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Risk Minimization by the use of Failure Mode Analysis in the Qualification of New Technology – Recent Project Experience in Completions and Sand Control

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Abstract

This paper reports on a Reliability Assessment Program for sand control completion technology. The Failure Modes Effects and Criticalities Analysis (FMECA) method was used to provide a systematic reliability assessment, identifying and ranking critical issues and potential improvements focused on those criticalities. The FMECA process is an integral piece of the qualification program for the operator's new technology developments.

The FMECA analysis was utilized by the operator to provide assurance in the technical and functional capability of the new technology systems. A detailed systematic approach provided opportunities to identify potential risks and mitigate them prior to operations. The process helped identify potential issues, otherwise possibly not considered.

The importance of this process is critical given the current trend of more complex completion designs in increasingly adverse conditions. The increasing capital completion cost for subsea, high pressure, high temperature (HPHT), deeper, and more complex systems necessitates a high level of assurance and long-term sand control integrity.

The main objectives of the FMECA projects were –

- to produce a reliability assessment of the system;
- to identify the critical aspects that need engineering resources focused on them;
- to identify key actions to address those critical aspects and reduce the risks.

The systematic approach for FMECA entailed 4 key steps -

1. Compiling the baseline system documentation set;
2. Establishing suitable ranking criteria for Severity, Probability of Occurrence and Detectability;
3. Identifying and exploring the failure modes;
4. Finally, analyzing the FMECA results to highlight critical failure modes, and producing a key actions list, addressing all of those critical failure modes.

The detailed analysis provided graphical views of the data to highlight points of concern and focus on key issues to mitigate during the technology implementation. The failure modes exhibited a wide range of RPN (Risk Priority Number) values, allowing those of most concern to be easily identified.

We identified more than 30 failure modes of concern for each project (out of more than 130 failure modes detailed in total). They were highlighted in the FMECA sheets, and extracted as a Key Actions list for implementation by the project team.

The value was realized from the rigor in the design and qualification process, identified QA/QC measures, implementation efficiency, and risk mitigation for future application. The identified failure modes produced a list of issues that could potentially jeopardize a well, production, reserves, or millions of dollars of expenses if not mitigated.

Each identification of a potential failure mode, along with the risk mitigation actions, contributed to an increased chance of success.

The quality of the results depended on the amount of challenge and creative input offered in the workshops. Diligence to the process and communication of actions are key to the success of a failure mode analysis for new technology.

Introduction

Industry has recently recognised the value of failure mode analysis, which is now being used on a rapidly expanding scale.

FMECA has been in routine use in various engineering industries for more than 40 years, and it is still a vital part of the engineering development process: “Finding failure modes early in technology and product development is the most important challenge we face as engineers“ - Richard Parry Jones - Chief Technical Officer and VP of Global Product Development, Ford Motor Company (Altair Technology Conference, November 2004).

There are strong similarities between the challenges in space projects and those in oil and gas projects. Both are high-cost, complex systems, operating in severe environments, with prohibitive intervention costs. Therefore, tools and methods developed in the space industry can be used, if appropriately adapted, with advantage in oil and gas projects (Ref 2).

Engineering development issues are important wherever the risk of applying new technology is high. The risks are higher still when projects have significant downhole complexity, because the downhole elements are subject to the most severe operating conditions and the highest consequences of failure.

FMECA techniques have been used for reliability risk analyses for operators and vendors separately and for both working collaboratively. These projects span -

- comparing different engineering designs within a intelligent well product;
- identifying key reliability risks in permanent downhole gauge systems;
- comparative evaluation of different intelligent well designs for a field development;
- evaluating reliability improvement options for an existing intelligent well product;
- comparing intelligent well completion with conventional for a field development;
- evaluating installation, production, and long-term completion integrity risks of downhole sand-control equipment and service tools.

Links to published papers in this field are provided in the References section.

Overview of the Qualification Process

The qualification process, outlined in Figure 1, aims to reduce the risk of applying new technology. It starts with a preliminary assessment of the technical risk, taking into account both the design and the application. Usually, a range of applications is foreseen, and these are defined in the functional requirements specification. That assessment decides how much qualification will be needed before wide-scale application, which leads to the qualification plan, which in this case required a failure mode analysis (FMECA) to be undertaken.

Figure 1 shows how failure mode analysis of the design and application should feed the formulation of test procedures at each phase, by identifying and prioritising the critical aspects of the design and application.

A particular characteristic of downhole equipment is that the installation process has a very strong influence on the subsequent reliability. So failure mode analysis, to be effective, must cover the interaction of the equipment itself (i.e. the completion) with the service tools that install and activate it, and the well conditions experienced during the entire life of the system.

Objectives

The operator had a need to understand and compare the key reliability issues concerning new sand-control completion technology, as part of the qualification process before wide-scale application.

The objectives of the project were –

- to produce a reliability assessment of the system using the FMECA process with the participation of engineers from the operator and the manufacturer;
- to identify the critical aspects that may need to have engineering resources focused on them;
- to identify key actions to address those critical aspects and reduce the risks.

Benefits of a FMECA for New Technology Application

The biggest issue of utilizing new technology is the inherent risk associated with it. Risk decreases with each application as learnings are captured. Efficiency in operating practices as well as design is built into each modification of the technology for future use.

Focusing on the qualification process through rigorous failure mode identification allows the operator to decrease the amount of assumed risk to economically progress technology in a shorter timeframe, thereby delivering the expected value.

The benefits were expected to be -

- Better understanding of the key reliability issues to put the operator in a stronger position to make well-informed decisions about the best applications for this technology;
- The focus to ensure that action plans and resources are targeted where they will provide most benefit – on preventing or mitigating the critical failure modes;
- A baseline for comparisons with other technology options;
- New skills and awareness for the operator’s engineers, from being involved closely in the process;
- The independent views of experienced but external engineers to challenge input and produce valuable results for analysis;
- A rigorous and systematic approach to the FMECA process, with results and conclusions that are directly

traceable back to the system diagrams and specifications;

- A framework which can be used for future FMECA's;

This work required access to detailed design information from the operator and the manufacturers, sufficient to identify failure modes and their effects and the probabilities of occurrence. It also required access to expertise to evaluate consequences of failure from both those organisations.

A successful approach to reliability risk analysis can be summarised as -

- good preparation ready for the technical sessions, providing the clear framework that is essential both for undertaking FMECA efficiently and for the completeness checks;
- templates and software tools for all stages of the process;
- the expertise to facilitate the technical sessions effectively, keeping the process on target to its objectives and ensuring a rigorous and systematic approach;
- the engineering resource to provide an independent review of the FMECA data in progress, checking for completeness and consistency; Input from the expertise of the technical team is critical.
- the experience to extract the important engineering issues from the captured data.

The Systematic Approach of a FMECA

A well established technique for reliability analysis is Failure Modes, Effects and Criticalities Analysis (FMECA) technique, for which we used the systematic approach illustrated in Figure 2.

- The life-cycle scenario is established, identifying the phases of construction and production;
- The baseline system is defined unambiguously, and documented;
- The system documentation is then subjected to independent review for completeness and consistency;
- Suitable rankings for Severity and Probability of Occurrence are agreed;
- The failure modes of each subsystem in turn are identified;
- Each failure mode is systematically explored, using pre-prepared formats, to identify cause of failure, local and end effects, severity, probability of occurrence, design controls, detectability, and preventive and remedial actions;
- The FMECA results are analysed to highlight critical failure modes;
- The key actions necessary to mitigate the risks are collected in an action list for implementation.

Organisation of the Project

It is important to use experienced engineers with relevant backgrounds so that they are able to engage in technical dialogue with the technical design experts, their manufacturing colleagues, and the operators' technical staff where appropriate. Mutual respect is important for a productive and efficient process. Technical expertise from all company personnel involved provides challenge to the ranking and brainstorming of possible failure modes utilizing previous experience. Well completion systems are exhibiting an ever more complex mix of technologies, and the team engaged on an analysis of this kind needs to have the range of disciplines to match that.

The sequence of tasks and the inputs they require are shown below in Figure 3 – Project Logic

Baseline System Definition

The completion systems are intended to be flexible, so that they can be implemented in many different configurations. For our analysis, an agreed baseline was needed, defining the configuration that will be analysed in a suitable format for the purpose of structuring the FMECA work.

The first task was to establish the baseline system definition, in terms of –

- block diagrams showing the scope of the system in each of the phases - the configuration, boundaries, constituent subsystem and their interfaces;
- schematic diagrams showing the sequence of installation;
- the functional requirements.

The system was divided into primary subsystems such as the outer completion assembly, the service tool, and the fluids.

The system definition covered 3 different phases of application.

1. Installation – Make-up and running to depth, preparing for completion phase;
2. Execution – Completion pumping phase and pulling out of hole;
3. Production – Long-term sand control integrity on production.

Block diagrams were created for each of those phases, defining the boundaries of the FMECA; Figure 4 shows an example.

System schematics were used to illustrate the sequence of installation and the tool movements involved, and thereby facilitate discussion of the failure modes.

Failure mode identification cannot be performed properly until the functions of the system are defined. Functional requirements need to be handled in a systematic way, so that they can be checked for completeness. For each functional requirement item, there needs to be a technical specification quantifying all the relevant parameters.

There is a wide variety of downhole components and systems, with an equally wide variety of functions. However, the task of generating the functional requirements (and checking them) is easier if they are broken down into different categories such as:

- Connection, Support and Compatibility
- Flow and Access
- Isolation
- Control & Activation
- Measurement
- Safety

Ranking Tables

For each identified failure mode, judgments were made on the relative Severity, Occurrence and Detectability in terms of ranking codes (1 to 10). For reference we used the operator's current de-facto standard ranking tables, to support their aim to have a consistent approach within the organisation and thereby maximize comparability between this and other projects.

Identifying and Characterizing Failure Modes

Each failure mode was systematically explored to capture its characteristics. Local and end effects, severity, cause of failure, probability of occurrence, current design detections, and detectability were all discussed. Our aim at this stage in the work was to compile a thorough representation of all the failure modes.

The focus then shifted to interpretation of the FMECA results and preparation of a criticality analysis to highlight critical failure modes.

Evaluation of FMECA results

The analysis uses the traditional method of Risk Priority Number (RPN) to rank the failure modes in terms of criticality. $RPN = \text{Severity} \times \text{Occurrence} \times \text{Detectability}$.

The chart in Figure 5 shows the spread of RPN values for all the failure modes. It is a good preliminary check that the values have sufficient range to enable the critical ones to be separated easily from the rest.

Applying thresholds to the FMECA data in the workbooks indicated which of the failure modes are considered critical on that basis. Those were indicated by red highlight coding, making for easy distinction from the others. The supporting software allowed any part of the matrix to be interrogated by a mouse-click, to show which are the specific contributory failure modes.

Many different forms of graphical presentation are based on the Criticality Matrix, which uses Severity and Occurrence as

two of the parameters. For example, Figure 6 uses colour-coding to highlight failure modes of most concern, and Figure 7 uses a 3-D view with coloured ellipses for emphasis, which can be helpful in understanding the distribution of failure modes in the Criticality Matrix.

Comparing various derivatives of these 3-D plots, with and without the Detectability parameter, gives useful insight into the influence of current means of detecting and preventing potential failures.

Analysis of the FMECA data using this approach indicated >30 failure modes of most concern out of the more than 130 documented for each technology studied.

Summary of Failure Modes of Most Concern

The primary result of the analysis is a prioritized listing of key actions required to address the failure modes of most concern.

Failure modes of most concern in these completion technologies were predominantly focused on the ability to stop the flow of sand into the well. This dominance is not surprising because the consequences of this failure are clearly very serious. Specific measures were identified in several respects -

- sand particle analysis and screen selection;
- draw-down causing flow hotspots;
- gravel pack voids leading to flow hotspots;
- packer integrity;
- shifting profiles;
- relief valves;
- material selection for completion components;
- welding methods;
- debris in the well, or protruding rams;
- buckling loads.

In addition, scaling, waxing and tools left in the wellbore are indicated as potentially serious, having consequences in reducing the volumetric flow through the well and preventing the running of intervention tools.

Lastly, specific aspects of torque monitoring, pressure monitoring, and temperature monitoring were highlighted for special attention.

Most results could be mitigated by the following actions:

- pre-job verification testing;
- component testing assurance;
- front end loading engineering calculation checks;
- quality control of equipment make up and load out;
- operational modifications to best practices;
- fluid QA/QC measures;
- proper communication of requirements.

Delivering Value

The value from these FMECA studies was in the use of rigorous systematic failure mode identification. This process forced the detailed analysis of the design and operational procedures to identify potential failure modes. Identifying and

mitigating these risks prior to field application results in tremendous operational and production cost savings.

The results of the FMECA triggered revisions of the qualification program to include additional quality checks on the fluid design as well as identifying a need for a system integrity test. These tests identified completion design changes which were implemented prior to a field trial.

One surface test, dictated by the FMECA and operator qualification process, revealed a shortcoming in the design that could have been disastrous in the field. This resulted in a fluids program redesign and changes to the operational limits and procedures

Conclusions and Recommendations

The FMECAs performed on each completion system were a value-adding exercise to identify critical failure modes during the installation, execution and production phases of the technology application.

The spread of RPN (Risk Priority Number) values in the FMECA data highlighted the critical failure modes and critical actions were documented and implemented. This process most definitely mitigated the majority of the perceived risks.

While attempting to identify and mitigate all potential failure modes, it is extremely difficult to predict every possibility. A rigorous approach produces the best results, but it is still not a guarantee that every possibility will be identified. This is especially the case with new technology when there is little or no experience in actual downhole operation and the saying “what you don’t know, you don’t know” should be borne in mind.

The main value of a FMECA analysis is increasing the efficiency of technology development. Identifying issues upfront decreases the development time by decreasing the number of field trials prior to application. Through a rigorous qualification program and capturing learnings from field trials, technology can be developed more quickly, delivering the benefit to the industry more rapidly.

Reducing the number of redesigns and costly surface tests and field trial iterations is a powerful incentive to utilize a rigorous qualification program. A FMECA program is a powerful learning tool for technology development.

When comparing economics of an effective qualification program to potential problems during installation, the value is clear. The cost requirement of each stage of qualification increases dramatically, from FMECA to prototype design reviews to system integrity stack-up tests and then to field trials. Adding efficiency into this process is key.

The FMECA process is now a standard piece of the operator’s qualification program and a best practice for reliability and new technology assurance.

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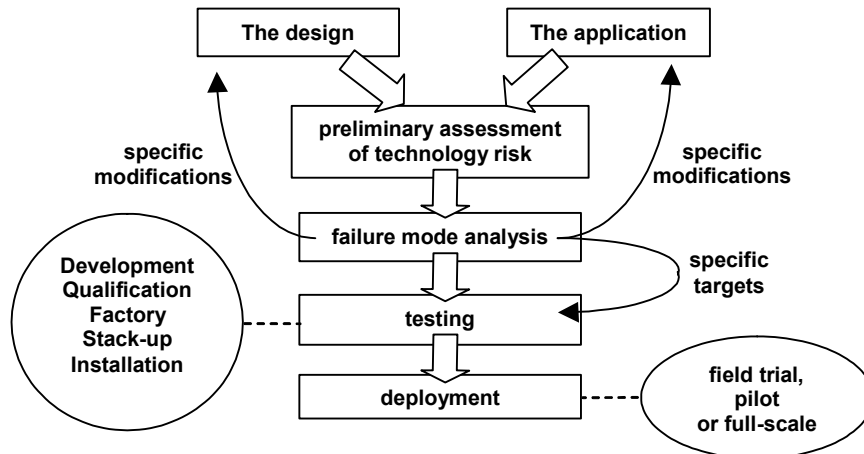


Figure 1 – Qualification Process (Simplified)

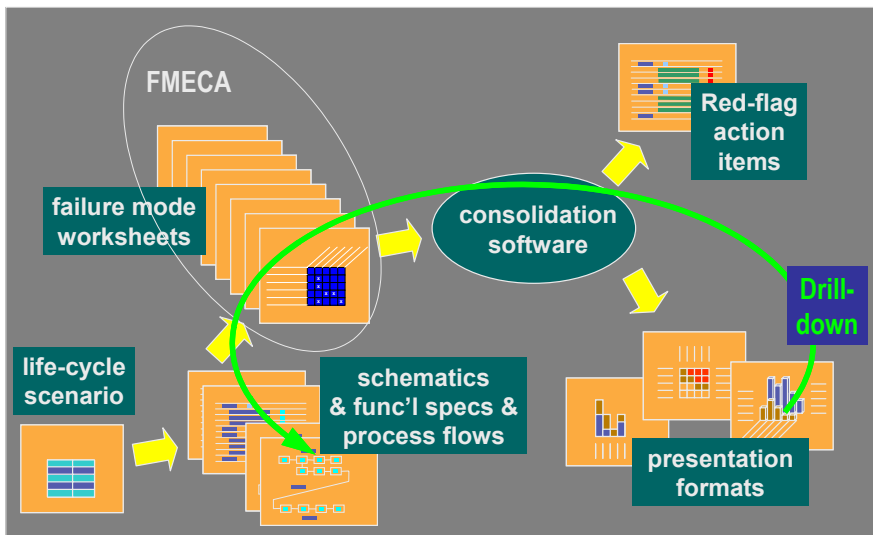


Figure 2 – Systematic Approach for FMECA

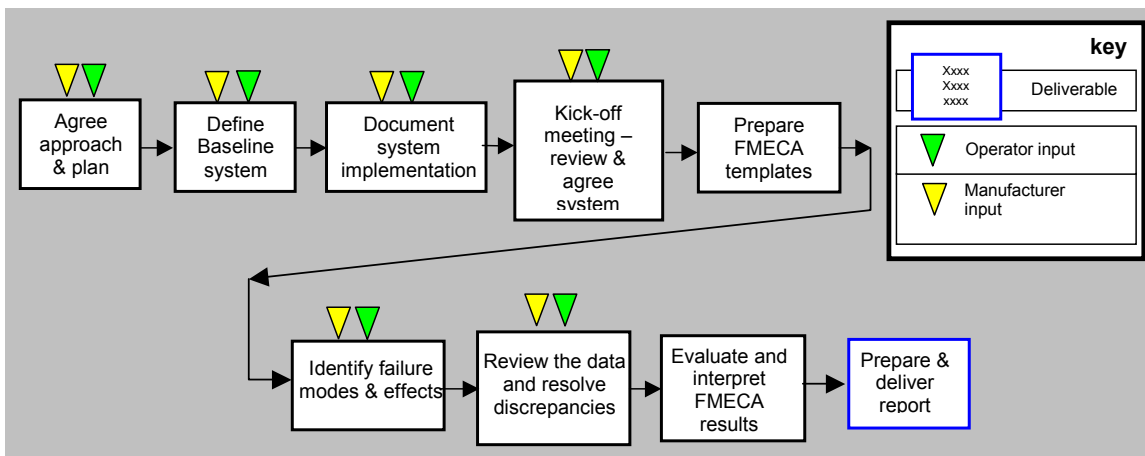


Figure 3 – Project Logic

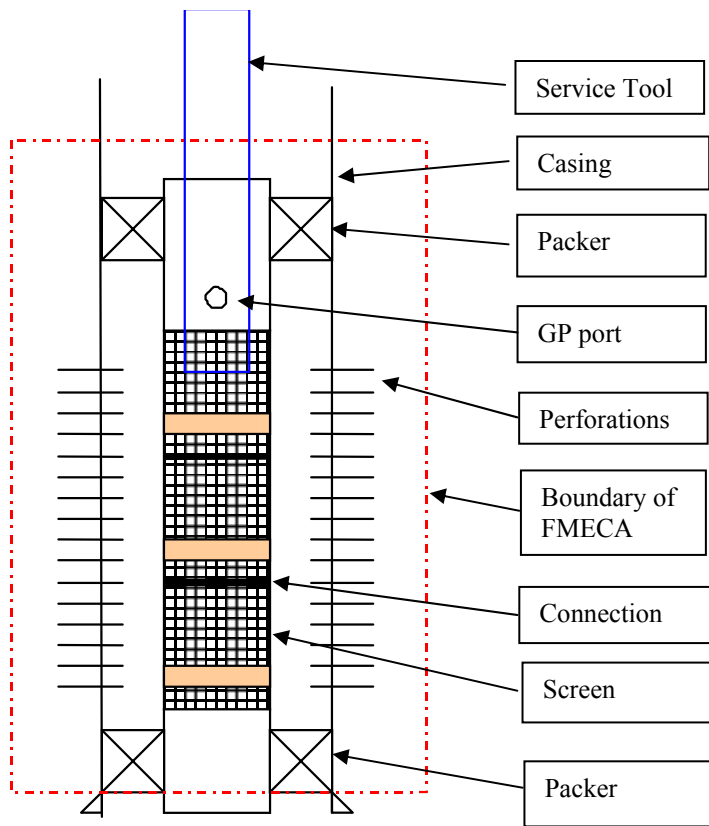


Figure 4 – Example System Block Diagram.

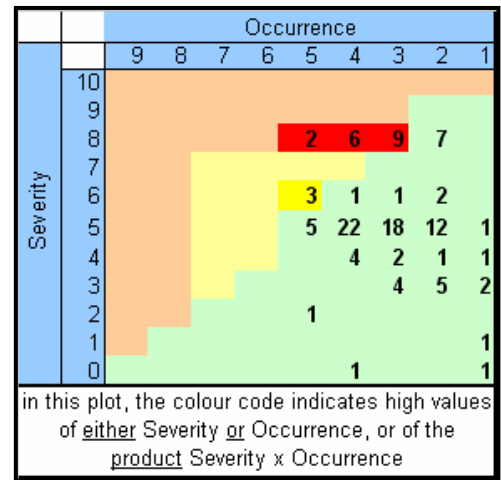


Figure 6 – Criticality Matrix Chart

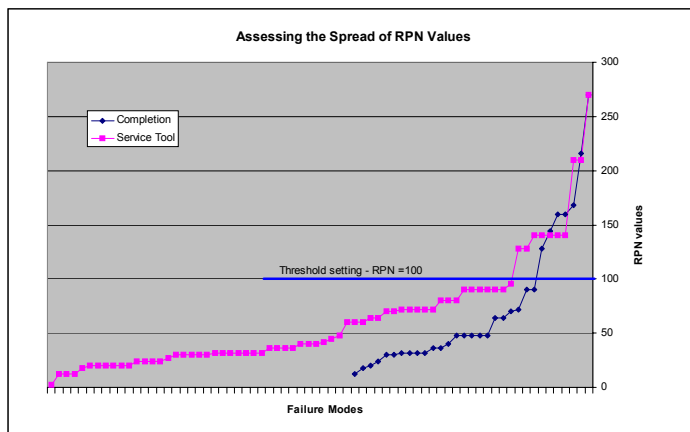


Figure 5 – Assessing Spread of RPN Values

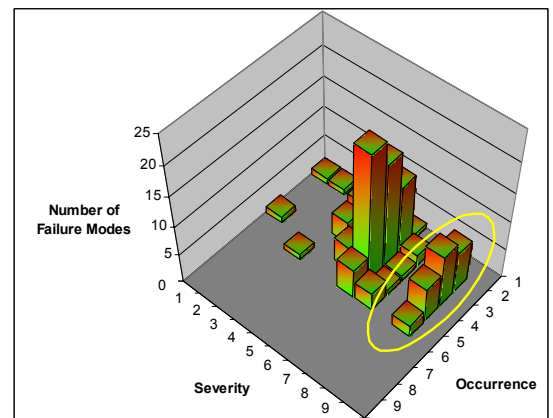


Figure 7 – 3D Plot of Criticality Matrix