<u>Process FMEA: Preventive Risk Measures for Offshore Wind Farm Projects</u>

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Summary

This concept study describes the design of a Process Failure Mode and Effects Analysis (P-FMEA) in order to promote the preventive quality and risk management for offshore wind farm projects. The design follows the special demands of the client’s project management.
To support the input, processing, analysis, documentation, and presentation of all data, a macro-based spreadsheet application was developed (FMEA-tool). The results are suitable for further processing by technical and commercial risk control.

1 Project Related Risk Management

Several project developers have already gained extensive experience with the installation of offshore wind farms and have been faced with a significant amount of major failures in various contract packages.
One lesson learned by the project companies is to go for a higher vertical integration of risk tracing. Even if certain risks are contractually shifted onto contractors, liability limitations usually do not allow the full recovery of heavy losses. Moreover, a simple contractual transfer of risks sometimes makes it even harder to intervene, if necessary.
Even first-hand experience with recent failures does not necessarily mean having suitable prevention measures for future incidents in place. Moreover, the next project would most probably employ different contractors and feature new technologies. Even the company's project team might have changed.

Therefore, a systematic and sustainable approach to identify and deal with risks is essential for a company's learning curve and also increases the confidence of the stakeholders in an improved control of project risks.

Such a systematic approach is provided by the Failure Mode and Effects Analysis (FMEA) method. The method was developed by NASA during the Apollo-Project [1]. Other sources trace its origins to the US Armed Forces [2]. Nowadays, several FMEA types are well established within the aviation, automotive, and other industries.

Experience demonstrates that initial project planning consists of hundreds of processes which subsequently diversify into thousands of sub-processes. As a consequence, a macro-based spreadsheet application has been developed (FMEA-tool) to guide the FMEA team through a structured process in order to deal with such a large quantity of data.

2 The FMEA Concept

There are various FMEA-types to choose from on a case by case basis. Any decision about the FMEA-type and its design is driven by various aspects, e.g. the subject matter and purpose of the FMEA, the actual project phase, the required vertical integration, and the purchasing strategy (e.g. multi-contracting).

Here, a modified Process FMEA (P-FMEA) was chosen to improve preventive risk management at an early project stage. The basic approach (Fig. 1) originates from common FMEA concepts as described in PFEUFER [1].

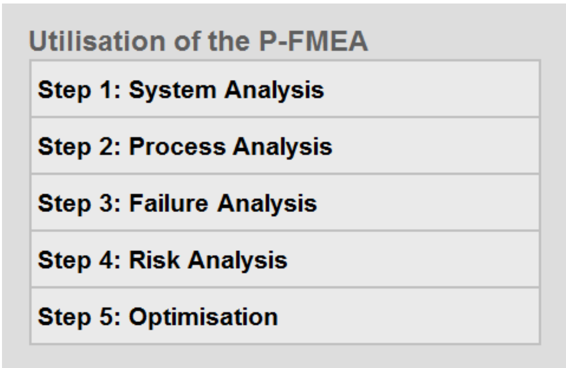

Fig. 1: Utilisation of the P-FMEA

2.1 The Right Time to Start

At each project phase, the client’s options to affect the quality of the purchased products and services are different. This is also highly dependent on the individual contracting strategy. In particular, an obligation to comply with a mandatory tender procedure requires an early determination of quality and risk related commitments – even before the contractors are designated.

Therefore, the FMEA should be set-up at an early stage of the front-end engineering to enable the transfer of results into the client’s invitation to tender (ITT) and into the supply contracts.
However, an FMEA is not a single event in the course of a project but is recommended to be rerun on several occasions. Thereby, the scope, the objective, and the level of detail, may vary.

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2.2 The FMEA Tool

The FMEA-tool documents the entire FMEA process, executes all basic calculations, verifies data consistency, and provides quick-evaluations in the table headers. The tool facilitates the tracking of agreed actions and preserves the full data set for any subsequent FMEA. The modular set-up reflects and interconnects all main elements of the P-FMEA concept (Fig. 2). The tool also supports a System FMEA and provides the respective interfaces.

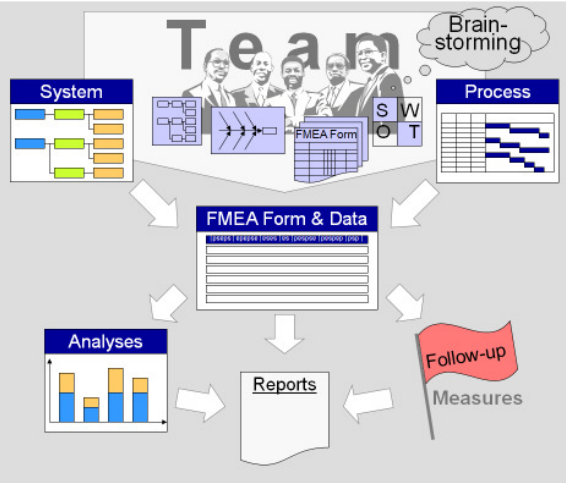

Fig. 2: The FMEA-tool corresponds to the elements of the P-FMEA concept

The utilisation of a common macro-based spreadsheet application (here MS-Excel©) enables data exchange with commonly used software (e.g. MS Project©). Furthermore, it promotes user acceptance and facilitates individual adaptations and analyses.
For example, risk-shifting between internal and external process owners (e.g. contractors) is an essential aspect of any contracting strategy. However, potential high risk accumulation at a single sub-contractor is critical and can be disclosed by simple tool routines. Furthermore, a cost comparison of potential losses versus respective rectification costs is practicable.

For the illustrations, an English data set is used by way of example and is included purely for illustration purposes.

3 Operating the P-FMEA

As well as a suitable FMEA concept, the implementation of the method within the organisation is a critical success factor. An FMEA expert or a respective training programme for FMEA is crucial. A gradual implementation is briefly summarized in the following:

- Assure the support of the top management and the provision of proper resources, in particular, the involved experts
- Define objectives and system boundaries
- Schedule the FMEA concept
- Arrange expert workshop(s) for analysis and optimisation measures
- Follow-up assigned tasks and measures
- Review and improve the FMEA concept for further reruns

The responsible process owner plans the FMEA. The preparation includes the definition of the objective and the system boundaries of the FMEA, as well as defining certain basic rules, e.g. to set elements outside the defined system boundaries as failure-free.

A central feature of an FMEA is the expert workshop, where the system, processes, functions and potential malfunctions are analysed and preventive measures and other optimisations are developed. The cross-functional and interdisciplinary expert team does not only consist of technical experts. For example, legal experts contribute valuable input for measures on a contractual basis.
At the workshop, common management methods are used, e.g. SWOT analyses, cause-effect diagrams, and brainstorming techniques.

In preparation for the workshop, it is helpful to develop preliminary system and process descriptions. Depending on the current project phase, there are various input sources to take advantage of, e.g. field reports, project schedules, interface registers, method statements, risk assessments, or shop drawings.

3.1 The System Analysis (Step 1)

In the course of the system analysis, the complete system (e.g. wind farm) is broken down into sub-systems, which results in a hierarchical tree structure with a distinct defined depth (Fig. 3).

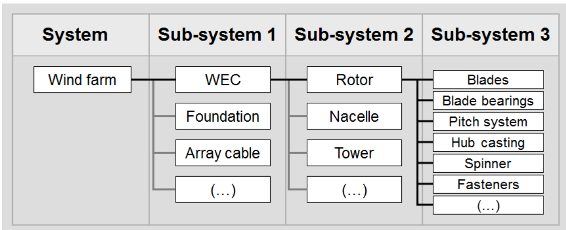

Fig. 3: The System Analysis (exemplified)

The FMEA-tool highlights logical errors within the tree structure during data input. Related background information, e.g. technical drawings, are accessible via hyperlink straight from the desktop (Fig. 4). Further data fields, e.g. the related contracts, are provided for customised analysis at a later stage.
It is obvious that the results of the system analysis are suitable for varifying the scope of supply and to ascertain the respective interfaces. This is of most importance for project owners following a multi-contracting strategy. The same also applies to the following process analysis.

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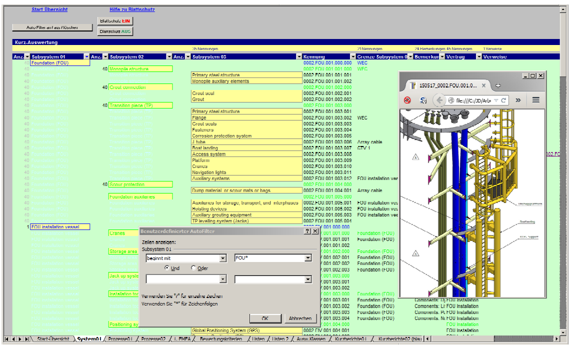

Fig. 4: System Analysis with the FMEA-tool (some fields are hidden to preserve a clear arrangement)

3.2 The Process Analysis (Step 2)

In the course of the process analysis, the main process, e.g. the installation of the wind farm, is broken down into sub-processes. All processes within the system boundaries are described in their chronological and logical sequence. The Gantt chart of the FMEA-tool helps to illustrate the logical structure (Fig. 5).

Itemised process steps, corresponding to level 3 in Fig. 6, will be described and examined in the course of the expert workshop by use of the FMEA Form (see below).

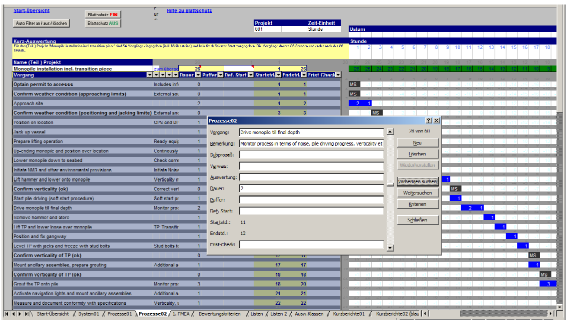

Fig. 5: User interface for the Process Analysis (some fields are hidden to preserve a clear arrangement)

3.3 Process Function and Malfunction Analysis

An intended process output, here referred to as function, needs to be described before a respective malfunction can be derived (Fig. 6).

For structuring the malfunction analysis, the analysis depth and the starting point within a hierarchical malfunction structure has to be defined (compare Fig. 6, bottom lines). In the following considerations, the 'potential failure' is chosen as the starting point. Accordingly, each identified 'potential failure' is assigned to one (or more) subordinate 'potential failure cause' and at least one superordinate 'potential failure effect'.

Process Function and Malfunction Analysis

Analysis level			
Level 0	Level 1	Level 2	Level 3
Example process			
Wind farm installation	Foundation installation	Vertical alignment of TP onto monopile	Adjustment of Transition Piece (TP) with hydraulic jacks before permanent stud bolts are set (followed by grouting)
Function of a process (output)			
• Save installation • Suitable for 25a operation at defined LCOE (levelized cost of energy)	• Inclination of TP and flange within specification • Fit for purpose in due time • Suitable to carry loads for 25a	• Ensure TP and flange inclination within specifi-cations	• Counteract any deviation of monopile verticality • Temporary support the TP in vertical position • Enable to fit stud bolts in right position
Potential Malfunction of the process above			
• CAPEX (Capital expenditure) increase due to delay and/or need for rectification measures • Increase of LCOE	**Early detection:** (before grouting) • Minor delay, repeating vertical alignment of TP **Late detection:** (after grouting) • No suitable foundation for WEC-Tower • No certification • Rectification required	• Tilting of TP • Flange dip out of tolerance	**Malfunction A:** <u>Machine</u>: Error of verticality measuring instrument, e.g. incorrect factory-calibration **Malfunction B:** <u>Human</u>: Incorrect use of instrument or error in reading **Malfunction C:** <u>Environmental</u>: Use of instrument outside of accepted operating conditions (e.g. salty atmosphere) • (...)
Two options to correlate the Malfunction Structure (analysis depth)			
	Potential failure effect	Potential failure	Potential failure cause
Potential failure effect	Potential failure	Potential failure cause	

Fig. 6: Exemplified Function and Malfunction Analysis and the correlation with the Malfunction Structure (WEC: Wind Energy Converter)

3.4 The Risk Priority Number (RPN)

A characterising and challenging part of an FMEA is the utilisation of Risk Priority Numbers (RPN). The RPN scheme was introduced to prioritise intervention measures on a quantitative and comparative basis.

In a nutshell, the traditional RPN of a 'potential failure cause' results from the multiplication of its occurrence probability (P), its detection probability (D), and the severity (S) of the resulting 'potential failure effect'. The descriptive criteria to quantify each of the values P, D, and S on a scale between one (low) and ten (high) have to be individually developed.

Current thinking rightly questions the traditional calculation of the RPN based solely on a simple multiplication of P, D, and S and various alternative methods have been developed [2, 3].

In any case, an improved risk understanding for each single malfunction results from the collective evaluation of the values P, D, and S in the course of the workshop – regardless of which mathematical method is chosen to generate and process them further. However, in the context of this paper there is not enough room to examine this matter in detail.

3.5 The Failure and Risk Analysis (Step 3 & 4)

At the expert workshop, the FMEA Form provides the basis to examine functions, potential malfunctions and to develop preventive measures (Step 5) as well as to quantify risk aspects.

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Upon agreeing on the underlying system and process structure, the experts at the workshop examine each single sub-process with regard to its function (output) and potential malfunctions. Considering the chosen starting point in the malfunction hierarchy above, each identified ‘potential failure’ of a sub-process is assigned to at least one ‘potential failure cause’ and to at least one related ‘potential failure effect’ (see Fig. 6).
Subsequently, the experts estimate and quantify for each ‘potential failure cause’ the related P, D, and S values within the defined boundaries (e.g. for D: Before leaving the offshore site).

The previous course of action reproduces the ‘status quo’ (or ‘actual status’) of project planning. The above generated values P, D, and S, together with the resulting RPN can be used for prioritising the optimisation demand for each sub-process.

3.6 The Optimisation (Step 5)

As part of the optimisation process, the expert-team develops detection, mitigation or corrective measures. The previous values P, D, and S may already indicate an optimisation strategy to improve the status quo. For example, a very low detection probability (D) with high P and S values may indicate the need for improved quality control from the client with regard to the particular process step.
The values P, D, and S of each improved process design become re-quantified. Thereby, a comparison of the former and the improved process design is possible. The FMEA Form of the tool instantly provides an overview of the actual status and of the optimised planning (target status) (Fig. 7).

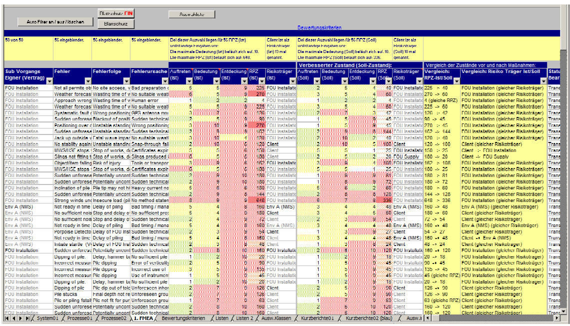

Fig. 7: User interface for the FMEA Form (most columns are hidden)

Each developed improvement becomes transformed into a precise task with a set deadline and an appointed task holder. The new risk values above and the resulting RPN help to prioritise the task’s urgency.

At the front-end engineering phase, the developed technical optimisations are most likely reflected in the technical requirements of the client’s ITT. However, from the client’s perspective, there is also a broad range of contractual leverages apparent. The concept provides a comprehensive picture of the processes and respective risks as a basis for designing a well matched contractual risk diversification.

4 Further Evaluations

Aside from the already implemented filter, analysis, and illustration features, the use of a spreadsheet based tool allows for a wide range of subsequent analyses and illustrations. However, this should not lead to an overestimation of the quantitative values, in particular with regard to the RPN as a stand-alone expression of risk evaluation.

5 Results

The proposed P-FMEA concept is a capable method to identify risks, to improve failure detection, and to develop preventive measures. This results in an overall optimisation of the project planning.
The concept is also recommended to improve the general risk awareness of the team as well as to clarify internal and external responsibilities and interfaces.

6 References

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