7).

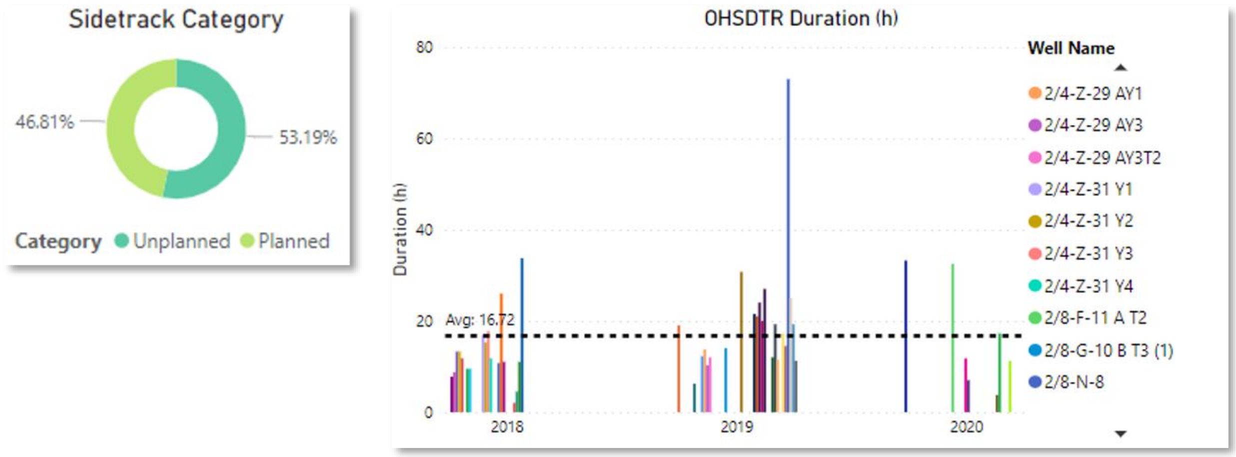
One can notice that there is an increase in the number of unassisted openhole sidetracks since 2018 (fig. 4.3). Most of the operations in the sample were performed between 2018 and 2020. This increase in the unassisted operations may be due to other sidetrack technologies being preferred in the past, like the cement plug and the whipstock. Moreover, now the preference may be changing. Another factor is the increase of planned sidetracks as part of the production strategy of the operators in Norway. It is possible to see in figure 5.1 and 5.2 that between 2007 and 2017, no sidetracks were planned, but this picture changed in the following years.

Figure 5.1 - Unassisted OHSDTRs 2007 - 2017



Source: Own author.

Figure 5.2 - Unassisted OHSDTRs 2018 - 2020



Source: Own author.

5.1.1.2 BHA Configuration

The point-the-bit RSS was the most used BHA type in the sample (fig. 4.8). However, the BHA with the higher success rate was the push-the-bit RSS with 86% against 82% of the point-the-bit system (fig 4.11 and 4.12). By examining the success rate by power source (fig. 4.17), one can see that the Geo-Pilot XL was the reason for the lower success rate from the point-the bit RSS systems.

Even though the push-the-bit system's success rate was higher than the point-the bit, the average time of the successful operation was lower for the point-the-bit RSS (fig. 4.18). The point-the-bit RSS had around 8 hours less average operational time for the successful operations than the push-the bit RSS (fig. 4.19). From the results, it is possible to infer that the push-the-bit RSS is more reliable than the point for sidetracking, however, slower.

As expected, following the theoretical background, the mud motor was less effective than the RSS systems for openhole sidetracking; it achieved a mere 40% success rate on this historical analysis (fig. 4.18).

For the successful OHSDTRs, the average operational time was lower for the point-the-bit systems, including the mud motor, than for the push-the-bit (figure 4.19). Thus, one can infer from the results that point-the-bit systems are faster than push-the-bit for openhole sidetracking.

Among the push-the-bit RSS systems, one can see that the PowerDrive and the iCruise had the higher success rate in this group. The sidetracks using the AutoTrak had the lowest success rate. However, the AutoTrak category had more data points.

Therefore, it is impossible to infer if the non-rotating housing push-the-bit (AutoTrak) has worse performance than the rotating housing (PowerDrive and iCruise). Among the point-the-bit RSS systems, the Geo-Pilot Hybrid was the most successful tool, while the Geo-Pilot Dirigo was the fastest. See figure 4.17.

5.1.1.3 Drill Bits

Most unassisted OHSDTRs, 94.3%, were drilled using a PDC bit (fig. 4.21). Some probable reasons why PDC bits were preferred:

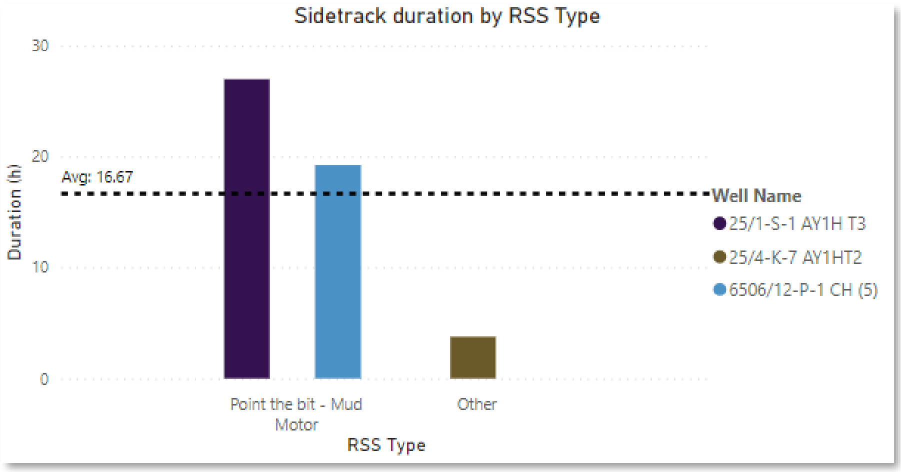
- PDCs are more durable than roller cones; it is possible to drill longer sections without need for tripping.
- To eliminate the risk of a fishing operation due to lost cones.
- PDCs are easy to rent in Norway. [10]

Suppose one considers only the sidetracks that used the PDC bit; the operation success rate increases from 77% to 82% (fig. 4.22).

All the sidetracks drilled using a roller cone bit were unsuccessful, and for that, this historical analysis infers that the PDC bits are better than roller cones for performing unassisted openhole sidetrack. The bad performance explains the lack of interest of the operators in using roller cones. Operators may be focusing on drill bit durability (less trips) and also pursuing to reduce the risk of losing cones.

Most of the use of the roller cones was also associated with the use of a mud motor. The lousy performance of the roller cone may have been a consequence of the BHA type used.

Figure 5.3 - OHSDTRs performed using Roller cone bits



Source: Own author.

PDC bit characteristics

The primary table in the dashboard was not enough to analyse the **PDC bit length** effect in unassisted OHSDTR (fig. 4.23). For that reason, additional charts were created. One can observe in the line graph from figure 4.24 that with the increase in bit length, the average duration of the operation seems to increase. The same trend is observed when only analysing the successful operations (fig. 4.25); however, for the failed operations, the analysis is inconclusive (fig. 4.26). The conclusion that the higher the length, the less steerable the bit agrees with the directional drilling theory presented in section 2.3.4.1. Regarding the success rate, the results do not seem to be following a pattern based on the bit length, figure 4.27.

The primary table in the dashboard was not enough to analyse the **PDC bit taper angle** effect in unassisted OHSDTR (fig. 4.28). For that reason, additional charts were created. The additional graphs results were inconclusive (fig. 4.29, 4.30 and 4.31). It is not possible to confirm the effect of the taper angle in openhole sidetracking duration; there are too few data points for making solid conclusions about this parameter. The results do not seem to be following a pattern based on the taper angle regarding the success rate (fig 4.32). The lowest success rate in taper angle is for the 0.6 angle, which is also the category with the most data points (fig 4.28).

The original table in the dashboard was not enough to analyse the PDC **gauge pad length** effect in unassisted OHSDTR (fig. 4.33). For that reason, additional charts were created. The additional graphs results were inconclusive (fig. 4.34, 4.35 and 4.36). It is not possible to verify the effect of the gauge pad length in openhole sidetracking duration; there are too few data points for making solid conclusions about this parameter. The success rate decreases with the gauge pad length increase (fig. 4.37); this trend matches the directional drilling theory presented in section 2.3.4.1. The category with the most data points is the 3 inches gauge pad length, with 31 of the 40 measures. The minor part of the data points is scattered between the other categories (fig. 4.33).

The original table in the dashboard was not enough to analyse the PDC **gauge pad relief** effect in unassisted OHSDTR (fig. 4.38). The additional graphs results were inconclusive (fig. 4.39, 4.40 and 4.41); there are too few data points for making solid conclusions about this parameter.

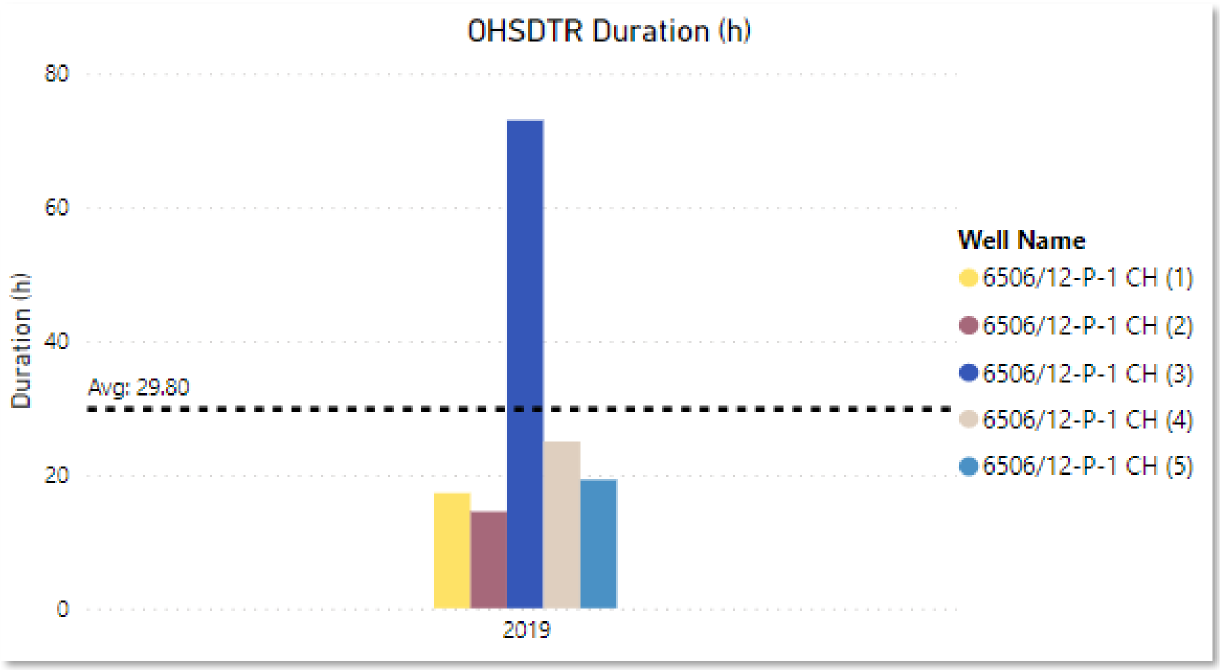
5.1.2 Remarks per well section

Operators drilled most of the sidetracks, 72 %, in the sample with an 8.5- or 9-inches drill bit (fig. 4.42).

A relationship between the sidetrack category and outcome was noticed: the planned sidetracks have a higher success rate and lower average time than the unplanned ones (fig. 4.47 and 4.49).

Concerning the different bit sizes, one could not find a relation between sidetrack outcome and well section. The 6.5 inches drill bit achieved a 100% success rate, and the 8.5 inches, the most sidetracked well section, reached 90%. The worst performer was the 6 inches section in which all the sidetracks have failed (fig. 4.43). However, all the 6 inches sidetracks were attempts in the same well. The poor performance result for this section may be misleading because it may have been a challenging formation to drill.

Figure 5.4 - Sidetracks performed with the 6 inches drill bit



Source: Own author.

The analysis could not find a relation between drill bit size and average operational time. Disregarding the 12.25 inches well section, because there is only one operation in this group, the successful sidetracks with the shortest average time used the 6.5 inches, followed by the 9.5 and then the 8.5 inches drill bit (fig. 4.43).

5.1.3 Best performers

The best performers included the ten fastest successful unassisted openhole sidetrack operations.

This group had an outstanding average operational time of 6.85 hours time-drilling to fully separate from the pilot hole (fig. 4.51).

Some remarkable features are that all sidetracks in the best performers list used a PDC bit and a point-the-bit RSS system (fig. 4.50).

Concerning the category, a clear majority of the best performance sidetracks (80%) was listed as planned. This trend of the relationship between the sidetrack category and outcome was also noticed earlier in this chapter. The higher success rate for the planned sidetracks may be due to the better planned and less restricted well trajectory when compared to the unplanned sidetracks.

The best performers mainly had sidetracks drilled with the 8.5- and 9-inches bit (fig. 4.52). This trend may be observed because most of the sample consisted of sidetracks in those well sections. The 6.5 inches drill bit also appears in the list; this was the well section with the higher success rate in this historical analysis with 100% successful operations (fig. 4.43).

A significant part of the operations in the best performers list (70%) used the Geo-Pilot Dirigo; the top four fastest sidetracks used this as their power source (4.53).

5.1.4 Worst performers

The worst performers included the ten greater duration time unsuccessful unassisted openhole sidetrack operations.

This group had a poor average time of 26.93 hours of time-drilling for later inability to entirely separate from the pilot hole (fig. 4.55). The longest sidetrack in the list used 73 hours before the operator considered it a failure. The shortest operation in the list accounted for 14 hours - duration time which is lower than the average for the successful OHSDTRs (refer to fig. 4.55 and 4.5).

In the worst performance group analysis, it is clear that unplanned sidetracks add difficulties to the operation. The great majority of the sidetracks in this list, 90%, were unplanned (fig. 4.56).

The worst performers mainly had sidetracks drilled with the 6- inches bit (fig. 4.56); all these sidetracks were attempts in the same well (fig. 5.4). The 6 inches poor performance result may be misleading because it may have been a challenging formation to drill.

Roller cone bits, mud motors, and the Geo-Pilot XL presence are noteworthy in the worst performance list (fig. 4.54). 30% of the worst performers used the mud motor as a power source; 66% of these cases also used a roller cone bit.

Concerning the Geo-Pilot XL, it is interesting that 40% of the worst performers used this tool; however, it also accounted for 20% of the best performers (refer to fig. 4.50 and 4.54). The presence of the Geo-Pilot XL in the worst performers list is associated with the 6 inches section.

5.2 LESSONS LEARNED & COMPARISON TO DD THEORY

This thesis proposes the *Lesson Learned* of the drill bit features and BHA configuration influence in unassisted openhole sidetracking performance in Norway. In addition, it intends to compare if the findings for unassisted openhole sidetrack align with directional drilling theory.

The lessons learned with the data analysis of this research will be exhibited in the following order:

- Unassisted openhole sidetrack operation
- BHA configuration
- Drill bit
- Well section (bit size)
- Best performers
- Worst performers

Unassisted openhole sidetrack operation

1) Most sidetracks drilled in Norway between 2007 and 2020 were unplanned. Unplanned or technical sidetracks are due to an operational unforeseen, such as junk in the hole or missing the target formation.
2) Operators in the Norwegian Continental Shelf (NCS) are using unassisted openhole sidetracks in their production strategy. Since 2018, there is an increase

in the number of planned openhole sidetracks. A common application of planned SDTRs is for drilling multilateral wells.

3) Planned unassisted openhole sidetracks have a higher success rate than unplanned. The lower success of the unplanned sidetracks may be due to limited planning in the well trajectory.
4) A successful unassisted openhole sidetrack has an average operational time of 14.73 hours.
5) There is a trend of operators in Norway considering the unassisted OHSDTRs as failed after 24 hours of operational time.

BHA configuration

1) Successful unassisted OHSDTRs drilled with point-the-bit systems (RSS + mud motor) achieved a lower average operational time than sidetracks drilled with the push-the-bit.
2) The push-the-bit RSS had a greater chance of success than the point-the-bit RSS for unassisted openhole sidetracking.
3) Successful unassisted OHSDTRs drilled with the point-the-bit RSS had a lower average operational time than those drilled with the push-the-bit RSS.
4) The mud motor was less successful for unassisted openhole sidetracking than the rotary steerable systems. Mud motors are not as advanced as rotary steerable tools, so this finding matches the directional drilling theory.

Drill bit

1) Operators in the NCS mainly use PDC bits for performing unassisted openhole sidetracks.
2) Roller cone bits have a poor performance in unassisted openhole sidetracking.
3) The average operational time in unassisted openhole sidetracking grows proportionally to the PDC bit length. The lengthier the bit, the longer the time needed for time-drilling a ledge. This finding matches the directional drilling theory that says that the drill bit steerability decreases with bit length.
4) The PDC bit length does not seem to affect the unassisted OHSDTR outcome.

5) The investigation of the effect of the taper angle and gauge pad relief in the average operational time and success rate of the unassisted openhole sidetracking was inconclusive. More data points are necessary for making solid conclusions about these characteristics of the PDC bits. It was not possible to compare the findings with directional drilling theory.
6) The examination of the effect of the gauge pad length on the average operational time of the unassisted openhole sidetracking was inconclusive. It was not possible to compare the findings with directional drilling theory.
7) The examination of the effect of the gauge pad length on the success rate of the unassisted openhole sidetracking showed that the increase in length decreases the chance of success. This finding matches the directional drilling theory that says that the drill bit steerability decreases with gauge pad length.

Well section (bit size)

1) Most of the unassisted openhole sidetracks in the NCS were drilled with an 8.5- or 9-inches drill bit.
2) A relation between bit size and average operational time could not be found. It is not possible to infer if there is a well section that is easier to sidetrack because there were too few and scattered data points.
3) A relation between bit size and sidetrack outcome could not be found. It is not possible to infer if there is a well section with a higher chance of success in unassisted openhole sidetracking because there were too few and scattered data points.

Best performers

The best performers included the ten fastest successful unassisted openhole sidetrack operations.

1) All best performers unassisted OHSDTRs used a PDC bit with a point-the-bit RSS.
2) The majority of the best performers consisted of planned unassisted openhole sidetracks.
3) Most of the best performers in the NCS were drilled with an 8.5- or 9-inches bit.

4) The most used power source among the best performers in unassisted openhole sidetracking was the point-the-bit RSS by Halliburton, Geo-Pilot Dirigo.

Worst performers

The worst performers included the ten greater duration time unsuccessful unassisted openhole sidetrack operations.

1) Most of the worst performers unassisted OHSDTRs used a roller cone bit or a mud motor.
2) The majority of the worst performers consisted of unplanned unassisted openhole sidetracks.
3) Most of the worst performers in the NCS were drilled with a 6-inches bit. However, all the 6 inches sidetracks were attempts in the same well. The poor performance result for this section may be misleading because it may have been a challenging formation to drill.
4) The more used power sources among the worst performers in unassisted openhole sidetracking were the point-the-bit RSS by Halliburton, Geo-Pilot XL, and the mud motor. Nevertheless, the worst performers sidetracks that used the Geo-pilot XL were all drilled in the same well with the 6 inches bit.

6. CONCLUSION

This thesis proposed the *L*esson *Learned* of the drill bit features and BHA configuration influence in unassisted openhole sidetracking performance based on a business intelligence strategy. Data-driven decisions based on operations history contribute to improving performance and, consequently, reducing operators costs with drilling activities. The lessons learned from the historical analysis were summarised and compared to directional drilling theory in section 5.2.

The approach used for the data analysis of this research was the combined use of the Microsoft tools Excel and Power BI. This study clearly illustrated the power and possibilities of applying business intelligence tactics for learning with data that the companies already have.

The database used for the analysis was created by a manual process of examining several drilling reports from different operators. The number of parameters that could be examined in the analysis was limited by which data was available in the reports. If the drilling reports had less missing information, the effect of more variables on unassisted openhole sidetracking could have been analyzed. Operators and service companies should consider stricter reporting of drilling operations to avoid losing valuable data.

The manual examination of drilling reports may have been a source of error. The database had to be created manually due to a lack of operations reporting standard by the operators. If the operators described the activities using standardized terms in the reports, such as "time-drilling unassisted openhole sidetrack", a scraper tool could automatically read the reports and summarize information faster than manually examination and with fewer errors.

Further research is still required to understand the PDC bit characteristics influence in unassisted openhole sidetracking. The results obtained in this study, on this matter, were rough due to the few data points available.

Halliburton Norway provided the drilling reports used for creating the sample of this study, so most of the operations analyzed were performed by them. Continuing gathering reports from other operators would help expand the number of data points and improve the quality of the conclusions of this analysis. The database obtained with this study on unassisted openhole sidetracking operations in Norway is public for supplying the first step for further researches on this theme.

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Appendix A: Unassisted OHSDTR database

The database, obtained with the examination of the drilling reports, is available below.

Figure A.1 - Excel Database Unassisted OHSDTRs

	A	B	C	D	E	F	G	H	I	J	Q	R
1	Date	Operator	Field	Well Name	Planned/Unplanned	Success/Failed	Duration (h)	Bit Size (in)	Manufacturer	Bit Type	Power Source	RSS Type
2	23/06/2018	Aker BP	Kameleon IM	24/6-B-6(KIS)/O1	Planned	Success	2	9 1/2	HDBS	PDC	Geo-pilot Dirigo	Point the bit
3	28/06/2018	Aker BP	Kameleon IM	24/6-B-6/02	Planned	Success	4,5	9,5	SMITH	PDC	Geo-pilot Dirigo	Point the bit
4	03/07/2018	Aker BP	Kameleon IM	24/6-B-6/03 (1)	Planned	Success	11	12 1/4	SLB	PDC	Geo-pilot Dirigo	Point the bit
5	30/07/2018	Aker BP	Kameleon IM	24/6-B-6/03 (2)	Planned	Failed	33,75	9 1/2	SMITH	PDC	Geo-pilot Dirigo	Point the bit
6	01/07/2007	BP	Tambar	1/3-K-5-A	Unknown	Success	3	8 1/2	HDBS	PDC	Geo-pilot Dirigo	Point the bit
7	14/01/2020	Aker BP	Valhall IP	2/8-F-11 A T2	Unplanned	Success	32,5	8 1/2	HDBS	PDC	Autotrak	Push the bit
8	29/04/2020	Aker BP	Alvheim	25/4-K-7 AY1HT2	Unplanned	Failed	3,75	12 1/4		Roller Cone	NB stabilizer	Other
9	06/07/2020	Aker BP	Alvheim	25/4-K-7 AY1HT6	Unplanned	Success	17,25	9 1/2	HDBS	PDC	iCruise No flex	Push the bit
10	21/11/2019	Aker BP	Skogul	25/1-S-1 AY1H (1)	Unplanned	Failed	21,5	9 1/2	HDBS	PDC	Geo-pilot Dirigo	Point the bit
11	21/11/2019	Aker BP	Skogul	25/1-S-1 AY1H (2)	Unplanned	Success	21	9 1/2	HDBS	PDC	Geo-pilot Dirigo	Point the bit
12	24/11/2019	Aker BP	Skogul	25/1-S-1 AY1H T3	Unplanned	Failed	27	9 1/2		Roller Cone	Mud motor	Point the bit - Mud Motor
13	26/11/2019	Aker BP	Skogul	25/1-S-1 AY1H T2 (1)	Unplanned	Failed	24	9 1/2	HDBS	PDC	Mud motor	Point the bit - Mud Motor
14	27/11/2019	Aker BP	Skogul	25/1-S-1 AY1H T2 (2)	Unplanned	Success	20	9 1/2	HDBS	PDC	Mud motor	Point the bit - Mud Motor
15	23/11/2019	Aker BP	Valhall Flank West	2/8-V-3 T2	Unplanned	Success	30,75	8 1/2	HDBS	PDC	Geo-pilot Hybrid	Point the bit
16	10/05/2019	Aker BP	Valhall IP	2/8-G-10 B T3 (1)	Unplanned	Failed	14	8 1/2	HDBS	PDC	Autotrak	Push the bit
17	28/02/2020	Aker BP	Valhall Flank West	2/8-V-2-Y2	Planned	Success	7	8 1/2		PDC	Geo-pilot Hybrid	Point the bit
18	09/12/2018	Aker BP	Valhall Flank North	2/8-N-8	Unplanned	Success	10,75	8 1/2	HDBS	PDC	Autotrak	Push the bit
19	13/12/2018	Aker BP	Valhall Flank North	2/8-N-8 T2	Unplanned	Success	26	8 1/2	HDBS	PDC	Autotrak	Push the bit
20	27/12/2018	Aker BP	Valhall Flank North	2/8-N-8 T3	Unplanned	Success	11	6 1/2	HDBS	PDC	Autotrak	Push the bit
21	16/09/2020	Aker BP	Ivar Aasen	16/1-D-17 AY1	Planned	Success	33,25	8 1/2	SLB	PDC	Powerdrive Orbit	Push the bit
22	12/04/2020	Aker BP	Valhall Flank West	2/8-V-12	Unplanned	Success	11,75	8 1/2	HDBS	PDC	Geo-pilot Hybrid	Point the bit
23	06/12/2019	Aker BP	Ula	7/12-A-13 BT2	Unplanned	Success	11,25	6 1/2	HDBS	PDC	Mud motor	Point the bit - Mud Motor
24	16/02/2012	Equinor	Visund	34/8-V-4 BY1H	Unplanned	Success	35,75	8,5	HDBS	PDC	Geo-pilot Dirigo	Point the bit
25	01/12/2012	Equinor	Hyme	6407/8-C-2 AY1H	Unplanned	Success	14	8,5	HDBS	PDC	Geo-pilot XL	Point the bit
26	03/12/2012	Equinor	Hyme	6407/8-C-2 AY1HT2	Unplanned	Success	18	8,5	HDBS	PDC	Geo-pilot XL	Point the bit
27	17/08/2019	Equinor	Smørbukk Sør	6506/12-P-1 CH (1)	Unplanned	Failed	17,25	6	HDBS	PDC	Geo-pilot XL	Point the bit
28	17/08/2019	Equinor	Smørbukk Sør	6506/12-P-1 CH (2)	Unplanned	Failed	14,5	6	HDBS	PDC	Geo-pilot XL	Point the bit
29	21/08/2019	Equinor	Smørbukk Sør	6506/12-P-1 CH (3)	Unplanned	Failed	73	6	HDBS	PDC	Geo-pilot XL	Point the bit
30	25/08/2019	Equinor	Smørbukk Sør	6506/12-P-1 CH (4)	Unplanned	Failed	25	6	HDBS	PDC	Geo-pilot XL	Point the bit
31	27/08/2019	Equinor	Smørbukk Sør	6506/12-P-1 CH (5)	Unplanned	Failed	19,25	6	HDBS	Roller Cone	Mud motor	Point the bit - Mud Motor
32	26/04/2019	Equinor	Trestakk	6406/3-A-4 AY1H	Planned	Success	11,5	8 1/2	HDBS	PDC	Geo-pilot Dirigo	Point the bit
33	03/05/2020	Equinor	Trestakk	6406/3-B-1 AY1H	Planned	Success	11,25	8 1/2	HDBS	PDC	Geo-pilot Dirigo	Point the bit
34	02/09/2019	Equinor	Trestakk	6406/3-A-3 AY1H (1)	Planned	Failed	12	8 1/2	HDBS	PDC	Geo-pilot Dirigo	Point the bit
35	02/09/2019	Equinor	Trestakk	6406/3-A-3 AY1H (2)	Planned	Success	19,25	8 1/2	HDBS	PDC	Geo-pilot Dirigo	Point the bit
36	10/03/2011	Equinor	Brage	31/4-A-14 B	Unplanned	Success	17,5	8 1/2	HDBS	PDC	Geo-pilot Dirigo	Point the bit
37	29/06/2018	Conoco Phillips	Ekofisk	2/4-Z-31 Y1	Planned	Success	17	9 1/2	HDBS	PDC	Geo-pilot Dirigo	Point the bit
38	03/07/2018	Conoco Phillips	Ekofisk	2/4-Z-31 Y2	Planned	Success	15,25	9 1/2	HDBS	PDC	Geo-pilot XL	Point the bit
39	06/07/2018	Conoco Phillips	Ekofisk	2/4-Z-31 Y3	Planned	Success	17,75	9 1/2	HDBS	PDC	Geo-pilot XL	Point the bit
40	10/07/2018	Conoco Phillips	Ekofisk	2/4-Z-31 Y4	Unplanned	Success	11,75	9 1/2	HDBS	PDC	Geo-pilot XL	Point the bit
41	21/11/2018	Conoco Phillips	Ekofisk	2/4-Z-16 AY1	Planned	Success	9,5	8 1/2	HDBS	PDC	Geo-pilot Dirigo	Point the bit
42	24/11/2018	Conoco Phillips	Ekofisk	2/4-Z-16 AY3	Planned	Success	9,5	8 1/2	HDBS	PDC	Geo-pilot Dirigo	Point the bit
43	23/12/2018	Conoco Phillips	Ekofisk	2/4-X-18 AY1	Planned	Success	13,25	6 1/2	HDBS	PDC	Geo-pilot Dirigo	Point the bit
44	26/12/2018	Conoco Phillips	Ekofisk	2/4-X-18 AY2	Unplanned	Success	13,25	6 1/2	HDBS	PDC	Geo-pilot Dirigo	Point the bit
45	30/12/2018	Conoco Phillips	Ekofisk	2/4-X-18 AY2T2	Unplanned	Success	11,75	6 1/2	HDBS	PDC	Geo-pilot Dirigo	Point the bit
46	04/03/2019	Conoco Phillips	Ekofisk	2/4-X-45 AY1	Planned	Success	6,25	6 1/2	HDBS	PDC	Geo-pilot Dirigo	Point the bit
47	02/04/2019	Conoco Phillips	Ekofisk	2/4-Z-29	Planned	Success	12,25	9 1/2	HDBS	PDC	Geo-pilot Dirigo	Point the bit
48	14/04/2019	Conoco Phillips	Ekofisk	2/4-Z-29 AY1	Planned	Success	13,75	6 1/2	HDBS	PDC	Geo-pilot Dirigo	Point the bit
49	22/04/2019	Conoco Phillips	Ekofisk	2/4-Z-29 AY3	Unplanned	Success	10,25	6 1/2	HDBS	PDC	Geo-pilot Dirigo	Point the bit
50	22/04/2019	Conoco Phillips	Ekofisk	2/4-Z-29 AY3T2	Unplanned	Success	12	6 1/2	HDBS	PDC	Geo-pilot Dirigo	Point the bit
51	26/11/2018	Conoco Phillips	Ekofisk	2/4-VC-2 H	Planned	Success	7,75	8 1/2	HDBS	PDC	Geo-pilot XL	Point the bit
52	28/11/2018	Conoco Phillips	Ekofisk	2/4-VC-2 Y2H	Planned	Success	8,75	8 1/2	HDBS	PDC	Geo-pilot XL	Point the bit
53	11/07/2019	Conoco Phillips	Ekofisk	2/4-K-10 BY1	Planned	Success	19	6 1/2	HDBS	PDC	Geo-pilot Dirigo	Point the bit

Source: Own author.