

## A Comprehensive Approach to Well-Collision Avoidance

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### Abstract

Well-collision avoidance has gained greater importance as fields become more crowded and well paths increasingly complex. The safety and financial implications of shutting in production wells on platforms or repairing damaged wells have established a need for the industry to evaluate the potential for collision with a producing well.

This paper will cover three main topics related to minimizing the risk of well collisions:

- Evaluating the risk
- Managing the risk
- Demonstrating the results of the new risk-minimization process.

The paper will detail the processes of gathering appropriate data such as completion type, offset surveys, well pressures, casing depths, reservoir fluids, and mud densities. Each well and field poses different challenges; not all data are available and wells can vary from simple vertical land wells to crowded offshore fishbone designs.

Well position uncertainties are determined by using survey error models from the Industry Steering Committee on Wellbore Survey Accuracy. This method was chosen because it is an industry-recognized standard of defining the magnitude of survey uncertainty.

Recommendations for minimizing risk are based on the status and conditions of the adjacent wells and the nature and severity of the risks associated with a collision. These recommendations are formulated to minimize the risk while ensuring that production is disturbed as little as possible.

### Introduction

With the expansion of drilling operations worldwide in recent years, avoiding well collisions has become an increasingly critical challenge for the industry, especially in previously developed fields where existing well density is high and well paths can be extremely complex. The safety, environmental, and financial consequences of a collision can range from minor to catastrophic, and the cost of shutting in nearby producing wells during drilling or repairs can be prohibitive for producers.

The industry has a growing need for an effective approach to accurately evaluate the potential for collision and to eliminate or to manage the risks. The authors and their team have developed an effective and comprehensive approach to collision avoidance, and this paper will illustrate its design and application.

As part of an international drilling and services provider (the Company), the authors are familiar with the challenges presented by today's complex drilling scenarios. The Company recognizes the importance of proper anticollision procedures and, in lieu of an industrywide standard, has established its own standard to deal with these situations.

To comply with this standard when any new well is drilled, the drilling engineers must analyze each of the offset wells within a certain radius of the proposed subject well. This can be a relatively quick and simple process in a new field where only a few wells are involved. In these situations, the anticollision process might take no more than a few hours and be solved at the location level. But in highly developed brownfield locations, the anticollision process becomes much more complex, requiring the analysis of hundreds of adjacent wells before finalizing a new trajectory.

### *The Challenge of Avoiding Well Collision*

A number of recent trends contribute to an ever-increasing complexity in the anticollision process.

In land drilling activities, new production in older, established fields can pose an increased hazard of collisions with existing wells. In some parts of United States land operations, for example, the government rules concerning well density have been relaxed to facilitate more domestic production. From a former spacing limit of one well per 25 acres, new regulations have reduced that to a 20-acre limit and then a 10-acre limit, with proposals for a 5-acre limit in the future. The same trend worldwide has opened opportunities for producers to return to established fields with an infill drilling campaign, drilling new wells between and in relatively close proximity to existing wells, which are often still producing.

Another factor is the type of wells being drilled. In the past, operators drilled mostly vertical wells with wide spacing between surface locations. Now, the trend is toward more directional, horizontal, and fishbone multilateral wells, often several of them from a single pad location using subsurface wellheads. This trend increases the problem of borehole proximity at very shallow depths where a collision may have especially severe consequences in gas-producing reservoirs. Additionally, many of these new well designs call for reduced center-to-center distances between wells.

Urban development and congestion also contribute to the complexity of well design. As market economics make it attractive to tap reservoirs that are now beneath dense, urban

populations, the limited number of places where a rig might be positioned puts major constraints on well designs and further complicates the collision problem.

Worldwide, offshore platforms with ambitious drilling programs seek to increase the number of available slots without the expense of major additions to infrastructure. Coupled with an already crowded environment of existing wells, the need to add new ones to extend platform life creates very challenging collision-avoidance scenarios.

Finally, in many older fields the lack or low quality of data on borehole position and conditions in wells that may be more than half a century old can make precise mapping and evaluation of potential hazards extremely difficult and time consuming. For many of these wells, reliable data was never collected in the first place, requiring in some cases a complete resurvey of nearby offset wells.

### ***Creating a Comprehensive Approach***

While health, safety, and environmental considerations remain paramount, an effective anticollision solution must be flexible enough to support the producer's resource development goals and must recognize the realities of each field's unique economics. This is especially true in low-tier, high-volume markets where financial margins are already quite thin. As we will see in the case histories to follow, this approach does exactly that, drawing on an extensive knowledge of all the factors involved and using innovative techniques and technologies to create and execute safe, successful well plans in the most difficult and complex of environments.

The goal is not to eliminate all risk, but to manage risk effectively, to drill "with eyes wide open" and to develop adequate plans that mitigate and minimize those risks deemed acceptable.

In the following section, we will outline the basics of this comprehensive approach to collision avoidance.

## **Anticollision Process Workflow Description**

### ***The Principles of Hazard Analysis and Risk Control***

The Company uses a standard process of Hazard Analysis and Risk Control (HARC) for loss prevention and continuous progress toward a zero-defect culture. The principles established in HARC are the foundation of the Company's collision-risk assessment process.

Key objectives of HARC include a proactive and systematic analysis of hazards and subsequent minimization of associated risks. For any activity being assessed, the first step is checking to see if there is a generic Risk Assessment that can be used as a template. All hazards at the site are recorded in the HARC Record Form, assuming no prevention or mitigation measures are in place. The likelihood and potential severity of an undesired event are assessed and assigned an initial risk level using the Risk Assessment Matrix (see below).

Carefully taking into account all contributing or escalating factors, a detailed analysis is prepared and recorded. This analysis is more detailed where more severe risk is posed. Any

current and planned prevention and mitigation measures are also recorded on the HARC Form (see Appendix, Figure A-1).

Using the Risk Assessment Matrix (Figure 1), a classification is made of the residual risk level associated with each hazard. The likelihood of the undesired event, the potential severity, and the resulting residual risk level are then recorded.

- For activities with risk levels in the blue area of the matrix, work may proceed with existing control measures.
- For activities in the green area, work may proceed, but additional control measures that would reduce the risk level to the blue area should be considered.
- For activities in the yellow area, additional control measures or a redesign of the activity should be recommended and work may proceed only after demonstrating that the risk level is as low as reasonably possible (ALARP).
- For activities with risk levels in the red area, the work may not proceed until additional control measures have been implemented that lower the residual risk level at least to the yellow area and ALARP has been demonstrated. In some cases, work may be allowed to proceed in the red zone with additional control measures in place.
- For activities with risk levels in the black, "Nonoperable" area, the zone or area at risk must be evacuated.

### ***Mapping the Anticollision Process***

The entire anticollision process is illustrated in a flowchart (see Appendix, Figure A-2). The first step in the process is establishing the standard that will guide the evaluation of risks. There is as yet no industrywide standard available, but the Company has developed its own comprehensive drilling standard that includes detailed anticollision requirements and procedures. In practice, the metrics and limitations it specifies may be modified to accommodate real-world geophysical and economical considerations, and local regulations and customary practices. The goal of the standard, however, does not change: to shape and to approve a drilling plan that can be executed without unacceptable risk to health, safety, environment (HSE), or the economical well being of the participants.

The next step is to perform survey quality control and quality assurance, looking at each survey to determine if the quality of data is sufficiently accurate for the risk-assessment process or if additional data need to be collected.

Next, the well design is optimized to meet the agreed-upon standard and the survey program is optimized to make sure that the tools selected have sufficient resolution to produce the data required. Close approach analysis can then proceed, consisting of the many different complex calculations performed on the data to create an accurate picture of the potential risks. Checks are made to determine if there is magnetic interference from nearby wells to eliminate surprises during drilling and to define the contingency plans for responding to such an occurrence.

At this point, detailed reports are generated and drilling engineering's technical judgment is required to determine whether or not the plan will meet the standard. If it does, well

design can be finalized, all necessary approvals acquired, and drilling can begin.

If the plan does not meet the standard, a series of questions is asked in an effort to find a solution by a) redesigning the survey program, b) adjusting the well design, or c) resurveying the offset wells in question, looping back to previous points in the process depending on the answers, as shown in the flowchart.

If none of these remedies is possible, the process of requesting an exemption from the standard for the subject well begins with the gathering of data for offset wells at risk of a collision. (The exemption process is discussed in more detail below.) If an exemption is not technically approved, the well cannot be drilled under the present scenario.

Once a well design has been approved and drilling has begun, the status of the well is monitored constantly to make sure there is no unacceptable deviation from plan. If there is a deviation, drilling is paused and the situation is carefully evaluated. If the deviation is indeed unacceptable, the process loops back to “Optimize Well Design” and necessary adjustments are made. The intention of the monitoring process is to react quickly when problems begin to develop, to prevent or mitigate the damages a collision would cause.

## **The Risk Analysis Process**

### **Definitions**

The following factors represent the key elements of the risk analysis process.

### **Ellipsoid of Uncertainty and Tool Error Model Selection**

The ellipsoid of uncertainty (EOU) is a volume used to indicate the magnitude of the wellbore position uncertainty at a particular depth. Calculation involves the use of survey tool error models in the well-design software. Some surveying systems are more accurate than others, but they are all prone to some degree of inherent error. Surveys are also subject to errors resulting from the surveying environment, such as external magnetic interference from nearby wells and internal magnetic interference from the drillstring.

As illustrated in Figure 2, an ellipse can be drawn to represent the encompassing volume that gives the most likely position of the wellbore at a given level of statistical confidence. The well-accepted industry standard is the Industry Steering Committee for Wellbore Survey Accuracy (ISCWSA) error model, documented in SPE 67616 for magnetic tools and SPE 90408 for gyroscopic tools.

Selecting the best Tool Error Model is essential to an effective analysis. A number of different models exist, and it is essential to select the one that will provide an adequate margin of error without being too conservative and placing unnecessary restrictions on well-design options. The tool error model can also be used to optimize the driller’s target to meet geological requirements. Figure 3 illustrates the variation in predicted uncertainty using three different tool error models created to assign uncertainties at different formations and depths.

In situations where adequate data on nearby wells are not available and surveying all those wells would pose a prohibitive cost, it is possible to analyze data from a subset of those wells, to identify shared trends and conditions, and to interpolate sufficient data to satisfy the requirements of an accurate risk assessment (see Case History 2, below).

### **Separation Factors**

With traditional separation factor (SF) calculations (Figure 4), it is possible to have two collision scenarios with the same SF, but that have very different probabilities of collision because the individual orientation and shape of the EOUs are not taken into account. This traditional SF can result in overly conservative well planning, which can at times be unnecessarily restrictive. To avoid this problem, oriented separation factors (OSFs) are used. OSFs (Figure 5) take into account the geometry of the EOUs so that all scenarios with the same OSF have the same probability of collision. Obviously, if a well is drillable using an SF, it will be drillable using an OSF, but the reverse is not always true.

### **Types of Close-Approach Situations**

- **Alert**, where  $OSF < 5$ . This OSF is the first alert condition. The report contains sufficient information to closely examine the proximity condition of nearby wells that have failed the alert zone condition.
- **Minor**, where  $1.0 < OSF < 1.5$ . A minor risk well that falls within an OSF of less than 1.5, but greater than 1.0. This OSF represents the limit of the “drill ahead” separation threshold and requires a written exemption.
- **Major**, where  $OSF < 1.0$ . This OSF represents the point at which the probability of collision is high and drilling cannot proceed until the risk has been reduced.

### **Exemption Requests**

An anticollision exemption request must be initiated for any well that breaks the rules. The exemption approval process will clearly define the prevention and mitigation activities that must take place to minimize the risk and/or the consequences of a collision.

Out of a total of 9,097 wells drilled by the Company in North and South America from 2002 to the present, 1,796 required an exemption. As illustrated in Figure 6, both the number of total exemptions and the percentage of them that involve an HSE-related exemption have steadily increased, a trend that can be expected to continue as fields become more densely occupied and the subsurface picture grows more complex.

### **Tools to Measure Anticollision Risk**

To assist in the 100% implementation of the anticollision standard, the authors have created a set of analytical tools—including special software—designed to produce a comprehensive well survey report and detailed exemption requests, when necessary, in the shortest possible time and with the highest degree of reliability.

Currently the anticollision risk is based on a proximity analysis, an OSF < 1.5 and center-to-center distance rules. Additional data may also be required to properly assess the collision risk, including offset well completion design, reservoir data, well pressures, casing depths, reservoir fluids, and mud densities. As illustrated in Figure 7, the modern production environment can pose a great number of possible risks, each of which must be recognized and accounted for in the exemption process.

The next step is the generation of an anticollision Risk Assessment Matrix based on the available data from offset wells, to evaluate the risk of drilling the subject well and thus to connect the risk with a set of technical recommendations that prevent the occurrence and/or mitigate the severity of any event by managing that risk.

The purpose of the Risk Assessment Matrix is to use a set of criteria and metrics that will facilitate a description of the collision risk for the specific well design in question when the standard anticollision rules cannot be satisfied.

The risk assessment is divided into the following parts:

- A brief explanation of which rule(s) will potentially be broken
- A summary of the offset wells divided into Major and Minor risk and further subdivided by well status (active, inactive, natural flow, abandoned, etc.)
- A statement defining the risk situation with regards to HSE and the performance of the subject and offset wells
- A set of mitigation actions that must be executed before drilling can begin, in cases where there is an HSE risk to people, environment, or general safety
- A detailed set of prevention actions and while-drilling recommendations.

The software generates a report that includes the anticollision status (major, minor, or pass), offset trajectories, tool-error models, and a host of other vital data (see blank form in Appendix, Figure A-3).

The software also produces a set of recommended actions, based on the Company's experience as well as specific data and drilling history in the subject field. These recommendations can range from the simple to the complex, depending on the nature of the risk, and can include such items as specific borehole parameters to monitor while drilling, optimum mud weight and volume for well control, specific inclination and azimuth targets, contingency plan, and so forth. The software can be easily adapted to reflect additional field experience and changes in standards or technologies.

All the data that go into the Exemption Request are quality-controlled to ensure consistent and precise inputs, yielding an accurate risk assessment that must demonstrate a negligible risk to personnel and environment in the event of an unplanned collision. This is the cornerstone of the exemption process and is intended to provide quality input into the risk assessment process for an informed decision on whether and how to proceed.

## **Factors in the Exemption Process**

A number of other factors can shape the exemptions process. For example, inadequate survey data or high field density may require some creative strategies for drilling within the standard guidelines. Each well and each field is unique, and each must be approached on a case-by-case basis.

Advances in technology also affect the very definition of what is safe. Just as modern positioning technology has made it safe to reduce the permissible distance between airplanes, effectively increasing airport capacity, so advances in subsurface mapping and drilling capabilities have made it possible to reduce the permissible OSF without compromising operational safety.

Some situations pose such a high risk of collision, or the costs of any collision would be so costly that, from the Company's point of view, drilling the well is clearly out of the question. But in many cases, a change in approach can reduce the risk of collision or the consequences of an incident sufficiently to permit drilling ahead with caution.

The goal of the exemption process is to guide the creation of a well plan that can be carried through to completion without incident, or to confirm or create the capability to deal effectively and at an acceptable financial cost with any collisions that do occur.

## **The Anticollision Process: Two Case Studies**

### **Case Study 1—Offshore Platform**

The first example case involves an assignment to determine the potential collision risks of adding new slots to a large offshore platform. The project included evaluating the existing wells and additional slots for a total of over 100 slots to best mitigate the risk and determine how many additional slots are drillable based on the anticollision rules.

The wells for the new slots were studied at various true vertical depths (TVDs) to assure that there would be sufficient separation and that most collision risk could be sufficiently reduced without shutting down production while drilling.

### **Evaluation**

Initial plans for each additional slot and existing well were evaluated based on the anticollision standard using various conductor profiles and sizes. The well plans were then optimized to reduce the risks, using a standard conductor profile and a total 60% of the proposed additional slots passed.

Each of these passed slots was also analyzed to determine the allowable deviation from plan—the distance the well can be away from plan before the standard will be broken at measured depth.

### **Conductor Profile Alternatives**

Although the current standard practice at this location is to drill a vertical hole and set surface conductor at a certain depth, several variations were considered to determine the effect they would have on the potential collision risk. One of these changes

was to decrease the wellbore size; the second was to change the conductor profile.

With these changes, the number of useable slots increases to 70% with a substantial increase in OSF as well. The additional slots were also examined for both minimum separations from any of the offset wells as well as minimum OSF.

### **Recommendations**

Recommendations based on these studies included the optimum order in which the wells should be drilled to minimize collision risk, additional slot-planning optimization to better achieve geological and drilling requirements, and the need for further detailed analysis if any of the current execution plans are changed. Additional risk assessments were also recommended before any existing or new slots are drilled, even if they met the anticollision requirements, to facilitate further minimization of the risk.

Several additional recommendations were made. They included noise-monitoring-while-drilling conductors in close-proximity environments and the use of magnetic ranging techniques to assure adequate separation from offset wells in cases of serious collision risk. Because of potential difficulty in obtaining adequate data in certain wells, precision drilling and survey tools were recommended as needed to monitor dogleg severity.

For proposed changes in conductor profile, a feasibility study was recommended with emphasis on determining the best bit and drive system to achieve planned goals. Batch drilling of the conductors was suggested as a means of achieving further operational efficiencies. Finally, new technologies were suggested to better maintain inclinations within the desired range where the plan calls for perfectly vertical wells.

### **Case Study 2—Dense Brownfield**

This field has been in production since the early 1930s and lacks adequate data on well deviation for approximately a third of its 3,000 wells. Much of the information that did exist is stored in old printed archives, and almost no digital data is available on those wells. This makes it difficult to achieve the ideal of accurate and complete information in the survey database used to perform an anticollision analysis.

Most of the older wells have no trajectory data and only some of them have inclination readings. A reliable, digital database exists for less than 5% of total wells.

On the older wells, the normal practice had been to obtain a simple inclination-only reading at the end of each run, when possible, and in some cases a single inclination reading at a given depth. On newer wells that show an increasing tendency to deviation, a simple survey to provide inclination and azimuth was included, as required.

In such a densely occupied field, using the standard radius for the initial global scan would mean that every new well drilled would require an anticollision exemption and the analysis of more than a thousand nearby wells. In this lower-tier field, where the operator's margins are quite narrow, this would prove prohibitively expensive.

### **Creating an Effective Well Plan**

The goal was to find an effective process without unduly increasing the risk of collision with offset wells, using the minimal survey data available.

In this field, S-type profiles with a horizontal displacement to a maximum of 650 ft are the most common directional wells. There was never a need for horizontal wells or other complex well designs. The field features low reservoir pressure, and drilling mud weights were determined to be sufficient to counteract the hydrostatics of the offsets if the casing were breached. Mechanical pumping is used, so none of the additional risks are associated with submerged pumps or gas-lift wells. The risks posed are mostly financial, with no significant risks to HSE. All of these factors made it possible to reduce the radius of the initial scan—and thus reduce the number of offset wells to be considered during the exemption process—without posing any unacceptable risks.

To resolve the problem of poor or nonexistent data for many of the offset wells, an analysis of available data revealed certain predictable trends that could be used to aid the risk-assessment process. For example, wells drilled vertically tended to go slightly toward the center of the field (Figure 8), following the natural tendency of the formation; this was determined by a sampling of a minimum number of the vertical wells surveyed. By determining the behavior of a vertical well drilled with the conventional techniques in the area, the team was able to perform a statistical analysis and developed special tool codes for the remainder of the wells with no survey data. Optimum tool-error models were selected to assure a sufficient margin of error in the unsurveyed wells.

Through this more flexible approach, an effective well plan was created that fulfilled the desired production goals without posing an unacceptable risk to life, property or environment

### **Conclusions**

This paper has outlined the basic components of a comprehensive collision-avoidance approach designed to meet the growing challenges posed by today's ambitious drilling programs and complex subsurface environments. The authors have demonstrated the importance of gathering adequate data of sufficient accuracy and reliability and have described new tools and techniques evolved to analyze this data thoroughly in a minimal amount of time.

In addition to predicting and reducing the likelihood of collisions, the anticollision process also generates recommendations for minimizing or mitigating the resultant damages should any collision occur.

Based on a clearly defined anticollision standard, this approach allows for a degree of flexibility in applying that standard to accommodate the unique geological and economic challenges posed by a given drilling environment. This flexibility permits an optimum development of reservoir resources without compromising required protection of HSE and without posing an unacceptable financial risk for the participants.

Figures

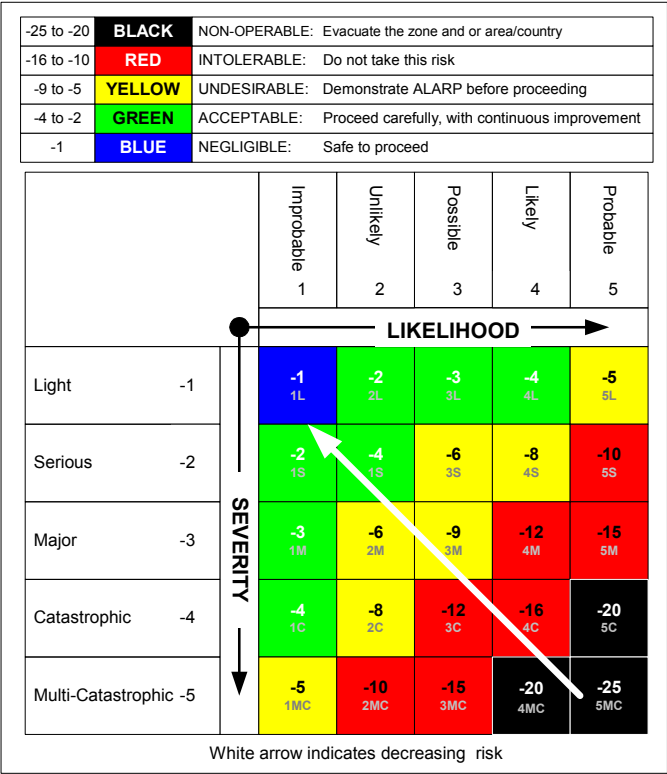


Figure 1. HARC Risk Assessment Matrix

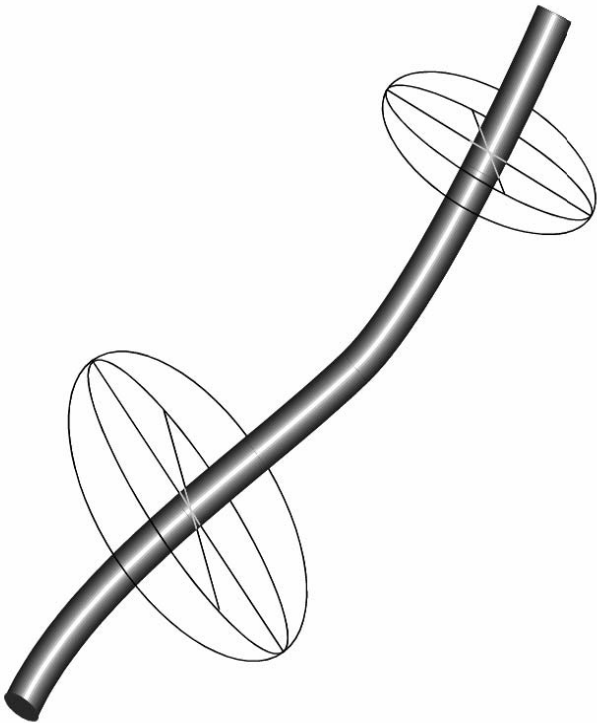


Figure 2. Ellipsoid of Uncertainty

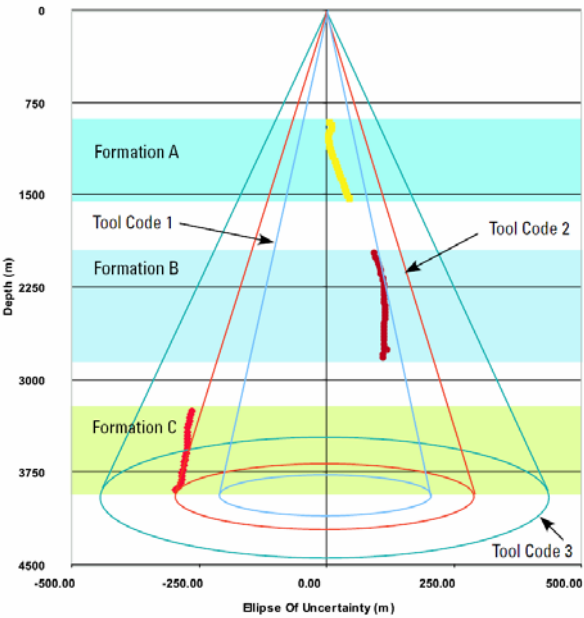


Figure 3. Tool Error Models

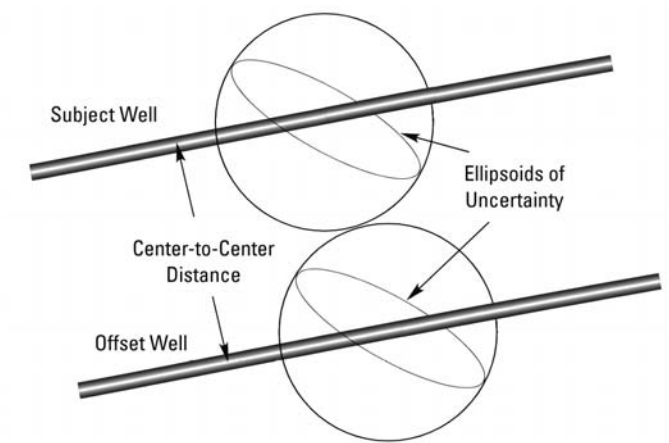


Figure 4. Traditional Separation Factor

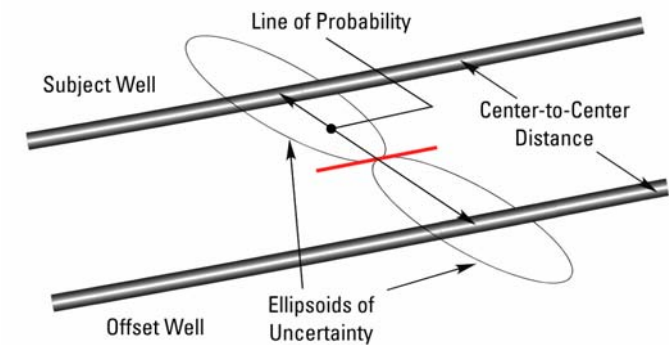


Figure 5. Oriented Separation Factor

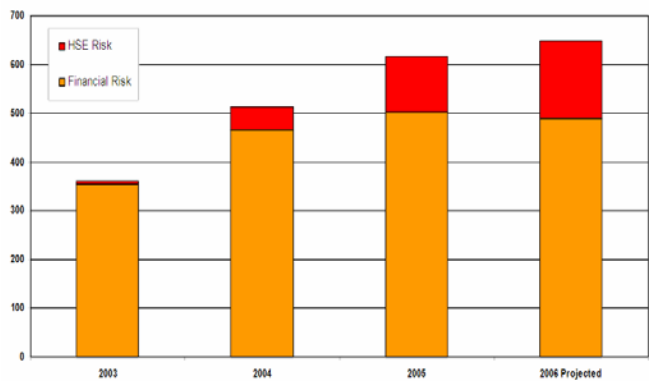


Figure 6. HSE, Financial Exemptions—Growth by Year

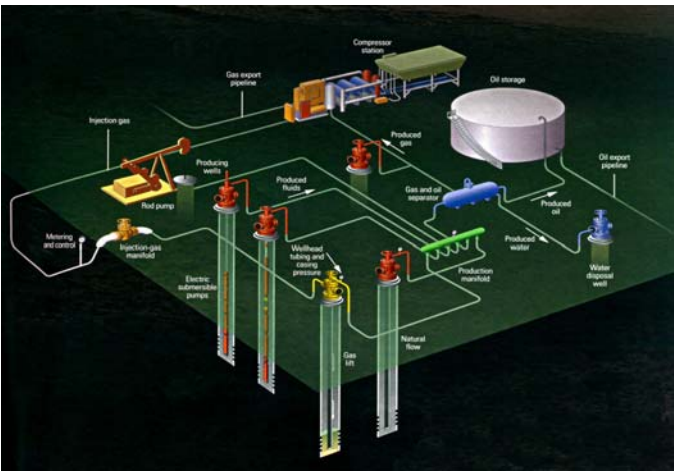


Figure 7. Examples of Risks in Production Environment

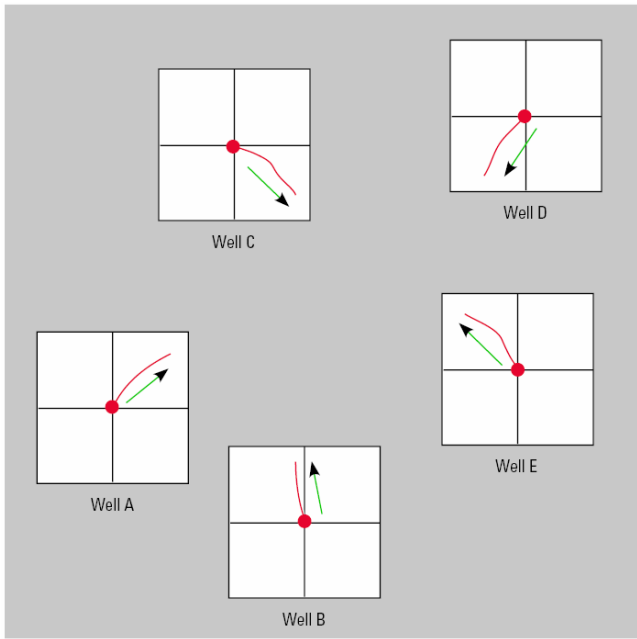


Figure 8. Plan View Formation Tendency Analysis

**Figure A-1. HARC Form**

[illegible]



Figure A-2. Anticollision Process Flowchart

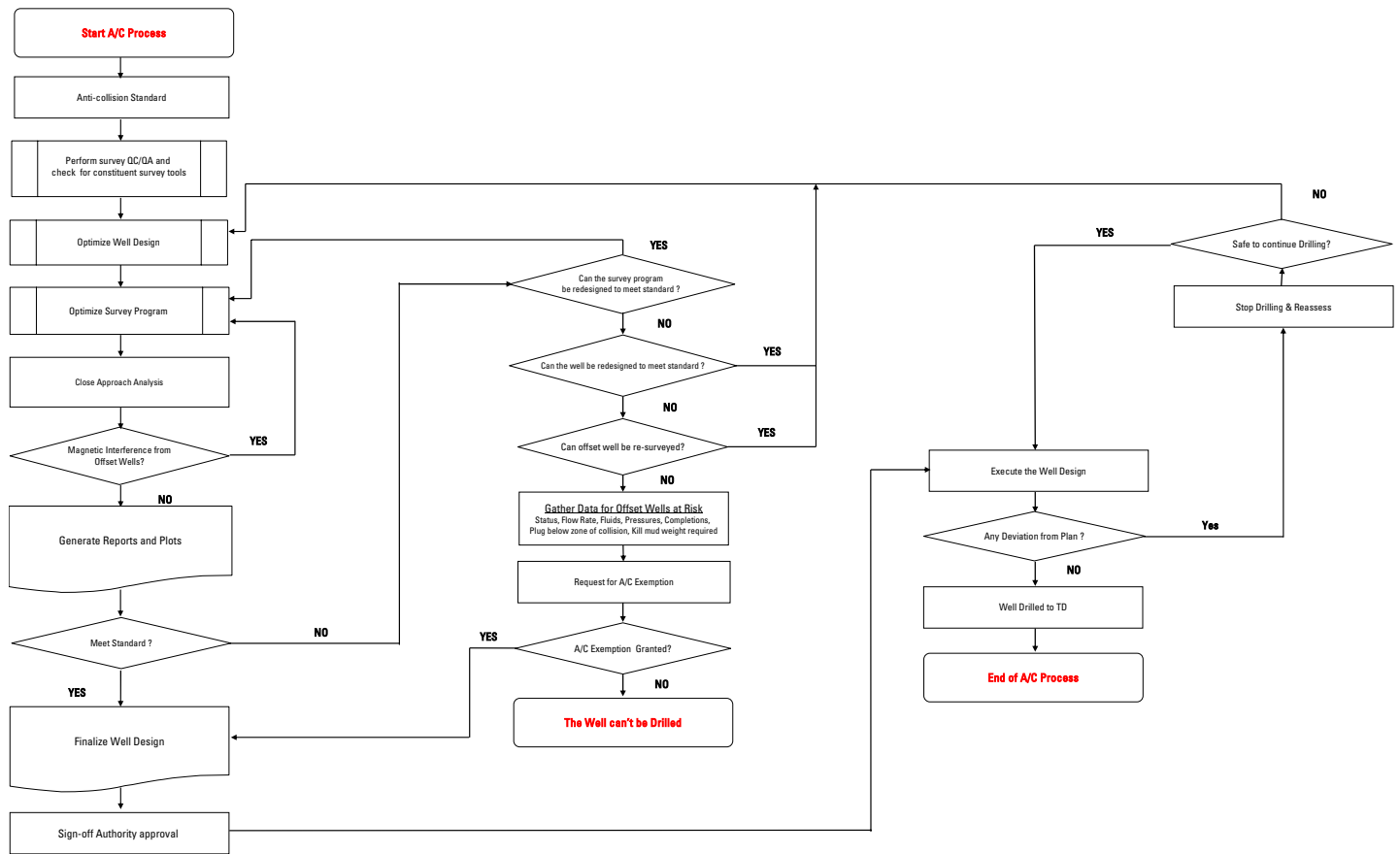


Figure A-3. Blank Anticollision Analysis Report Form Page 1 of 3



## D&M SQ S002 - Well Surveying and Anticollision STANDARD EXEMPTION REQUEST FORM

Location:	EXEMPTION NUMBER:
Request Date:	Client:
Date exemption required:	Well Name:
Prepared by:	Field Name:
Review by (in Location):	Job Number:
DEC Representative:	Operation Manager:

AC Exemption Form Rev 6.00

**An Exemption request is required for each planned well where the standard is broken**
**Subject Well Name and Location**

Well Name:	Structure / Slot:			
Platform:	Rig:	Rig Type (Semi-Sub, Jack-up, land etc):		
Well Type (oil producer etc):		Well Profile (S-type, Horizontal etc):		
Surface Coordinates (UTM / Lat. Long.): /				
North Reference (Grid, True):				
Water Depth:	GL-MSL:	RKB:	Total Depth MD:	Total Depth TVD:

**Subject Well Drilling Fluid Data**

Open Hole			Case Hole			Mud Properties	
Hole Size	Depth		Casing Size	Depth		MW	Type
(in)	From (ft)	To (ft)	(in)	From (ft)	To (ft)	From To (PPG)	

**Reservoir Lifting Mechanism**

Natural Flow <input type="checkbox"/> Sucker Rod <input type="checkbox"/> Gas Lift <input type="checkbox"/> ESP <input type="checkbox"/> Other <input type="checkbox"/>	Can be Shut-in (Y/N)? <input style="width: 80px;" type="text"/> Specify: <input style="width: 200px;" type="text"/>
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Maximum reservoir pressure at the collision TVD for the highest RISK of collision.

Figure A-3 Blank Anticollision Analysis Report Form Page 2 of 3

FAIL_MAJOR																
Offset Trajectory	Tool Code at	TD MD	Ct-Ct	Min OSF	Subject Trajectory		AC Method	Flowing	Well Type	Oil/Water/Gas	Csg	WH	D/H	Well Lifting	Can well be	Offset Well
	Collision Point	(ft)	(ft)		MD (ft)	TVD (ft)	3DLD/NP	Status	V/J/S/H/L/FB		(psig)	(psig)	Valve	Mechanism	Shut-in	Survey Status

Provide a brief explanation of risk situation:

FAIL_MINOR																
Offset Trajectory	Tool Code at	TD MD	Ct-Ct	Min OSF	Subject Trajectory		AC Method	Flowing	Well Type	Oil/Water/Gas	Csg	WH	D/H	Well Lifting	Can well be	Offset Well
	Collision Point	(ft)	(ft)		MD (ft)	TVD (ft)	3DLD/NP	Status	V/J/S/H/L/FB		(psig)	(psig)	Valve	Mechanism	Shut-in	Survey Status

Provide a brief explanation of risk situation:

Figure A-3 Blank Anticollision Analysis Report Form Page 3 of 3

Actions taken at the design stage:

Assessment of worse case scenario that would result from a well collision.

Measures and actions to be taken to reduce risk during execution stage:

Risk Assessment Recommendations

Approved by Local Sign-Off Authority?		Name:		Date:	
Cc to HQ DEC ?		Name:		Date:	
Submitted to Location Manager?		Name:		Date:	
Approved by DEC?		Name:		Date:	
Submitted to VP Operations for Approval ?		Name:		Date:	