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IDENTIFICATION OF FLEXIBLE DESIGN OPPORTUNITIES (FDO) IN OFFSHORE DRILLING SYSTEMS BY MARKET SEGMENTATION

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1. Introduction

The offshore drilling industry faces significant uncertainties regarding the future utilization of the drilling rig when drilling systems are offered and designed in early phases of the project. Especially floaters such as drillships and semi-submersibles must often be specified on speculation leading to strong deficits in performance (such as time-efficiency, reliability, safety, etc.) across its lifecycle [Allaverdi et al. 2013]. As incentives are rather low and the expectations of the drilling system vary across stakeholders and lifecycle phases, drilling systems are rarely prepared to cope with those changes making upgrades time consuming and expensive during operational phases.

In contrast to rigid design, the embedment of flexibility into the initial design could minimize the risk of investments while providing the means to take advantages of potential future opportunities. Flexibility, however, faces difficulty in being introduced in the first place as stakeholders of drilling systems change or have different responsibilities and interests.

Drilling system suppliers must play an important role in introducing flexible drilling systems to the market. However, as preferences amongst their customers are different, differentiation of customers and, thus, market segments is crucial to offer the "right" flexibility. This is especially true for the offshore drilling industry where offers undergo time-pressured competitive tenders and mismatches between offers of flexible systems and customer expectations are to be punished immediately by losing those tenders. Independently of this field of application there is limited theoretical knowledge on how to deal with the challenges of introducing flexible design to the market [Cardin 2013a]. Hence, this paper suggests an approach on differentiating market segments accounting for individual acceptability thresholds of customers to guide the identification of Flexible Design Opportunities (FDOs) being the physical components enabling flexibility in the system. Hereby, the intention is to increase the efficiency and effectiveness of offers while providing stakeholders of the offshore drilling industry with added value across the lifecycle.

Initially, this paper motivates the need for this approach, both from an industrial and academic perspective emphasizing the flexibility areas of concern. Then the methodology is presented as a whole, followed by stepwise focusing on the different constituents of the methodology. Relevant literature is provided along those steps to relate to existing work in the context of the proposed methodology. The paper closes with a summary and a reflection.

2. Problem description and motivation for flexible design with market focus

The challenges and losses in the offshore drilling industry are twofold, namely related to the highly uncertain environment and the multiple and heterogeneous type of stakeholders of the drilling industry

[Allaverdi et al. 2013]. The first aspect relates to various uncertainties in early stages of the systems lifecycle mainly rooted in country/economy specific (e.g. political stability), market specific (e.g. oil price) or industry specific factors (e.g. rig demand, business model or oil reserve capacity of certain oil fields). Fluctuations in all of those fields trigger uncertainties in so-called "use contexts" [De Weck et al. 2007] triggered by changes in operational environment (e.g. changing the operating area being exposed to different terrains, climate, weather conditions; changing the drilling path) also referred to as changes in "missions". Additionally, "use contexts" also refer to changes on the rig regarding operating crew, equipment and type of operations (both 3rd party). As a result requirements for system designs change with their use context requiring upgrades in operational phases to avoid value losses of those drilling systems. The domination of rigid (non-flexible) system design in the drilling industry leads to negative effects:

- If no upgrades are performed (to avoid high opportunity costs) this leads to locked system configurations and possible rejection of orders by drilling operators (oil companies)
- If upgrades are performed they are usually expensive, time-consuming and also mean a loss of contracts during the long period of upgrading

The other challenge, namely the missing or only fragmented actions to deal with uncertain use contexts, can be explained by the multiple and heterogeneous stakeholders of the drilling industry and a missing overall system owner and operator across the different lifecycle phases. Particularly, this is rooted in the following circumstances:

- Customers of system suppliers often not being system users (e.g. shipyards or investors)
- Undefined system user and user environment in early phases
- Short period contracts between drilling contractors and operators in operational phases
- Partial and bias perspective on system and operations across stakeholders

Together with the highly regulated environment this leads to a more risk averse, i.e. conservative industry, that endorses system designs that primarily fulfill their initial requirements with limited anticipation and embedment of properties into the system that have long-term value.

Nevertheless, as mission uncertainty increases due to the making of more complex wells and operations in harsher and less known environments (e.g. in the Arctic), lifecycle considerations become even more important especially for floaters that operate globally and are more sensitive towards environmental influences.

Robust design as a means to deal with uncertainty can be observed in the drilling industry (e.g. conservative water depth, drilling depth, etc.) but, in general, only allows "adequate" operations over a range of operating conditions [De Weck 2008]. Flexibility in design and intelligent management decisions, on the other hand, which have only been applied partially and in niches of the drilling industry, can minimize the impact from possible downside losses and prepare the system to capture possible upside opportunities once favorable circumstances occur [De Neufville and Scholtes 2011]. It is in the very early phases that flexible design has to be accounted for, i.e. in response to customer requests, to be further considered during design and forwarding the benefits to operations.

Drilling system suppliers must play a key role in better managing this hurdle by deriving strategies to introduce this added value to the market. As an over-fulfillment in offers regarding flexible design might be punished by losing tenders and an undershoot in offers might mean lost potentials for both customer and system supplier (lifecycle performance, revenue), a differentiation of stakeholders and their individual acceptability thresholds for flexible design is required. It is suggested to differentiate market segments when responding to customer requests and make offers for flexible drilling systems that better meet the needs of customers.

3. Research basis and focus

In this chapter the basis and focus of this research is presented. In 3.1 relevant definitions and classifications of flexibility are provided that are related to the problem description of this research. As an important reference work for the methodology presented in this paper, an overview over the taxonomy of procedures to support the design of engineering systems for flexibility [Cardin 2013a] is given in 3.2. In 3.3 the identified research gap is presented followed by highlighting the research goal.

3.1 Relevant literature and classification of research

Until recently flexibility has been a multi-disciplinary not yet academically mature concept [Ross et al. 2008], [Saleh et al. 2009] relevant in various application fields referring to systems, processes and organizations. Flexibility has experienced significant contributions in different industrial branches such as in the aggregated field of engineering systems [Cardin 2013a] that includes long-lived systems (+20yrs) with irreversible investments facing strong uncertainty (e.g. aerospace, defense, energy). Further developments of flexible design concepts can also be seen in other fields such as production engineering [Nyhuis 2010] or automotive [Fricke and Schulz 2005]. Nevertheless, also due to its multi-disciplinarity, there is still a strong ambiguousness of “flexibility” [Kissel et al. 2012], [Lafleur and Saleh 2010], [Ross et al. 2008] motivating several definitions (also reflected in Table 1). The review of literature provides a suitable set of definitions for flexibility and classifications that are relevant in this industrial context and addressed problem description (see Table 1).

Table 1. Relevant definitions and classifications for flexibility and relation to own problem description

Aspects of definition / classification	Reference	Relevant aspects within that definition / classification	Confined aspects within that definition / classification
Flexibility	[Saleh et al. 2001]	"The property of the system to respond to changes in its initial objectives and requirements occurring after the system has been fielded, i.e. is in operation in a timely and cost-effective way.”	
Real options "in" projects	[Wang 2005]	"Right but not the obligation to do something” by modifying technical design components to make the system adaptable to its environment	
Architecture options	[Engel and Browning 2008]	Extention of real options “in” projects by providing a (quantitative) means of exploring the optimal degree of design flexibility to maximize its lifetime value for varied stakeholders	
Change agent location: Flexible type change and adaptable type change	[Ross, et al. 2008] [Fricke and Schulz 2005]	"Flexible-type change" as change agent external to the system	"Adaptable type change" as change agent internal to the system
Intra- and inter-mission flexibility	[Lafleur and Saleh 2010]	"Intra-mission flexibility" referring to one-of-a-kind system (i.e. physical system) which is then modified over time to adapt to the changing environment and requirements	"Inter-mission flexibility" referring to multiple vehicles fielded in series and adapted from one mission to another during the course of the program
Configurational and non-configurational flexibility		"Configurational flexibility" as ability to enable configurational changes of hardware, i.e changes in the physical system architecture	"Non-configurational flexibility" such as flexibility of software and trajectory (e.g. flexibility in modifying drilling plans)
Product and design adaptability (subject of adaptability)	[Hashemian 2005]	"Product adaptability" referring to the ability to use the physical system or product in different service environments	"Design adaptability", i.e. the same design, with minor changes, can be used to create different products, usually in the form of variations of the original product within a product portfolio
Specific and general adaptability (certainty of adaptability)		“Specific adaptability”referring to the ability to foreseeable changes and developments in its service environment, thus, including provisions in the design for known scenarios	"General adaptability", i.e. the design of products in such a way that they are generally more adaptable than conventional designs
Sequential and parallel adaptability (sequence of adaptability)		“Sequential adaptability” that extends the service life of a product as needs and requirements change.	"Parallel adaptability" that extends the usage of a design or a product into various applications and is reversible
Design time, runtime and lifetime adaptability	[Chmarra et al. 2008]	"Lifetime adaptability" by prolonging the service life in its normal operational mode and by adapting it to new operational modes	"Design time adaptability", i.e. adaptability during design and "run time adaptability", i.e. adaptability when product performs a task

Additionally to the relevant definition of flexibility, [Saleh et al. 2001] provides guidelines on defining flexibility to avoid ambiguity. The definition of flexibility should provide information about the time reference to when the change occurs, the subject of change and the metrics of flexibility. Accordingly, flexibility is defined for this work being in line with the previous definitions and classifications of Table 1:

- Time reference: after fielding of system, i.e. when system is in operation
- Subject of change: change of use context reflected in changes of the operational environment (“missions”) and on rig changes (e.g. crew, 3rd party equipment, 3rd party operations) are drivers for physical changes of the drilling system (upgrades). Other fields such as “technical obsolescence” and “deterioration/wear of systems”, although generally also relevant in this industry, are explicitly excluded as triggers for flexible design in this application context.
- Metrics for flexibility: “Ease of system change” and the “agility of system change” as both effort (time, costs) and opportunity costs (upgrade time) play a major role in the offshore drilling industry

3.2 Reference taxonomy of procedures

In [Cardin 2013a] a five-phase taxonomy of systematic procedures to enable flexibility in the design and management of engineering systems is provided. It accounts for existing taxonomies and suggests a more complete framework to guide practitioners, researchers and educators through the identification and valuation of FDOs which is regarded very fragmented so far. The framework considers five steps which include:

- Phase 1, Baseline Design: Design for flexibility must start from an existing design configuration being developed enough to enable further consideration of uncertainty in subsequent phases (architecture captured by detailed sketch, computer aided design, etc.)
- Phase 2, Uncertainty Recognition: In this step the major sources of uncertainty affecting lifecycle performance, incl. both opportunities and risks, are identified and modeled. The outcome is usually models enabling explicit evaluation of baseline concepts and indicating potentials for flexible design.
- Phase 3, Concept Generation: It relates to the generation of "flexible systems design concepts", i.e. a concept that provides an engineering system with the ability to adapt, change and be reconfigured, to deal with the uncertainties identified in phase 2. Each concept contains a strategy (e.g. expand, contract, abandon) and an enabler (e.g. modularity, scalability). Former is related to the identification of how the system should respond to uncertainty. Latter refers to the instantiation and management (exercise of options) of flexibility in design.
- Phase 4, Design Space Exploration: In this step designers explore the design space for the most valuable system design concepts and exercise strategies to operate the system. It uses quantitative procedures ("valuation") to evaluate the generated concepts and computational procedures to speed up the process.
- Phase 5, Process Management: It addresses the social and collaborative setting under which flexibility is generated. Hence, it suggests how to go through all phases most productively by accounting for the stakeholders and possibly conflicting interests (agency problems) and information asymmetries.

The proposed methodology of this paper bases itself on this taxonomy of procedures by focusing on only relevant aspects with regards to the problem definition.

3.3 Research gap and goal

Within the field of flexible design, the concept generation and the consideration of process management in this framework reflect high potential research environments [Cardin 2013b]. The need for more process management in the field of flexible design is also emphasized in [Browning and Honour 2008], [Fricke and Schulz 2005], [Ross et al. 2008] arguing that it is not necessarily valuable to implement changeability into system architecture to its full extent but rather depends on the stakeholders and their preferences.

The industrial need for this research has been identified by experiences and collaborative research projects within the drilling industry as well as by interviewing expert groups in organizations of a drilling system supplier and a large oil company on this specific topic; latter led to a concretization of the research direction. It was emphasized that the heterogeneous market need and expectations on flexibility must be accounted for if flexible drilling systems should be offered successfully in the future. Hence, the following conclusive research direction addresses the research gap in academia as a result of the relevance in the industry.

Based upon the taxonomy of design procedures, the focus and main contribution of this research should be the development of a methodology addressing the efficient and effective identification of FDOs during time-pressured competitive tenders by strongly accounting for the heterogeneous market need in the drilling industry. The focus lies upon reducing the number of flexibility candidates significantly from the beginning before the more time-consuming valuation of flexible design concepts occurs. With regards to the reference taxonomy of procedures, this research highlights the concept generation of flexible drilling systems (Phase 3) by continuously considering diverse market needs and expectations across different stages of the methodology (Phase 5).

The main goal is to be better at enabling flexibility in the challenging real world context of the offshore drilling industry by minimizing the gap between offers and acceptability thresholds of customers. At the same time the methodology should help to increase the effectiveness and efficiency of such offers. The methodology is elaborated in the following.

4. Market segment based search for FDOs

4.1 Overview of methodology

Customers of system suppliers can be different in their role in the stakeholder network (e.g. investor, shipyard, drilling contractor, drilling operator). Stakeholder needs and expectations might differ across those roles but also individually across different organizations (e.g. across different drilling contractors). The methodology targets the identification of the right flexibility in systems that can be offered to customers by accounting for this heterogeneous market. In each step, the application of market segments limits the variance of input, allows the use of associations between customers, hence, reducing extensive and time-consuming requirements elicitation for new and existing customers and, most importantly, reduces the variance in output with regards to further considered flexibility candidates ending up with a final economic set of flexible designs. Figure 1 illustrates the methodology and the relevant constituents.

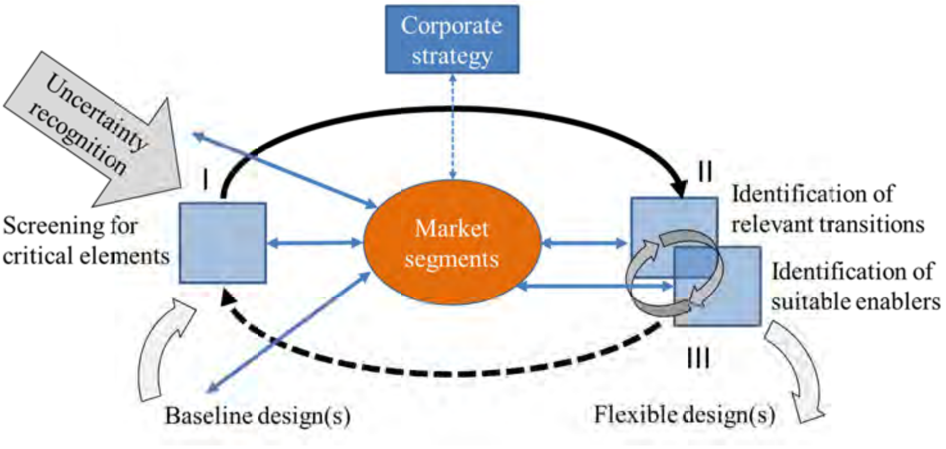

Figure 1. Methodology of market segment based identification for FDOs

As highlighted in 3.2, the baseline design is the starting point for the identification of FDOs. In this application context it stands for drilling systems of selected projects represented in general arrangement drawings, CAD models, etc. The recognition of uncertainty, namely that of the "use context", represents the reason for applying this methodology. The variance of input is restricted by a limited set of delivered projects as baseline designs and "scenarios", i.e. customer relevant and consistent future options of uncertainty factors, resulting from uncertainty recognition. Baseline designs and scenarios are already customer dependent, thus, can be significantly reduced by using market segments as a filter. For instance, baseline designs might be differentiated and narrowed down by certain criteria such as "vessel type" excluding vessel types that are irrelevant to certain customers (e.g. jack-up rigs). The actual identification of FDOs consists of:

- The screening of selected baseline designs for potentially critical and customer relevant elements that would highly benefit from being flexible in the face of use context uncertainties (see 4.4.1). "Elements" in this context represent both single products that fulfill a function (e.g. crane, roughneck, topdrive) and subsystems that represent a group of products and belong to certain processes (e.g. standbuilding, compensating, pipehandling, etc.). Unlike in [Cardin 2013a], this step is separated from the generation of flexible design concepts and put up front as a filter to prioritize elements with high potential and, hereby, reduce the time and effort for the identification of FDOs.

- The generation of flexible design concepts includes the identification of customer-relevant transitions of the selected elements (“strategy”) that better cope with identified scenarios (see 4.4.2). In a further and very integrated step it also considers identifying suitable and customer-relevant enablers for the identified transitions (see 4.4.3). The management of flexibility, i.e. the consideration of exercise strategies, is only considered as an important boundary condition.

Both steps of identifying relevant transitions and suitable enablers are highly interdependent and require iterations. If this iterative process turns out not to generate a sufficient number of flexible designs, the elements are to be reconsidered for selection. Even though newly selected elements might not be as critical, they might be better at incorporating flexibility and consequently worthwhile to be reconsidered in this new run.

4.2 Segmentation of market for identification of FDOs

Generally, market segmentation is a marketing strategy that involves dividing a broad target market into subsets of consumers, who have common needs, and then designing and implementing strategies to target these specific customer segments [Gautam 2012]. The quality of the market segmentation is crucial as the entire process of identifying FDOs depends on it. It is to consider different requirements such as:

- General requirements on market segmentation (e.g. internal homogeneity, large enough to make profit)
- Requirements related to the organization’s corporate strategy (e.g. to target important customers)
- Requirements based upon its application in this specific methodology

As highlighted in 4.1, this methodology uses market segments as a means to target customers better with offers of flexible design while limiting variances in flexible designs and reducing complexity and effort during the selection process of FDOs compared to elicitation and accountancy of single customer requirements. In each step of the FDO process different sets and combinations of criteria are used as a basis for segmenting markets; market segments are related to certain solution spaces. Thus, compared to general market segmentation, this methodology suggests to use step-specific (incl. uncertainty recognition, baseline design) views of market segments as a means to efficiently and effectively guide the process of deriving customer relevant flexible designs in the end.

Market segmentation can be done by alternative sets of criteria such as by similar preferences related to system and behavioral properties (e.g. safety, time-efficiency), product properties (e.g. weight), system responsibility, cost thresholds for flexible design, etc. Methods of customer preference elicitation (e.g. conjoint analysis) form the basis for the segmentation (e.g. by clustering) of customers according to their commonalities. The unique boundary conditions prevalent in this industry (e.g. type and timeframe of tenders, role of customer in stakeholder framework, number of players) have to be accounted for. The focus of this paper lies on presenting the FDO process and the sets of criteria for market segmentation rather than focusing on the market segmentation itself.

As reflected in Figure 1, the market segmentation does not only guide the identification of FDOs but might also be adjusted as a response to its application if, for instance, important criteria are not yet considered in a step. Hence, adjustments have to be made during development and initial use of the methodology. The consideration of the organization’s corporate strategy is also important as there might be restrictions to the market segmentation but also feedback from applying the methodology.

In the long run, the methodology should be able to utilize an approved and relatively stable set of market segments guiding the process of identifying FDOs.

4.3 Uncertainty of use context

The uncertainty of the use context [De Weck et al. 2007] is the motivation and starting point of the methodology for identifying FDOs. Uncertainty factors related to changes in use contexts can be related to changes in operational environments (“missions”) implicating changes in natural influences (e.g. wind, rig motion, pressure/temperature of formation) and contextual factors such as water depth, rules and regulations, etc. [Allaverdi 2012]. Whereas characteristics of influences can vary within a set environment, those of contextual factors vary only across projects as a result of changing operational environments. The "use context" might also relate to changes on the rig such as by changes of the operating crew, 3rd party equipment and operations. All types of uncertainty factors are usually strongly interrelated and highly affect required functions, capacities and interfaces on the rig [Allaverdi et al. 2013].

As highlighted in 4.1, uncertainty factors that are further considered for the identification of FDOs should already account for different market segments as needs and willingness to cope with those uncertainties might differ across stakeholders. For instance, customers operating only in tropical and benign environments might not account for scenarios "going to the Arctic".

There exist different approaches of modeling uncertainty. Scenario planning represents a method suitable for the collaborative design process [Cardin 2013a] and for a finite set of future scenarios [De Weck et al. 2007]. It is the most suitable method also with regards to limiting the input in the FDO process. The Delphi method describes a formal way of generating such discrete future scenarios based on expert group opinion [Helmer 1967]. Other formal approaches (e.g. Dempster-Shafer, probability, statistics, Bayesian) are not as suitable due to the unique application context (time pressure, expertise of users) and the discrete nature of mission uncertainties (sudden change of context and/or needs) does not favor many other practical approaches such as diffusion models or binomial lattice. Decision trees could be regarded as an alternative to scenario planning for discrete events, however, having a moderate application record in the industry [Cardin 2013a].

4.4 Identification of FDOs

4.4.1 Screening for critical elements

The screening for critical elements is the first step of identifying relevant FDOs in the system. It requires two classes of criteria for identifying critical elements (see Figure 2): market segment dependent and technical criteria. After the identification of elements by market segment dependent criteria, the second class of criteria narrows further down the relevant candidates of the system for embedding flexibility.

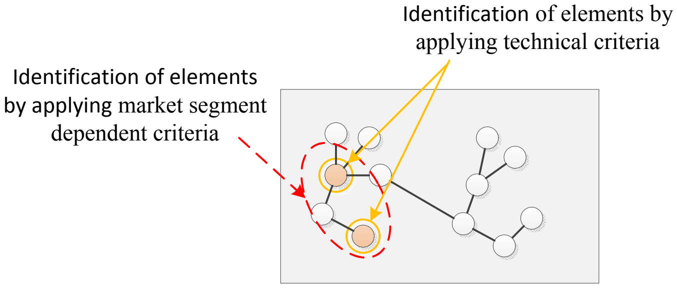

Figure 2. Identification of critical elements by market segment dependent and technical criteria

The first class of criteria includes critical elements that are customer dependent, thus, account for the interests and acceptability thresholds of relevant market segments. Relevant elements can be identified by:

- Responsibility of customers regarding operations and related systems
- Key properties of customers being critical in certain operations and systems (e.g. safety being important to the customer and "hoisting system" being very safety relevant due to potential danger of dropped objects in hazardous zone)

The identified elements are further filtered by technical criteria:

- Elements that are very sensitive towards uncertainty factors of the use context, i.e. are highly affected by already small disturbances (e.g. crane by wind loads)
- Elements on critical line representing bottlenecks of the drilling process, i.e. any disturbances having significant impact on the main process
- Elements with strong knock-on effect once disturbance occurs, i.e. certain elements might amplify or absorb the effect of being disturbed

The identification of relevant FDOs in systems can be done by interviewing subject matter experts (SME) or by information flow methods [Cardin and De Neufville 2008]. [Shah et al. 2008] illustrates the benefit of interviewing SME experts. Information flow methods are matrix-based (DSM) / graph-based methods with a codified representation of the system often used in combination of interviewing SMEs. They provide the opportunity to focus on the relevant aspects of system architecture. Relevant matrix-based methods which equally apply to the identification of enablers (see 4.4.3) can be seen in [Bartolomei 2007], [Kalligeros 2006], [Suh et al. 2007]. They might also be graph-based such as presented by [Hu et al. 2011]. Although matrix-based procedures are suitable for identifying areas of incorporating flexibility, they might be challenging to be used in the industrial context as data collection and expert interviews are very time consuming and challenging [Cardin 2013a].

Once critical elements are identified by both classes of criteria, relevant transitions to more effective end states are considered.

4.4.2 Identification of relevant transitions

The identified critical elements are now searched for suitable physical changes ("transitions") to deal more effectively with the uncertain use contexts. In this step, transitions are considered for rigid i.e. non-flexible elements that are then further assessed for its potential of embedding flexibility.

With regards to the established tradespace network of changeability [Ross et al. 2008], a transition of one element to a new element (end state) can be represented by an arc requiring a certain amount of effort (time, costs). Transitions are considered as "change mechanisms" in this framework of "Multi-Attribute Tradespace Exploration or "type" based on <mechanism, type> characterization of real options in enterprises [Mikaelian et al. 2011]. It can be defined as a set of actions ("managerial level") that may be exercised by the owner of the real option [Trigeorgis 1996] but might also relate to real options "in" projects where one takes into account the numerous design variables within a technical design [Wang 2005]. [Cardin 2013a] refers to it as "strategies" during concept generation as part of the taxonomy presented in 3.2.

In this application context those transitions are to be derived both from accessing already existing solutions (as part of the product portfolio, past system deliveries) and generating new solutions by applying, for instance, creative problem solving techniques such as TRIZ. In general, transitions of elements can occur on different layers [Ponn and Lindemann 2008]. Figure 3 (left) shows different transitions of elements:

- Change on functional layer (not represented in Figure): Although theoretically feasible, transitions to entirely different functions interfere strongly with predetermined processes by system users and also face difficulties in being implemented. Thus, transition paths on the functional layer are not further regarded.
- Change of working principle on behavioral layer (top): The transition lies in changing the working principle with the same/similar function. Ex.: Crane that is replaced by skid which runs on rails to better cope with wind loads.
- Change of physical appearance on physical layer (bottom): The transition lies in the reconfiguration of the physical appearance of the system element maintaining the working principle (e.g. change in form, position, size, number of elements, material, etc.). Ex.: Crane that is reinforced to better cope with changes in wind loads.

Although changes of uncertainty factors are often exemplified by increasing magnitude (e.g. stronger wind), it might also be relevant to consider the opposite where a decrease of magnitude in the uncertainty factor might trigger transitions (e.g. less wind leading to transition from skid to crane as latter is more versatile in operations).

Transitions on subsystem level (Figure 3, right) regard mainly three aspects to better cope with use context uncertainties:

- Change of topology (top): Transitions are related to new system configurations of existing elements to incorporate a process. Ex.: Crane might play a less critical role in process by decreasing the interactions to other products
- Change of position (middle): Transitions are related to new positions that decrease the impact of uncertainty factor on that element. Ex.: Moving crane to already wind-shielded areas.

- Change by other element(s) (bottom): Transition of system by adding, removing or changing other elements. Ex.: Wind shielding (element) might be introduced on the same floor to avoid a reallocation of the crane.

The consideration of transitions on element and subsystem level is not always independent. On the one hand, transitions on element level might require changes on subsystem level to be enabled (e.g. skids might require rails, potentially restricting or changing configurations of the system). On the other hand, changes on subsystem level might require certain transitions on element level (e.g. another product has to take over an additional function). Hence, an isolated observation of transition end states might lead to wrong conclusions and therefore requires a holistic assessment.

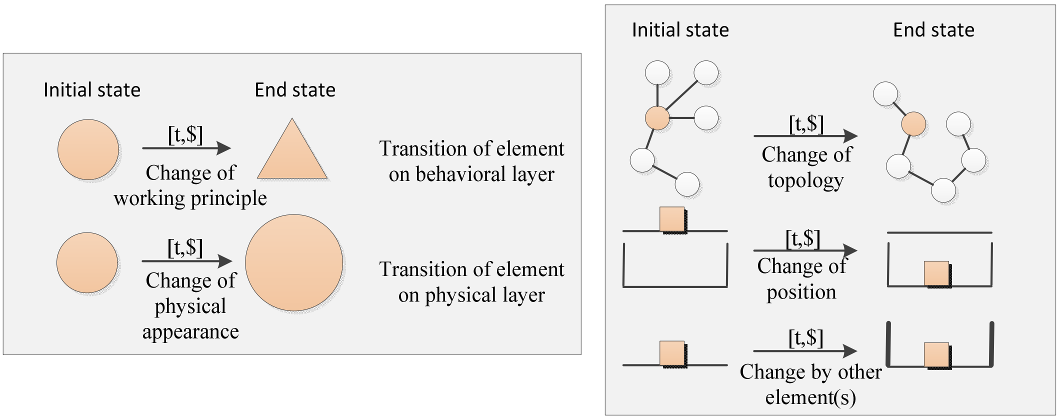

Figure 3. Transitions on element (left) and subsystem level (right)

The effectiveness of dealing with the uncertainty factors can be regarded as technical and independent of the market segment (e.g. crane of end state has less side movement induced by wind). Nevertheless, the effectiveness of the end state must be assessed under consideration of the effects of better dealing with the scenario being market segment dependent (e.g. higher safety, more reliability, more uptime due to less side movement). It must also consider system internal side-effects due to changes in states (e.g. less speed due to increased weight of element). Market segment dependent criteria are also required for assessing the efficiency (time, costs) of the transition as acceptability thresholds differ. Hence, flexibility candidates are considered transitions of rigid designs that:

- Lead to effective end states of elements, i.e. have improved behavior due to better coping with the uncertainty factors while not significantly deteriorating system internal properties
- Require a high amount and exceed the subjective level of effort to be incorporated

At this stage there is no distinction between upgrade costs and prices as assessing the effort is only an indication if flexibility is to be regarded further; hence, the discussion on margins plays a secondary role in the phase of identifying relevant transitions.

For the identified critical elements and relevant transitions, flexibility is regarded worthwhile to be further considered. Thus, in the next step suitable enablers are identified.

4.4.3 Identification of suitable enablers

“Enablers” are required to facilitate the relevant transitions, i.e. reduce the total effort (incl. costs for engineering and modified physical elements) as well as opportunity costs (see Figure 4) while having same or similar initial and end states. They constitute different measures that allow embedding options to make transitions more efficient such as by modularization, scalability, etc.

Industry guidelines provide lessons and principles to enable better flexibility in design. For instance, [Fricke and Schulz 2005] suggests basic (e.g. modularity) and extending principles (e.g. redundancy) as guiding principles to enable flexibility. [Qureshi et al. 2006] provides empirically derived principles to enable flexibility. The identification of the right enablers can also be supported by methods suggested for the identification of critical elements (see 4.4.1). Industry guidelines are considered most suitable as they are easy to use and have already proven applicability in the industry [Cardin 2013a]. Nevertheless, a combination of the suggested methods is considered.

It is evident that suitable enablers highly depend on the type of transition. For instance, enforcing the crane could be done by certain "modularity" whereas the transition from crane to skid requires the pre-consideration and embedment of structural interfaces as a means to reduce the effort of that transition. Suitable enablers for each type of transition must be determined to realize a more efficient transition process, hence, decreasing the effort. Thus, suitable "enabler-transition pairs" have to be identified and assessed.

Figure 4 illustrates the basis for decision making on suggested combinations of enablers and transitions (enabler-transition pairs). Opportunity costs are explicitly accounted for as they highly govern total costs and dominate decision-making in the offshore drilling industry. At this stage all costs represent the costs of the system user.

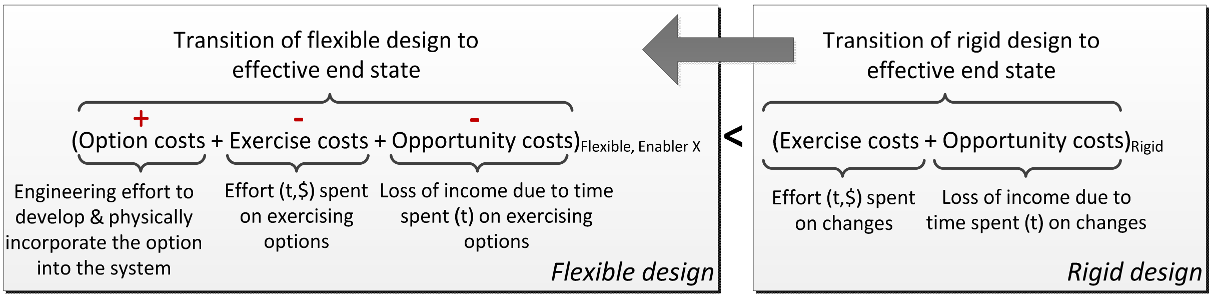

Figure 4. Relevant terms for both rigid and flexible design

The transition of a rigid design (i.e. upgrade without embedded flexibility) illustrated in Figure 4 (right) represents the starting basis for considering relevant enablers (see 4.4.2). By embedding flexibility into the design through enablers, the transitions should become more efficient, i.e. lead to less overall costs. As illustrated in Figure 4 (left), flexibility usually entails option costs that have to be compensated by significantly lower exercise costs (i.e. cheaper and less time consuming transitions) and opportunity costs that correlate to the period of exercise. The main criteria and rules for decision-making are:

- for same initial and end states, independent of market segment
  - As indicated in Figure 4 flexibility is relevant if the total costs of the transition are below that of the rigid design. An exception might be customers that are not system users and do not approve flexible design as additional option costs govern their decision making.
  - The identified "transition-enabler pairs" for same transitions (one transition of rigid design, multiple enablers) must be compared amongst each other. The ones that require less effort are preferable.
- market segment dependent
  - The identified "transition-enabler pairs" for different transitions (multiple transitions of rigid design, one/multiple enabler(s)) must be compared amongst each other regarding their effectiveness and efficiency (trade-off). For instance, the transition from "crane to enforced crane" and "crane to skid" might be more efficient by one enabler than another while representing a previously determined less effective transition for a market segment.
  - Initial and end states might have changed due to the transition (e.g. more weight in initial and end state due to modular design). The introduced side-effects by enablers must be assessed.

The possibly induced changes by enablers of initial and end states illustrate that the identification of relevant transitions and the identification of suitable enablers are strongly interdependent, thus, might require iterations as indicated in Figure 1. This also explains the integrated consideration of those two steps in literature. The separation of those two steps is still regarded beneficial as they allow sequential and logically different inquiry and assessment for identifying potential FDOs.

As highlighted in 4.1, "exercise strategies" represent important boundary conditions for the selection of relevant "transition-enabler pairs" as it might change the outcome of design concepts. For instance, an extremely high frequency of significantly different mission scenarios and exercise of options might increase the importance of the "efficiency" of transitions rather than the "effectiveness" to deal with uncertainties as those transitions might govern lifecycle costs.

Valuation methods as a means to identify (absolute) performances of FDOs might be required in this step but are not the focus of this paper.

5. Summary and discussion of methodology

The suggested methodology focuses on the ability to introduce suitable flexible systems to the customer by accounting for heterogeneous acceptability thresholds in the market. It regards the division into market segments as an integral element of the methodology fostering the incorporation of flexible systems despite the conservative business environment of the offshore drilling industry. This methodology considers market acceptance, and consequently, sales of flexible systems as prerequisites for system users to benefit from the increased predicted performance over its lifecycle. Whereas current research mainly focuses on the valuation of flexible designs, the main scientific contribution of this work and research is seen in the efficient and systematic reduction of the solutions space to a market-relevant set of flexible designs before valuation takes place.

The focus lies on better handling uncertain use contexts (such as drilling missions) without the consideration of other triggers for flexible design such as wear of systems, technological evolution, etc. At the same time it has a strong focus on critical elements as an initial basis for FDOs, thereby, less emphasis on elements with minor criticality but potential ease of embedding flexibility ("Low hanging fruits").

The proposed methodology is to guide engineers and technical sales in very early phases of competitive tenders by using different steps to identify most suitable FDOs. This is to result in generating more efficient offers of flexible systems reflected in lower participation costs, freed resources, etc. At the same time it is to increase the effectiveness of those offers by increased acceptance rates and delivered quality of offers.

The following limits of the methodology are that:

- It relies on the premise that the market can be segmented in the first place
- Represents only an approximation of ideal offers of flexibility that might deviate from offers when considering individual customer needs
- Requires technical understanding on different levels (product, system, process) for the use of the methodology

Future work lies in detailing the methodology to be executable with strong focus on the integration of market segments across the different FDO steps. The methodology requires thorough validation in the industry to test its applicability being revised if required.

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