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# Anti-collision Analysis of Pad Drilling and Optimization of Wellbore Trajectory: A Field Case Study

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## Abstract

Errors can occur in the wellbore position according to the fact the survey tools are not completely accurate; therefore, prediction of well path position is imperative for safe and cost-effective drilling operation. The aim of this paper is an analysis of collision avoidance as well as assessment and optimization of wellbore trajectory for minimizing the risk of collision by applying different anti-collision and planning techniques. Thus, anti-collision analysis of pad drilling in the Iraqi oil field has been investigated using Industry Steering Committee for Wellbore Survey Accuracy (ISCWSA) error model to estimate the wellbores position and assess their separation using different techniques available in the industry. Three actual offset wells X1, X2, X3, and one proposed principal X4 well in a drilling pad have been used in the collision avoidance model. Separation factor, ladder, and travel cylinder plots revealed a high possibility of X4 proposed well colliding with X3 actual offset well. The separation factor of 0.75 and 7.5 m center to center prove that the current design of X4 principal design doesn't meet the anti-collision standards, accordingly, a design revision must be highly considered. The field operator hasn't revised the well design due to the lack in the assessment of anti-collision risks, thus, the survey service company has advised the operator to modify the predetermined well trajectory due to major risk of collision with X3 offset well and the well has been sidetracked. After reviewing and optimizing the well trajectory by using slant and optimum align (curve hold curve) planning methods, the anti-collision results have been greatly improved. The results showed that, through adopting an adequate anti-collision risk assessment and the modified well design, problems associated with the execution of the improper well design could be totally eliminated.

**Keywords:** Pad drilling, Wellbore anti-collision, Wellbore trajectory planning, Iraqi Oil Fields.

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## 1. Introduction

The development of drilling methods and techniques cause a significant improvement of well productivity. One of these effective drilling techniques is pad drilling system. Well pads play an important role in the oil industry, making the development of oil and gas fields with complicated surface conditions feasible [1].

In pad drilling, it is crucial to conduct anti-collision study for the planned wells within the pad in particular as well as between offset pads [2]. Because of low space between wells surface locations within the pad, an accurate well trajectory plan and actual offset surveys are mandatory to avoid wells collision which if not designed properly could lead to potential drilling problems and catastrophic consequence to human beings and environment.

However, an anti-collision management is usually initiated by accurate survey program of reference well, offset wells as well as the future proposed wells [3]. Hence, to minimize the wellbore position uncertainty, two tasks should be performed: i) utilizing reliable survey tools with high confidence level, ii) fitting the wellbore trajectory to the measured parameters using the most accurate trajectory planning methods.

fact here are some sources of error in the measured data (measured depth, inclination & azimuth) which originates from different elements such as tool calibration performance, tool misalignment, BHA Sag, magnetic declination, magnetic interference, pipe stretch and thermal expansion [4]. Hence, the survey errors must be translated into well position errors whereas in extreme cases, these errors, if not considered can result to collision of neighboring wells and completely missing the predetermined underground target [5].

In 1969, Walstrom et al. [6] presented a method that produced too small ellipses of uncertainty. Later, the initial thought of random survey errors was proven to be wrong. Hence, their model was rejected by the oil and gas industry.

In 1981, an alternative approach for determining the wellbore position uncertainty was introduced by Wolff and de Wardt in which the systematic survey errors sources are adopted [7].

At that time, there was similar works which led to little standardization in the method of Ellipses of Uncertainty (EOU) computation which cause confusion to the oil and gas industry. Therefore, the Industry Steering Committee for Wellbore Survey Accuracy (ISCWSA) was founded to introduce a standardized uncertainty model [8]. Built on a rigorous mathematical

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framework a concept was presented by Williamson in 2000 for originally only MWD surveys. Later, this was extended with a gyro error model by Torkildsen et al. in 2004 [9].

The key objectives and contribution of this paper are analysis of collision avoidance in addition to assessment and optimization of wellbore trajectory in complex cases such pad system drilling, that involving a low space between wells surface locations within the pad, by applying different anti-collision and planning modern techniques.

## 2. Field Background

"N" oil field is one of the Iraq's major oilfields. It was discovered more than 30 years ago and it is located in Iraq southeast. This oil field is a gentle elongated anticlinal structure. Long axis of the field is extended in a NW – SE direction. The structure is approximately 32 km long by 8.8 km wide. The structure was defined by 2D seismic data shot during years 1976 and 1980. Up to June 2010, eight wells were drilled by governmental owner company. The deepest well depth was 4,788 m, down to the Lower Cretaceous-Sulaiy formation. Significant oil accumulations have been discovered in multiple reservoirs of Tertiary and Cretaceous formations.

A foreign operator signed a 20-years development and production service contract in January 2010 with the field owner. The Contract became effective on March 1st, 2010, and then expanded 10 years later to end in March 2040. 3D seismic acquisition was started in November 2010 and completed in July 2011, covering a total area of 496 $km^2$.

## 3. Methodology

The Anti-collision model is based on three parameters of survey error model: Sigma confidence level of output error, scan method, and error surface. In this paper, Compass 5000.1.9.0 Landmark software from Halliburton Company was used to build the anti-collision model for four wells in pad system of N field.

1- To reduce the uncertainty associated with measurements, thereby ensuring the proper wellbore positioning, the anti-collision model was built in accordance with the well accepted and modern industry standards. In this method, ISCWSA error survey tool model was adopted and the following options were set: Output error: 2 Sigma which means (the confidence level for the survey errors, number 2 refer to 95% confidence that survey lies in the quoted error, which mean 5% chance of being outside the EOU.

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2- Scanning method: closed approach 3D method, which shows a hypothetical 3D traveling spherical shape with designed reference well's trajectory. This 3D spherical would measure the distance between reference well and all offset wells in specified area, COMPASS will compute the distance and shows the values of separation factors for each comparison and gives the warning reports accordingly [10].

3- Error surface: to define the shape of the uncertainty envelope about the wellbore, the elliptical conic method was chosen which refers to an ellipse being formed perpendicular to the wellbore direction.

Actual survey data of three offset wells (X1, X2 and X3) are imported and their trajectories fitted to the real surveys using the minimum curvature method. Moreover, a reference well (X4) have been proposed with planned trajectory well by angel of 30° and azimuth of 200.6°, as shown in table 1.

Furthermore, to evaluate the risk of X4 well collision with offset wells, the EOU was calculated for all wells along their whole path. In these calculations, Magnetic MWD tool type was used for X1, X2 and X4 actual and planned survey data program, while EMS tool type was used for X3 actual survey program as shown in Table (1).

**Table (1) Wells information in pad drilling.**

| Well | Well Type | INC° | AZI° | KOP MDRT (m) | TD MDRT (m) | TVD (m) | Easting (m) | Northing (m) | Survey Tool |
|---|---|---|---|---|---|---|---|---|---|
| X1 | Offset: Actual | 90 | 118.46 | 2740 | 3694.29 | 2879.99 | 734076.48 | 3506452.58 | Magnetic MWD |
| X2 | Offset: Actual | 18.45 | 346.09 | 2150 | 3146.48 | 3100 | 733121.36 | 3507197.03 | Magnetic MWD |
| X3 | Offset: Actual | Vertical | | N/A | 3744 | 3744 | 733211.54 | 3506928.74 | EMS |
| X4 | Planned | 30 | 200.6 | 2250 | 3191.49 | 3083 | 733085.0 | 3506545.0 | Magnetic MWD |

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## 4. Results and Discussion

The separation factor computation summery which is based on the following simple algorithm:

SF=(C-C/R1+R2) …………………………………………………. (1)

Where, SF= separation factor, C-C = center to center distance in (m), R1: radius of major axis of ellipse of uncertainty of reference well in (m), R2: radius of major axis of ellipse of uncertainty of offset well in (m).

The Separation distances between reference X4 well and offset wells are introduced in Table (2).

From this table, it appears that in these range of measured depths, X4 proposed well become close to the offset wells as indicted by center to center and EOU distances. The separation factor is less than one between X4 and X3 wells due to overlapping of the ellipses of error (negative distance value) with small Center to Center (C-C) distance, which in turn, leads to high probability of wellbores collision. Consequently, X4 planned design can't be adopted and the current design must be reviewed and rectified to meet the anti-collision standards.

**Table (2) Separation distances between reference X4 well and offset wells.**

| Offset Well | Well Type | Reference measure depth (m) | Offset measure depth(m) | Between centers (m) | Between ellipses (m) | Separation factor (m) | Warning level |
|---|---|---|---|---|---|---|---|
| **X1** | Offset: Actual | 2,458.33 | 2,447.87 | 22.34 | 12.29 | 2.223 | N/A |
| **X2** | Offset: Actual | 2,296.46 | 2,297.29 | 32.13 | 22.59 | 3.366 | N/A |
| **X3** | Offset: Actual | 2,369.09 | 2,367.14 | 7.45 | -2.29 | 0.765 | Shut down |

Upon completion of EUO calculations, the next step was analyzing and assessing the results of the anti-collision. This was done by using different graphs concurrently so that the risk can be assessed from different perspectives. To effectively assess the anti-collision against the offset wells, four plots (separation factor in Fig. (**1**), ladder in Fig. (**2**), travel cylinder in Fig. (**3**), and 3D view in Fig. (**4**)) offered by Compass Landmark were utilized.

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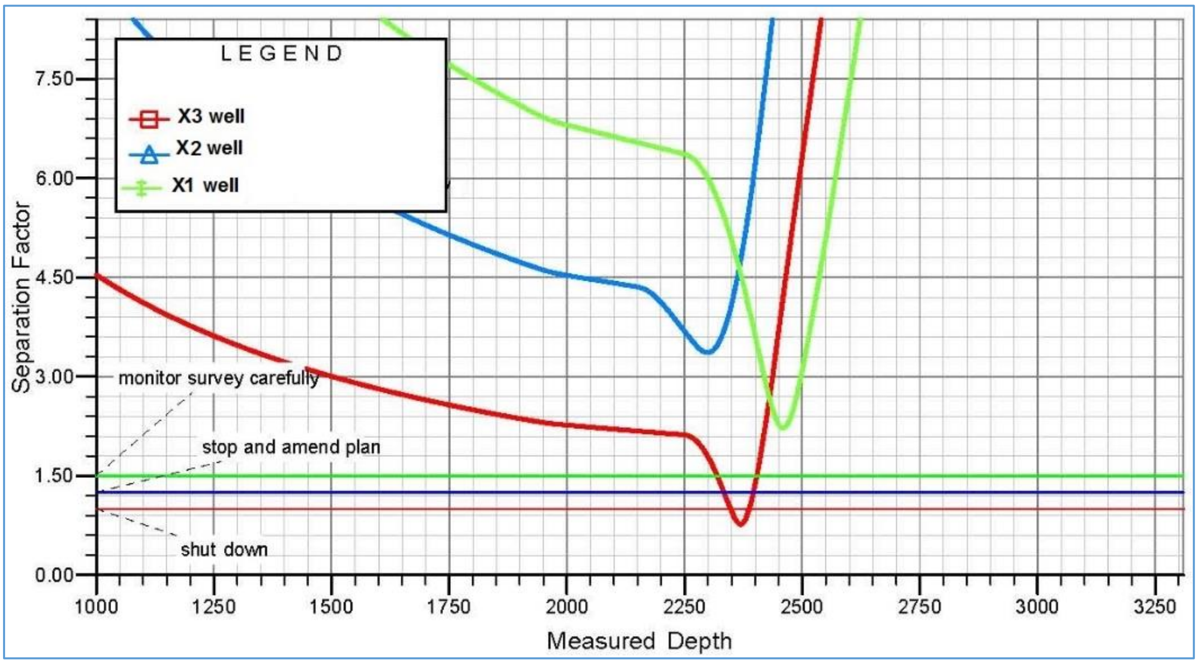


**Fig. (1):Separation factor vs. measured depth for X1, X2, X3 wells with refrence to X4.**

Fig. (**1**) represents the separation factor plot in which the risk is quickly reviewed against the warning level set previously in the model. In this plot, it is evident that X4 planned well is closing to X3 actual offset well at depth of 2,369 m. Also, the value of (SF) drops to 0.765 and the warning level is shutdown. SF value lower than one between the above mentioned wells means that their ellipses of uncertainty are overlapping. In other words, this value can't be tolerated due to small ellipses of error semi major axis (4.47 m for X4 and 5.28 m for X3) which implies high probability of collision. Hence, undoubtedly X4 planned well design is faulty and it must be reviewed.

Figure (2) introduces ladder plot in which the measured depth of reference well X4 against calculated center to center distances of X3, X2, and X1 offset wells is shown. It is obvious from the plot that the C-C distance between X4 planned well and X3 actual offset well at depth of about 2,370 m is converge to 7.5 m. Considering the positional errors associated with survey tools in which the EOU are overlaying for the case of X4 and X3 wells, accordingly, it could lead to X4 and X3 wellbores collisions. Other wellbores X1 and X2 are at safe center to center distances as it clearly demonstrated by ladder plot.

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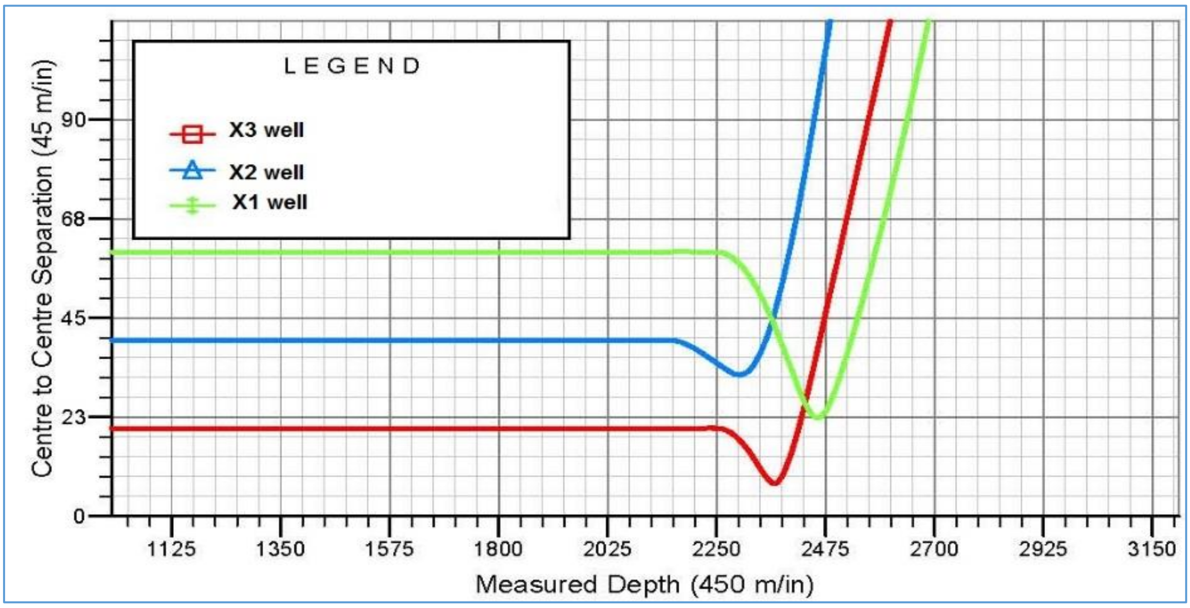


**Fig. (2): Ladder plot for reference well X4 relative to other offset wells.**

The travel cylinder plot (TCP) is presented in Fig. (**3**) , this plot is curtail for collision avoidance risk assessment in stage of well trajectory planning or amendment, there are three scales in this plot, first one referring to azimuth for 360 degree, which shown in plot as outer scale in interval 30° by 30°, second scale is a vertical radius of circle that referring to separation factor between the wells the scale start from center where the reference well (planed) exist, the value of separation defiantly zero that mean collision happens, and the scale increasing as much as the offset wells been far away from center where the reference well is existing, third scale is the numbers attached the colored lines (offset wells) where referring to measured depth in meter at different azimuth and inclination,

It is clear that X4 (reference well) in polar positions have a risk of collision with X3 well within 7.5m as the converted data obtained from survey tools read which mean low separation factor as shown in figure. X4 reference well also approaches X1 offset well but at a safe distance of about 22 m according survey data as we can notice in the plot (high separation factor) it's obvious that the well far from center. Consequently, X4 reference well must be reviewed and changed to avoid possible collision with X3 well.

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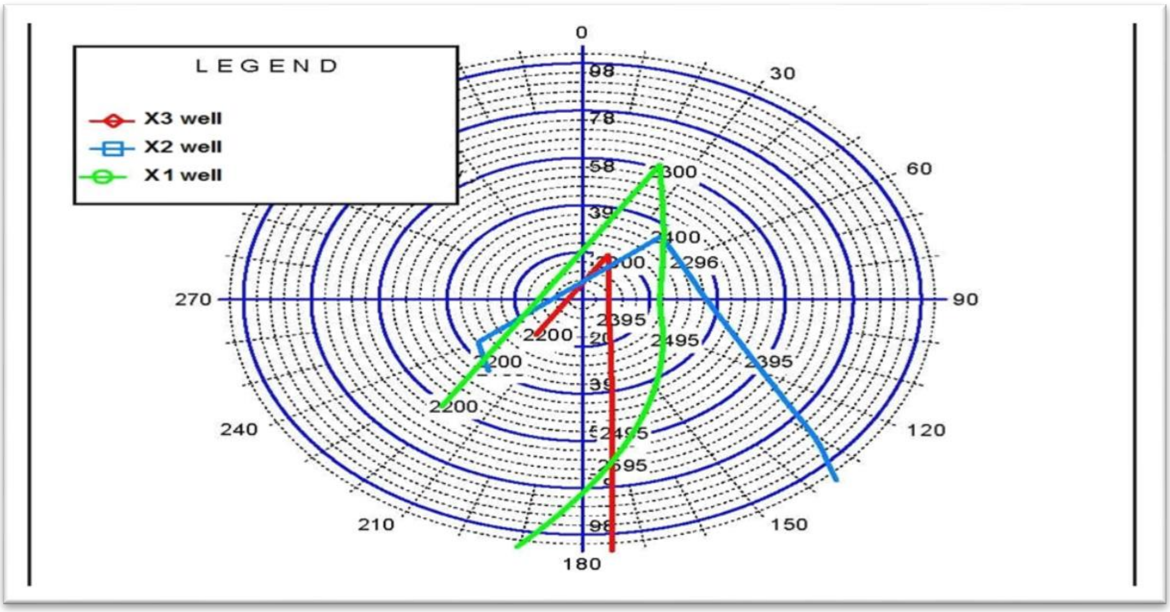


**Fig. (3): Travelling cylinder plot of wells X1, X2 and X3 with reference to that X4 planned well in polar positions.**

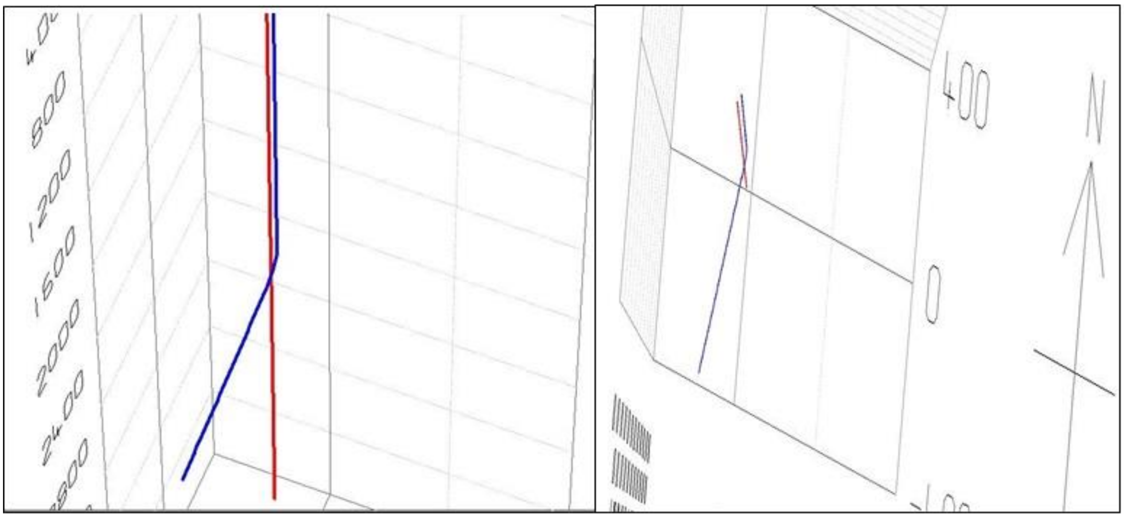


**Fig. (4): 3D views from different angle for wells X3(red) and X4(blue).**

In summary, the anti-collision results assessment of X4 proposed well against the offset wells suggest reviewing and modifying the principal design of X4 well Due to the lack in the assessment of anti-collision risks, the well design was not modified. Hence, during the implementation plan of the drilling program and at depth of 2023 m MD, the well has been side tracked and drilled using Rotary Steerable System (RSS) to final target.

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To tackle this problem, it was supposed to perform optimization of the previous version of the principal design of X4 well, by combination of slant and optimum align planning methods instead of using only slant planning method in the previous version of X4 trajectory design. This is because the well trajectory is J shape like so the slant planning method generates J shape trajectory and the optimum align method is to link different targets and take into account changing in azimuth . If the above planning method has been conducted, the drilling program would have been implemented smoothly avoiding any non-productive time and extra associated cost.

The optimization of X4 wellbore trajectory was performed using Slant planning method at first stage in which KOP was changed to depth of 2200 m MD in comparison with 2250 m MD of the previous design. The build section continued till reaching 31° and 170° Azimuth at depth of 2500 m MD. Optimum align method was used in the second stage of the planning method in which curve hold curve was selected. The build increased to 38° with 233° Azimuth during the first build section of the curve at depth 2755 m MD then hold followed by align to final target with 30° inclination drop and 200.6 ° azimuth at depth 3202 m MD. Fig. (**5**) depicts a 3D visualization of the optimized X4 well path (blue) along with the other offset wells and their ellipses of errors. There is a turn in the X4 well trajectory in the direction of 170° with 31° inclination till depth 2500 m MD then the trajectory was projected back to hit the target with 30° inclination & 200.6° azimuth at 3202 m MD using optimum align planning method (curve-hold-curve). Doglegs of the two curves in section curve-hold curve were at acceptable ranges of 4.29°/30m.

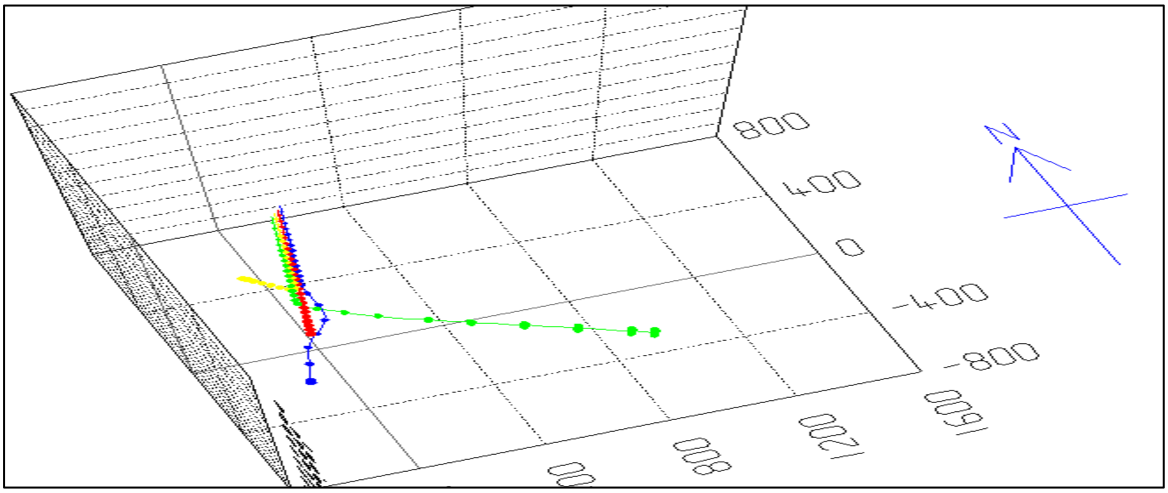


**Fig. (5): 3D view of X4 well plan after optimization**

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The results of C-C and EOU distances after modifying the design plan is shown in

Table (**3**). The optimization of the well trajectory design has greatly improved the separation distances and no more warning level become crossed.

**Table (3): Separation distances of X4 well with no warning levels against offset wells.**

| Offset Well | Well Type | Reference measure depth (m) | Offset measure depth (m) | Between centers (m) | Between ellipses (m) | Separation factor (m) | Warning level |
|---|---|---|---|---|---|---|---|
| **X1** | Offset: Actual | 2,402 | 2,397.87 | 47.6 | 37.74 | 4.829 | -------- |
| **X2** | Offset: Actual | 2,273.65 | 2,274.78 | 32.97 | 23.48 | 3.474 | -------- |
| **X3** | Offset: Actual | 2,316.43 | 2,315.58 | 15.86 | 6.26 | 1.652 | -------- |

Results of anti-collision assessment of X4 proposed well against actual offset wells are shown in Figure (6). The plots reveal that the new principal designs of X4 well were greatly optimized. Now, there is a quite safe distances among the wells in the pad drilling system. Hence, the drilling program of proposed well trajectory designed for X4 well would implement without any possibility of collision.

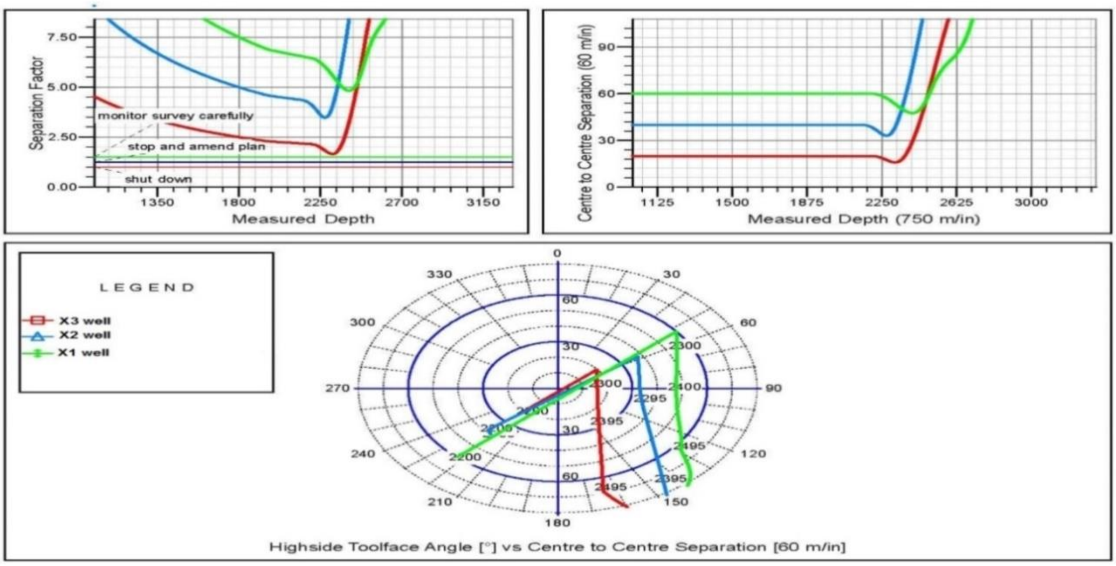


**Fig. (6): Separation factor, Ladder, and travel cylinder plot after X4 well plan optimization.**

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## 5. Conclusions

- Wellbore trajectory planning stage is crucial for safe and cost effect drilling operations, hence, great deal of attention must be paid in designing the final principal wellbore among different prototypes planned trajectories.
- Conducting anti-collision model during wellbore planning stage is very important for assessment of proposed wellbore separation distances and positioning uncertainty with respect to offset wells especially in pad drilling systems.
- Real-time of wellbore survey must be carefully monitored and collision avoidance assessment must be reviewed in case of wellbore trajectory deviation from the planned trajectory.
- Operator, directional driller, and survey companies must work together to ensure that anti-collision policies are in place and survey programs are valid and followed during drilling operations.

## Nomenclature

- ISCWSA: The Industry Steering Committee for Wellbore Survey Accuracy.
- EOU: Ellipse of uncertainty.
- MWD: measurement while drilling.
- EMS: Electronic Multi Shot Systems.
- INC°: inclination.
- Azi°: azimuth.
- KOP: kick off point.
- MDRT: measure depth referenced to rotary table.
- TVD: total vertical depth.
- SF: separation factor.
- C-C: center to center distance.
- R: radius of major axis of ellipse of uncertainty.
- R1: radius of major axis of ellipse of uncertainty of reference well.
- R2: radius of major axis of ellipse of uncertainty of offset well.
- RSS: Rotary steerable system.

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