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IDENTIFYING FLEXIBLE DESIGN OPPORTUNITIES: GETTING FROM A PROCEDURAL TO AN EXECUTION MODEL

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Abstract

An offshore drilling rig faces continuous need for upgrades especially due to significant uncertainty in all phases of the lifecycle. As in other application fields, rigid design usually prevails, thus leading to value losses that could have been avoided by flexible design. This research focuses on supporting system suppliers to identify and offer customer relevant and effective flexible design concepts. Based on a procedural model for identifying Flexible Design Opportunities (FDOs), it suggests how to use and embed industry specific knowledge in an execution model for application in tender projects.

This paper describes the different types of models required for supporting the identification of FDOs. It provides details on the interview procedure for data acquisition and suggests a mapping and processing of the elicited data in a dedicated model. This model supports generating classes of objects which facilitate the set-up, management and maintenance of the execution model. The paper indicates which parts of the procedure are generally applicable in related industries, and which require the integration of industry specific data.

Keywords: Flexibility, Flexible Design Opportunities, Uncertainty, Conceptual design, Decision making

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1 INTRODUCTION AND GOAL OF RESEARCH

The offshore drilling industry faces significant uncertainty over its lifecycle regarding the future use context, legal context and technology when drilling systems are conceptualized and offered to customers. Wear and tear and deliveries of deficient or malfunctioning systems are further potential causes for rig and system upgrades. So far those change drivers are rarely accounted for during systems design (Allaverdi et al. 2013) as, most often, the selling price of those drilling systems is the ultimate decision criteria. As a consequence upgrades are usually performed in operational phases at very high costs or are even deferred due those high costs. Minor and absolutely required changes are usually performed during planned overhauls of those rigs but lack larger changes on the rig that would actually be required.

The integration of flexible design into the drilling system to enable future rig users with more value across their lifecycle requires proactive offers of drilling system suppliers beyond the mostly deterministic technical specifications formulated by customers. As tender phases are usually very short, creating strong time pressure, engineers must be able to identify effective solutions at a reasonable time. Hence, it is crucial that engineers are supported in the process of determining and narrowing the number of technically reasonable and customer relevant Flexible Design Opportunities (FDOs) which represent physical components enabling flexibility in the system (Cardin and De Neufville 2008). Generating flexibility in engineering systems is challenging and requires guidance (De Neufville and Scholtes 2011). However, current procedures focus mainly on particular aspects for identifying the right flexibility (e.g. uncertainty recognition), however, lack a consolidated framework that guides users through the different phases to ensure quality outcomes (Cardin 2013, Allaverdi et al. 2014).

This paper is based on a previously introduced procedural model (Allaverdi et al. 2014) which is to support the efficient identification of customer-relevant and technically effective FDOs. This paper suggests that the use of such a procedural model should account for industry-specific data and predetermined classes of objects in the drilling system so that technically feasible and effective flexible design concepts can be identified at more ease. This paper describes the theoretical application of those classes, discusses the approach of data acquisition in detail and suggests a mapping, processing, verification and future analysis of the attained results. The actual results from those interviews, the data analysis and the use in an execution model is not the focus of this paper and subject to future publication.

2 MODELS SUPPORTING IDENTIFICATION OF FDOS

In Allaverdi et. al. (2014) a procedural model for identifying FDOs has been suggested that bases on a taxonomy of procedures to support the design of engineering systems for flexibility (Cardin 2013). The focus lies upon identifying FDOs by applying technical and market criteria for ensuring the relevancy of those solutions. The FDO Procedural Model consists of the following steps:

1. Identification of baseline design: In this step a set of existing drilling systems embedded into a previously delivered rig is selected that fits best to the articulated requirements of the customer. Engineers then usually adapt the baseline design to fully meet the customer requirements. In the context of flexible design, the baseline design also represents the reference basis and starting point for identifying FDOs in the system.
2. Change source recognition: This step identifies the factors for the potential change of objects embodied by change drivers and related system requirements. Change drivers are specific underlying causes (root causes) that lead to other causes and, potentially, to a target deviation (change trigger) of the actual state from a nominal state (Chucholowski et al. 2013). In this context all causes are related to as change drivers. As those change drivers go beyond sole "uncertainty recognition" presented in Allaverdi et. al. (2014), this step has been broadened to include also other change drivers. They can either be initiated from outside the product or emergent from the product (Eckert et al. 2004). In the drilling industry, the former are mainly related to uncertainties and changes of use context, legal context and technology whereas the latter are mostly related to deficient, malfunctioning systems or a deterioration of systems due to wear and tear. Those change drivers affect certain system requirements leading to target deviations of influenced drilling systems (change trigger).
3. Screening for change objects: Objects directly affected by the drilling system are mostly drilling equipment such as cranes, drilling machines, compensation systems. They can also be referred to

as "change objects" (Wiendahl et al. 2007, Hernández 2003). They are potential candidates to embed flexibility which must be identified in the baseline design. Change objects may also include indirectly affected objects of the drilling system due to change propagation comprising drilling equipment but also other constituents such as engineering structures, hydraulic piping or electrical cabling.

4. Identification of suitable transitions: Passive means, i.e. robust design, or transitions of change objects are required to handle any violated requirements. Latter can also be referred to as "upgrades" (Mateika 2005). They represent change strategies such as entire/partial replacements, relocations, extensions or reductions of systems (Trigeorgis 1996, Ross et al. 2008).
5. Identification of suitable change enablers: Transitions of change objects should be facilitated by appropriate change enablers that can be embedded within or outside of change objects. They are accounted for in advance to ease transitions once they are required in operational phases of the drilling rig. Change enablers might require other enablers as a prerequisite (Hernández 2003).

Figure 1 represents the FDO Procedural Model and the other models required for supporting the identification of FDOs. Although the FDO Procedural Model is motivated from the circumstances in the offshore drilling industry, it is considered to be equally employable to other fields of application. It represents the basis for the FDO Data Matrix where data elicited from expert interviews is mapped into, followed by being processed and verified. The results are then embedded into the FDO Execution Model which, again, builds upon the FDO Procedural Model. The FDO Execution Model represents the application model that is realized in a tool to be used by engineers during competitive tenders in order to support the identification of FDOs. In contrast to the generic FDO Procedural Model, the data from the FDO Data Matrix is considered to be application specific as boundary conditions differ strongly across application fields. This also applies to the FDO Execution Model which is filled with industry specific information and, hence, supports the identification of FDOs for drilling systems in this particular application context. The FDO Execution Model is not further elaborated on in this paper but only referred to.

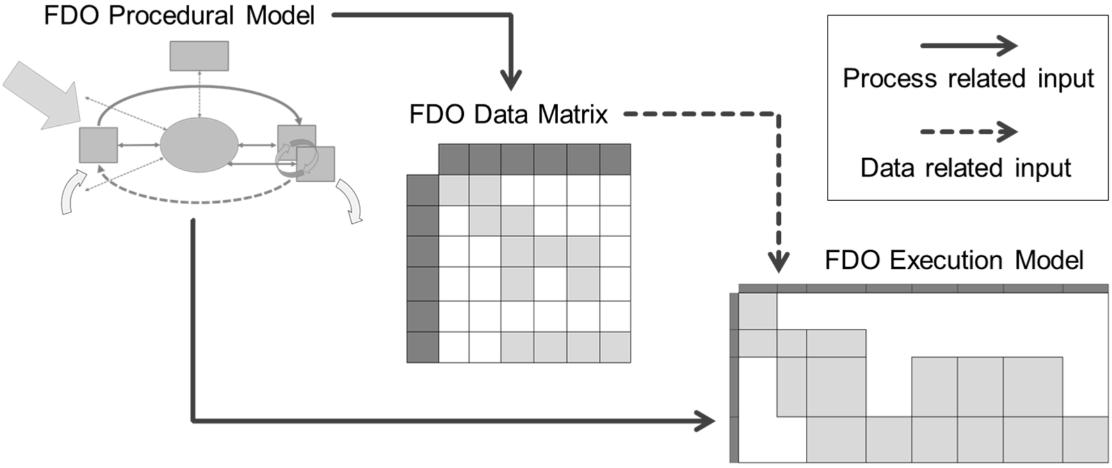


Figure 1. Models supporting the identification of FDOs

In order to support engineers with the identification of technically effective FDOs, the suggested FDO Procedural Model accounts for both market consistencies, i.e. the external alignment of FDO selections with customer preferences (Allaverdi et al. 2014), and technical consistencies, i.e. the internal alignment of selections made across the FDO procedure. Latter is regarded to be a prerequisite as technically infeasible or ineffective solutions are of no interest to any customers despite varying preferences. In order to guarantee that technical consistency is met effectively in the FDO Execution Model, the use of "object classes" is presented in the following before the meta-model of the FDO Data Matrix is introduced.

3 TECHNICAL CONSISTENCY OF FDOS

3.1 Technical consistency and the application of object classes

The FDO Execution Model requires knowledge on the industry specific technical factors and their relations to be of use for their users. The relevance of specific technical factors (e.g. change enablers such as bolts, reserved space, lifting lugs on equipment) depends on previously determined relevant technical factors (e.g. objects such as pipehandling cranes, tubular feeding machines) of other domains. Hence, the FDO Execution Model should account for this "fit" of technical factors across domains to support identifying technically effective flexible solutions. Although the individual relations are considered to be generic, they are often only "potential" relations as the actual validity might depend on other factors such as individual customer preferences (e.g. customer disagrees with adding lifting lugs), degrees of freedom (e.g. customer is not in charge of accounting for additional space on rig) or the system architecture of the baseline design (e.g. layout on rig restricts reserving additional space). Naturally this must be accounted for when applying the FDO Execution Model.
In addition to the technical consistency across domains, it could be observed that certain types of objects are affected by the same system requirements or that they require identical change enablers. This motivates generating classes of objects, where classes describe concepts in the domain (Noy and McGuinness 2001). The similar fit of objects to certain system requirements or change enablers might be based on certain criteria (e.g. similar function, physical structure). The FDO Execution Model would strongly profit from those "object classes" as they strongly reduce the efforts and thresholds of building up the initial model while easing its management and maintenance. For instance, adding new objects to the model is simplified if suitable object classes already exist that the new object can be assigned to. Figure 2 illustrates the general process of applying object classes in the FDO Execution Model to identify technically consistent solutions for new customer inquiries.

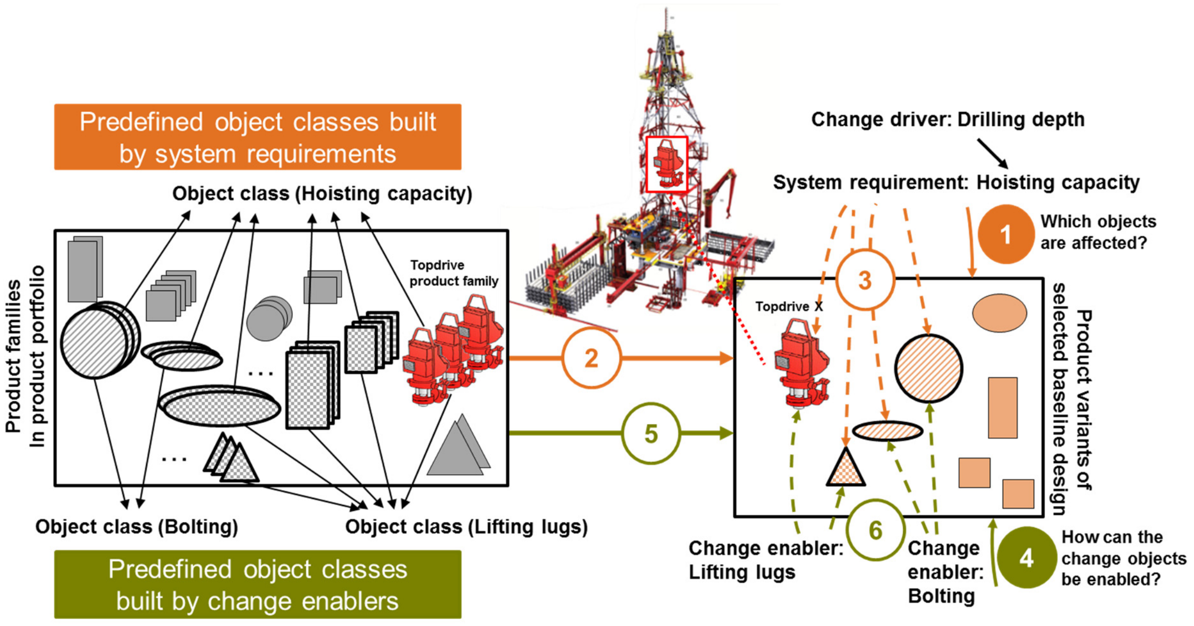


Figure 2. Predefined object classes (left) and selection of specific product variants (right)

As a prerequisite and starting point, an appropriate baseline design has to be identified that sufficiently meets the initial requirements of the customer. The baseline design includes information on the selected hull, drilling systems and their layout, i.e. their configuration on the rig. Based upon a change driver that is likely to occur in the future (e.g. significant increase in drilling depth requiring longer drillstring) being articulated or implicitly derived from the customer, system requirement "hoisting capacity" is affected (Figure 2, right top). Objects that have to fulfil this requirement are potentially affected in the future and, consequently, might require to be prepared for. Hence, initially the engineers must identify which objects of the selected baseline design are actually affected and relevant to consider ("1").

Independently of this particular project and baseline design it is known that only certain objects are actually affected by "hoisting capacity". They were grouped previously to so-called "object classes" (Figure 2, left top), representing product families that are all affected by "hoisting capacity". For instance, the product family of topdrives, devices rotating the drillstring and usually suspended from the derrick of the rig, is potentially affected. By using this knowledge ("2"), the baseline design is now screened for variants of the affected product families (Figure 2, right). In case the influence leads to a non-fulfilment of requirements of the objects which would represent a "change trigger", those variants are considered to be "change objects" ("3"). For instance, the topdrive variant of the baseline design might have insufficient hoisting capacity. Consequently it would be affected and therefore represent a "change object".

Now change enablers for the identified change objects have to be determined ("4") to reduce or even avoid the effort of a transition. Similar to before, classes of objects have been predefined that all require the same change enablers (Figure 2, left bottom). As the suitability of those change enablers also depends on the transition itself (Cardin 2013), feasible and relevant transitions for each change object must be known at this stage (e.g. entire replacement) to only select relevant change enablers in the object class. For instance, the product family of topdrives belongs to an object class that can integrate "lifting lugs" for easing a replacement. Another product family (e.g. drawworks) might belong to an object class that suggests "bolting" (instead of welding) as a joining technique to ease a replacement. Based on the known object classes, the knowledge can be applied ("5") by selecting change enablers that are suitable for the affected variants in the baseline design ("6").

Naturally, the generation of object classes is strongly simplified as they will not be referring to only one system requirement or change enabler but to a group based on certain commonalities (e.g. functions, structure). This is not visualized in Figure 2.

Literature mostly provides only high level principles and categories related to the technical factors in the different domains such as by Eckert et al. (2009) and Klemke (2014) related to change drivers and triggers or Hernández (2003), Fricke and Schulz (2005), Mikaelian et al. (2011) related to change enablers and transitions. As argued by Cardin (2013), change enablers can take a different form in each type of system being similarly valid for the other relevant domains. Hence, the empirical data must be derived from the field of application where it is to be applied. As a result the technical factors and their relations are identified bottom-up for offshore drilling systems and are then confronted with existing factors, categories and principles in literature.

As knowledge within the addressed domains is mostly tacit, interviewing experts has been considered most appropriate to elicit that knowledge. In the following a meta-model for the "FDO Data Matrix" is introduced that is used to map and process the data from interviews.

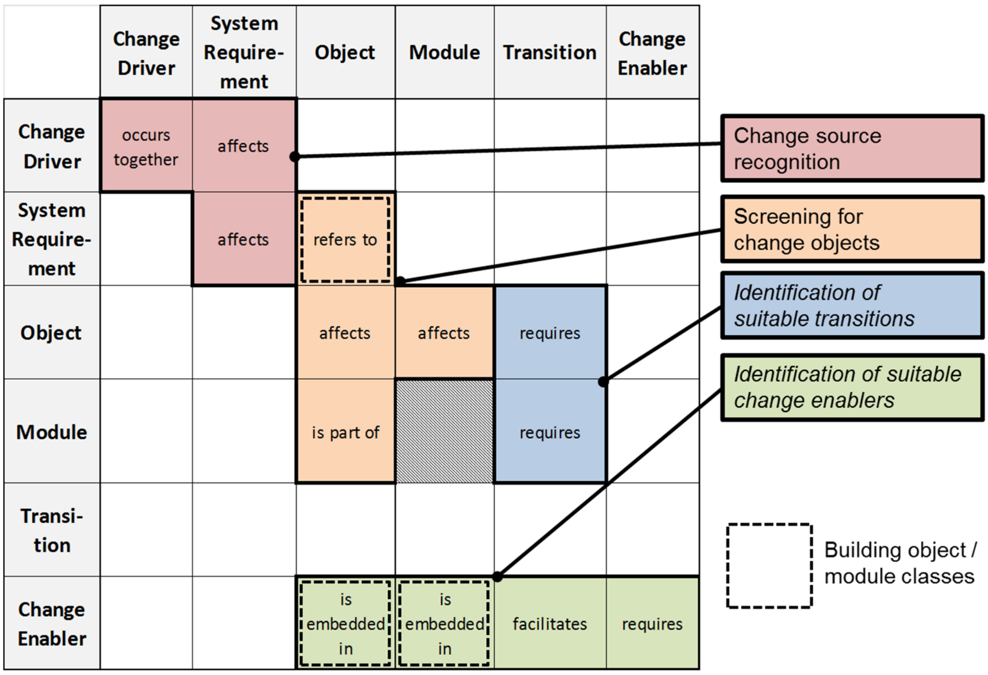
3.2 Meta-model of FDO Data Matrix

The Multiple-Domain Matrix (MDM) is a square matrix containing different types of elements (here: technical factors) which are grouped into domains (Lindemann et al. 2009) containing both DSMs (Design Structure Matrix) relating identical domains and DMMs (Domain Mapping Matrix) relating different domains. In this context it is used to transform the results from interviews into a condensed form allowing further processing, verification and analysis. The model (Figure 3) has not been used for information acquisition directly and has been adapted iteratively with the increased understanding from the interviews.

Figure 3 depicts the relevant domains and dependency types:

- Change source recognition: The "change drivers" and "system requirements" are part of this step. As change drivers usually do not occur isolated, the Change Driver DSM depicts which change drivers occur simultaneously. For instance, the occurrence of change drivers in the categories "wear and tear" could be accompanied by change drivers from other categories such as "technical obsolescence" or "rules and regulations". The causal relationships across change drivers might be relevant for the FDO Execution Model but had not been in the focus of the interviews, hence, are not explicitly represented in the meta-model by another dependency type. The DMM illustrates which change drivers affect which type of requirements; for instance, a "rig move" (change driver) could result in "increased drilling depth" (change driver) which would affect the "hoisting capacity" (system requirement) on the drilling rig. The last DSM in this step maps which functional system requirements on the rig affect each other. For instance, a change in "hoisting capacity" might affect the "power capacity" on the rig. In this example this could trigger changes of further objects such as the "diesel generator" that would not have been identified by "hoisting capacity" alone.

- Screening for change objects: It includes the domains "system requirement", "object" and "module". System requirements always refer to certain objects; in case the predefined change drivers affect certain system requirements, objects might require a change. Then those objects would represent "change objects". For instance, a change of the requirement "hoisting capacity" could mean that the "drawworks", mainly responsible for lifting and lowering the entire drill-string, would require a change. This DMM is subject to the introduced object classes built by system requirements. Depending on the transition, change objects very often affect other objects or modules (e.g. other drilling equipment, engineering structures, piping, and electrical cabling) and, hence, represent indirectly affected change objects. Modules, which are "part of" objects (e.g. "server" of the product family "CCTV system"), are especially relevant when partial upgrades of change objects occur (e.g. partial replacement, extension). Change propagations across modules are not further considered.
- Identification of suitable transitions: The identified change objects and modules, both being directly or indirectly affected, require certain transitions to re-fulfil violated requirements being represented by two DMMs. Transitions could mean a replacement, relocation, extension, etc. of change objects.
- Identification of suitable change enablers: Change enablers (e.g. "additional space around change object", pre-installation of "lifting lugs", "compact design") facilitate only certain transitions (DMM). Change enablers can be embedded in change objects or specific modules of the object. Both DMMs are the basis for building "classes". As change enablers often require other enablers as a prerequisite (e.g. pre-installation of "lifting lugs" requires "space above" for removal), this is represented in a DSM.



	Change Driver	System Require-ment	Object	Module	Transition	Change Enabler
Change Driver	occurs together	affects				
System Require-ment		affects	refers to			
Object			affects	affects	requires	
Module			is part of	▨	requires	
Transi-tion						
Change Enabler			is embedded in	is embedded in	facilitates	requires

Figure 3. Meta-model of FDO Data Matrix

The next section presents the approach on eliciting those technical factors and relations by interviews.

4 DATA ACQUISITION APPROACH

4.1 Classification of interview series

Based upon Summers and Eckert (2013), the interview has been classified to reason the research method, give details on the interview participants and the process (Table 1). Interviewing is regarded especially useful for understanding complex systems that are not easy to simulate or that include many different stakeholders, actors, and systems (Summers and Eckert 2013) like in the drilling industry (Allaverdi et al. 2013).

Table 1. Classification of expert interviews

Interviewing as a research method	
Purpose of research study	Understanding
Purpose of interview	Core
Additional methods	Document analysis
	Modeling
	Formal/informal interviews
Context of study	Oil & Gas
	Complex systems

Interview participants	
Organization	- 1 company: Topside drilling system supplier (Oil & Gas) - multiple production units covering product portfolio
Interviewee	- approx. 20 experts on Lifecycle Engineering - individual interviews
Relationship between interviewer and interviewee	Interviewee employed in organization
Interviewer	single interviewer

Interview process data	
Interview	on-site at corresponding production unit
Type of interview	- semi-structured - based on specific cases (past, present) - close precious, prompting
Supplemental material	- introductory presentation to research / educational training - audio recording - interview worksheet (content immediately verified during note taking)
Duration interview	- 2,0 - 3,0 hrs/session (effective) - 35 sessions - duration depending on complexity, scope and knowledge of interviewees on the addressed mini case

The main purpose of running those interviews has been to seek understanding of phenomena related to relevant technical factors and the relations amongst them. In order to attain rigorous information, a horizontal study was conducted by focusing on different and relevant product families that were discussed on specific present and past upgrade projects. The combination of a selected product family and an upgrade project is here referred to as a "mini case". As "mini cases" varied, this resulted in various stories with communalities and differences amongst them.

The interview is considered to be the core research method although other approaches such as informal interviews, project documentation and modeling have been regarded as crucial supplementary methods during the interview process, post-processing and post-analysis. After having had run a few pilot interviews in the early phases, questions were removed, combined or changed in order to improve the execution of the interviews and increase the quality of the results. A series of interviews was held at different production units of the investigated drilling system supplier as each site has its own product lines contributing to the entire product portfolio. Experts on Lifecycle Engineering (LCE) were interviewed that are both responsible for product families at the particular production unit while having expertise and knowledge on specific and critical upgrade projects in the past and present.

Depending on the product, project knowledge, scope of responsibility and current availability, the product responsible or project managers of upgrade projects were also interviewed. Mostly individual interviews were performed to receive a profound insight into the investigated "mini cases" and due to practical reasons such as saving resources and avoiding a derailing of discussions which might occur in larger focus groups. The interview had been performed on-site at the corresponding production unit providing direct and flexible access to the interviewees, also in case of follow-up questions. Choosing the interview to be semi-structured allowed flexible and individual clarifications or rephrasing of questions prompting the answers. The questions are considered as “close precious” (Summers and Eckert 2013), focusing on answers on particular facts, individual opinions and assessment. The length of each session deviated within the provided range as complexity, scope related to the upgrade project and investigated change object varied. As knowledge of the interviewees on the addressed "mini case" varied as well, this also strongly contributed to time variation.

4.2 Identification of critical product families

The product families were considered as a starting point in the interviews as in most cases they represent direct change objects (unlike piping, etc.). The product portfolio consists of a very heterogeneous and large set of product families that fulfil different purposes on the topside of the drilling rig. As the interview sessions of each mini case are time consuming, certain product families had to be prioritized. Figure 4 depicts the “Change Object Criticality Portfolio” that was used as a guide for identifying the most relevant change objects. The assessment of product families was performed once or multiple times at each production unit depending on the scope of responsibility of the assessor(s).

Similar to a risk portfolio, the criticality in the “Change Object Criticality Portfolio” could be subdivided into two categories, namely “likelihood of change” and “impact of change”. “Likelihood of change” concerns the frequency and probability of the object to be upgraded in the past and present. This also includes inquiries by customers on upgrades that have even been withdrawn as they equally contribute to criticality. Low values reflect a lower tendency to be upgraded whereas high numbers reflect strong tendencies of product families to be upgraded across the lifecycle. Product families with higher likelihood are more apt to be regarded during interviews as they indicate strong potentials and interest of the company while a large number also indicates that the interviewee can choose from a number of upgrade projects for the “mini case”.

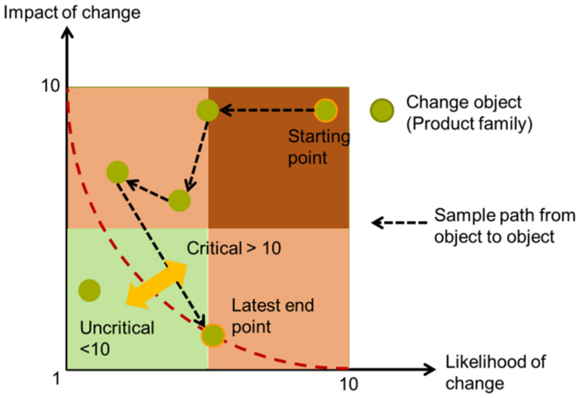


Figure 4. Change Object Criticality Portfolio

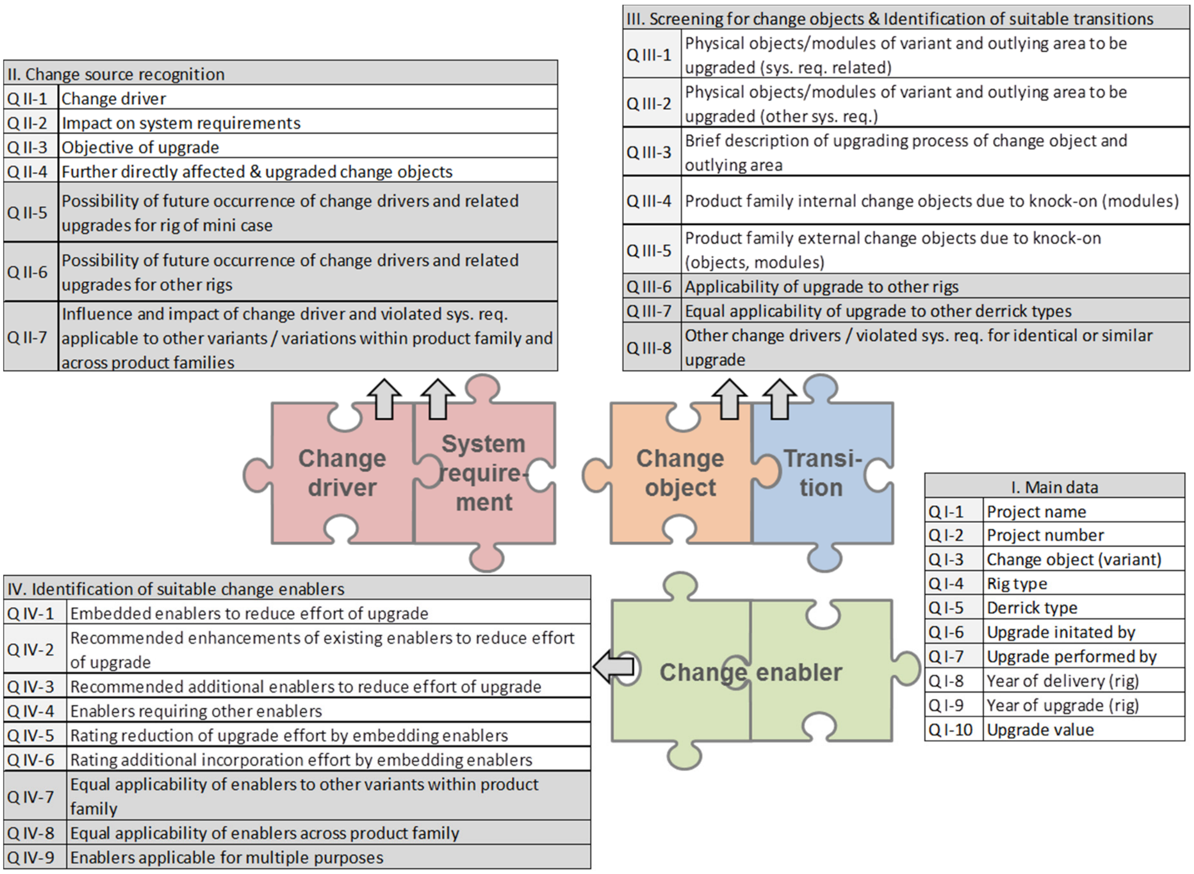
“Impact of change” includes various aspects such as the cost impact of objects (both direct and change propagation) as well as possible disturbances of critical processes that can create downtime. Selecting objects of high impact is preferable as they provide a high potential in savings if change enablers are to be embedded while being usually larger in scale and providing more relevant information for each case. The assessments do not differentiate amongst upgrade projects and therefore only reflect tendencies of product families.

To ease the effort of assessment, the contributing factors of "impact of change" were acquired separately being followed by calculating the total impact. To avoid strong deviations and allowing comparison between the assessments of different product families at different production units and responsibility, interviewees were encouraged to benchmark the assessment of their product families with previously assessed ones. The most critical product families were the starting point of interviews moving to levels of less criticality, i.e. towards hyperboles towards the origin of the portfolio (Figure 4). The process was stopped once objects were reached that were below a certain criticality. The interview procedure was adapted due to practical reasons and to maintain efficiency. Product families that are very similar were often omitted as they implied strong redundancy of information; sometimes product families were omitted due to limited expertise of interviewees on a particular upgrade project or product. Choosing between "Likelihood of change" and "Impact of change" the latter was preferred as it usually entailed highly relevant "mini cases".

The following section depicts the questions of the interview which are based on the FDO Procedural Model and the introduced meta-model of the FDO Data Matrix from Section 3.2.

4.3 Interview questions

Based on the assessed product families, the most critical objects were selected and confronted with a relevant upgrade project. After each session and depending on the novelty, the same product family was confronted with a new upgrade project or an equal or slightly less critical product family was selected. Hence, there was no predefined number of cases for each product family and decision-making was performed after each interview session individually. In line with the FDO Procedural Model and the FDO Data Matrix, the questions and the related main categories are represented in Figure 5.



II. Change source recognition	
Q II-1	Change driver
Q II-2	Impact on system requirements
Q II-3	Objective of upgrade
Q II-4	Further directly affected & upgraded change objects
Q II-5	Possibility of future occurrence of change drivers and related upgrades for rig of mini case
Q II-6	Possibility of future occurrence of change drivers and related upgrades for other rigs
Q II-7	Influence and impact of change driver and violated sys. req. applicable to other variants / variations within product family and across product families

III. Screening for change objects & Identification of suitable transitions	
Q III-1	Physical objects/modules of variant and outlying area to be upgraded (sys. req. related)
Q III-2	Physical objects/modules of variant and outlying area to be upgraded (other sys. req.)
Q III-3	Brief description of upgrading process of change object and outlying area
Q III-4	Product family internal change objects due to knock-on (modules)
Q III-5	Product family external change objects due to knock-on (objects, modules)
Q III-6	Applicability of upgrade to other rigs
Q III-7	Equal applicability of upgrade to other derrick types
Q III-8	Other change drivers / violated sys. req. for identical or similar upgrade

I. Main data	
Q I-1	Project name
Q I-2	Project number
Q I-3	Change object (variant)
Q I-4	Rig type
Q I-5	Derrick type
Q I-6	Upgrade initated by
Q I-7	Upgrade performed by
Q I-8	Year of delivery (rig)
Q I-9	Year of upgrade (rig)
Q I-10	Upgrade value

IV. Identification of suitable change enablers	
Q IV-1	Embedded enablers to reduce effort of upgrade
Q IV-2	Recommended enhancements of existing enablers to reduce effort of upgrade
Q IV-3	Recommended additional enablers to reduce effort of upgrade
Q IV-4	Enablers requiring other enablers
Q IV-5	Rating reduction of upgrade effort by embedding enablers
Q IV-6	Rating additional incorporation effort by embedding enablers
Q IV-7	Equal applicability of enablers to other variants within product family
Q IV-8	Equal applicability of enablers across product family
Q IV-9	Enablers applicable for multiple purposes

Figure 5. Main categories and questions of the interviews

Within each "mini case", questions to the particular upgrade project were asked. Additionally, questions generalizing the statements have been performed to document the relevancy of the upgrade case or identify further applicability of the statements for other cases and circumstances (marked dark grey in Figure 5). Although answers to questions are targeted to be embedded in the FDO Data Matrix, those questions also intend to elicit more background information both as a means to support transforming the data into the matrix but also for relevant insights when applying the FDO Execution Model.

The set of questions was divided into four categories:

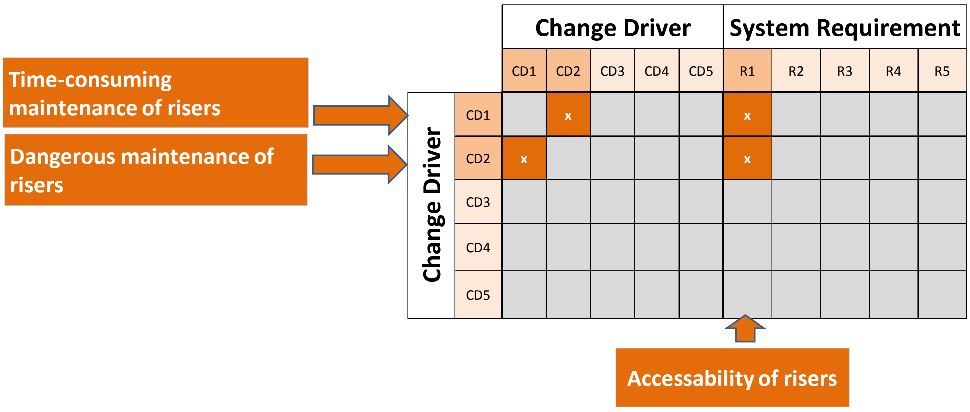
- General questions (Q I-1 - Q I-10): They relate to general information (main data) of the upgrade project. They are especially important for classifying this project, documenting, verifying and following-up on details if more information is required.
- Questions related to change source recognition (QII-1 - QII-7): Those questions relate to the change drivers and relevant system requirements of the drilling system (QII-1 - QII-3). It is also documented if the system requirements also affected other objects in this project which also led to an upgrade. QII-5 and QII-6 relate to the relevancy of the change driver(s) and the upgrade. QII-7 asks about the applicability of change drivers across variants and product families.
- Questions related to change objects and their transitions (QIII-1 - QIII-8): In this phase it was assessed which objects/modules of the affected product family have been upgraded directly (QIII-1) and which ones due to other reasons but in the same run (QIII-2). Describing the main steps of the upgrade for the trigger-related change objects and objects in the outlying area represented a key advantage for both interviewer and interviewees for the next questions regarding indirect impacts (change propagation) and stage IV. Generalization questions referred to the applicability of this upgrade under different boundary conditions and tested the relevancy by asking about other possible reasons for this upgrade than the one being investigated (QIII-8).
- Questions related to change enablers (QIV-1 - QIV-9): QIV-1 - QIV-4 focus on identifying embedded change enablers on the existing rig, suggestions on their improvement or suggestions on completely new solutions. It also asks about further required change enablers for the embedded or suggested ones. Embedded or suggested enablers were assessed qualitatively re-

garding their ability to reduce upgrade efforts and by rating the additional upfront efforts that flexible designs usually entail (QIV-5 - QIV-6). As a means of generalization, the suitability of those enablers for other variants and other product families was elicited (QIV-7 - QIV-8). As change enablers that serve multiple purposes usually increase the frequency of usage and are easier to be offered to potential customers, the interviewees had been asked which of the change enablers are generally also applicable for alternative purposes such as for overhaul, maintenance, etc. (QIV-9).

Although questions are assigned to each of those four categories, some questions represent border cases as they are highly interrelated and would only overwhelm the interviewee if not asked simultaneously (e.g. QII-4). The questions are intended to be asked in this order as answers have often required detailed insights and previous discussions to be able to provide satisfactory responses. The next section describes the mapping and processing of the elicited interview data.

5 MAPPING AND PROCESSING OF INTERVIEW DATA

The elicited data is consolidated after a set of interview sessions. It is intended that each "mini case" is embedded into a single FDO Data Matrix. Figure 6 illustrates the mapping of a data set (Mini case I) into a FDO Data Matrix for the process step "Change source recognition". In this "mini case" the maintenance of risers is to be improved by an upgrade.



		Change Driver					System Requirement				
		CD1	CD2	CD3	CD4	CD5	R1	R2	R3	R4	R5
Change Driver	CD1		x				x				
	CD2	x					x				
	CD3										
	CD4										
	CD5										

Figure 6. Mapped data into FDO Data Matrix for step "change source recognition"

Risers are large diameter pipes that connect the blowout preventer on seabed to a floating rig to take mud returns to the surface. Being disassembled they are stored on a deck where they require regular maintenance. In this "mini case" the maintenance of risers was both "time-consuming" and "dangerous". Access to those risers had to be improved by upgrading a crane and the riser storage area (not illustrated in Figure 6). Similarly to the mapping of the step "change source recognition", the interview data for the remaining steps is mapped into this single FDO Data Matrix.

Once there are more "mini cases" mapped into different single FDO Data Matrices, an aggregation of those matrices to a resulting matrix can be performed allowing an integrated view of both elements and relations. Figure 7 depicts the aggregation of two matrices to a tentative resulting matrix embodied by the introduced "Mini case I" and another "Mini case II". Naturally, the resulting matrix should contain the data of all addressed "mini cases" in the end. Before the analysis and the building of object classes, the resulting matrix requires processing.

The processing of data contains the following steps:

- A systematic and continuous aggregation of redundant technical factors and relations (“1”) and an abstraction of individual technical factors to a suitable level (“2”)
- A systematic extension of new technical factors and fill-in of missing relations ("white fields") based upon other sources (“3”)
- A systematic and continuous verification of aggregated and extended technical factors and dependencies (“4”)

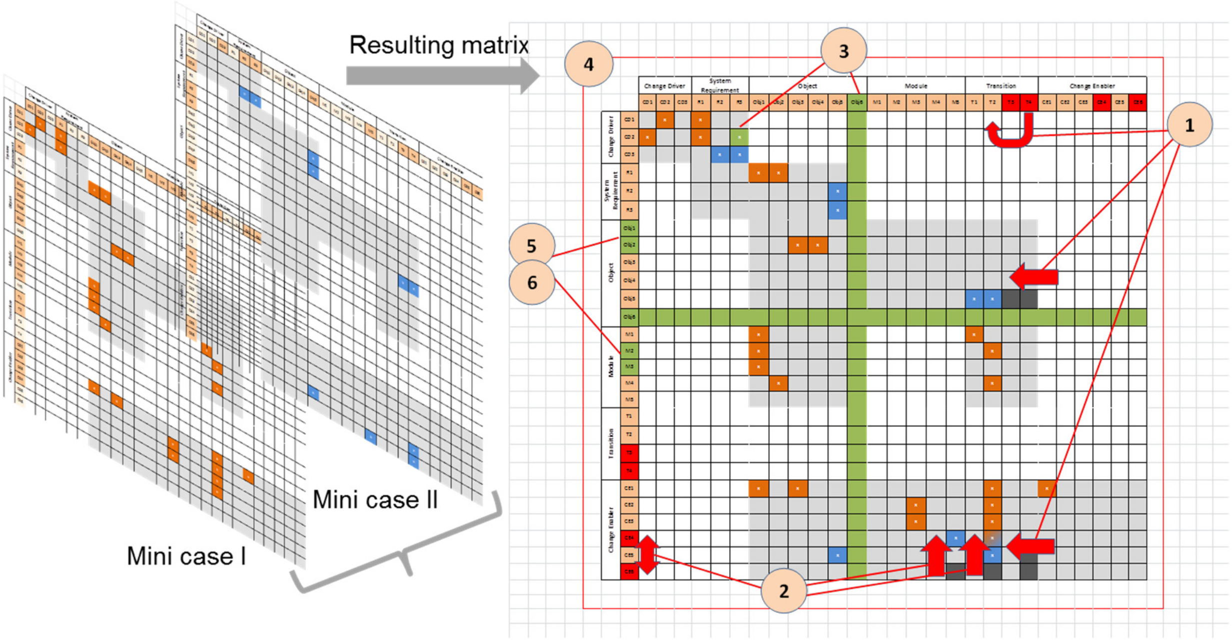


Figure 7. Consolidation of single FDO Data Matrices and aggregation into resulting matrix

Processing step “1” and "2" are preferably performed gradually after each aggregation of a single matrix to avoid extra efforts if postponed to the end. The identification of object classes, both related to system requirements and change enablers, is based on the analysis of commonly affected or enabled objects which are derived from the final resulting matrix. This might stem from a commonality of certain criteria such as functions, structure, geometry, layout and position of objects which can be determined bottom-up from the matrix based on reasoning the cause for the common influence. Hence, for the relevant DMMs (Figure 3), classes are identified and the according classing criteria determined (“5”). For instance, a "class" is based on functional criteria such as "lifting drillstring" representing a class of objects that are all affected by the requirement change of "hoisting capacity" such as the objects "topdrive" or "drawworks".

The classification of objects requires iterations especially between steps (“3”) and (“5”) once classing criteria are known. This strongly supports the identification of new technical factors and relations in step (“3”). A continuous and subsequent verification by domain experts is required to confirm the existence and correctness of the identified object classes (“6”). The results of the verified resulting matrix are then to be integrated into the FDO Execution Model for improved identification of FDOs.

6 SUMMARY AND OUTLOOK

This paper bases on a previously defined procedural model (FDO Procedural Model) to narrow down the solution space gradually and support the drilling system supplier in identifying relevant and effective flexibilities in the system. The introduction of suitable flexibility to the drilling market is to reduce upgrade efforts and also thresholds of system users to perform essential upgrades in the first place.

This paper focuses on the elicitation, mapping and processing of industry specific technical factors and prevalent relations to support the identification of technically effective FDOs in the future. In this context, the build-up of classes of objects is emphasized taking advantage of commonalities of drilling systems to allow the identification of technically effective FDOs with strongly reduced efforts upfront and along.

As the use of the FDO Execution Model is based on industry specific data, semi-structured interviews were performed addressing offshore drilling systems to identify relevant technical factors and their relations. Only critical product families and relevant upgrade projects were selected to provide relevant data from interviews. It is suggested to map this data separately for each case into a dedicated matrix (FDO Data Matrix). As multiple cases ("mini cases") have been addressed in those interviews, many matrices are generated that can then be aggregated gradually to a resulting matrix. This, in turn, is considered to be the starting point for further processing, verification and, finally, analysis of the data and generation of object classes.

The generation of object classes is ongoing and will require industrial verification. At the same time an executable model (FDO Execution Model) is being developed which bases on the FDO Procedural Model and embeds the industry specific knowledge to be of use.

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