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Availability assessment of subsea distribution systems at the architectural level

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ABSTRACT

This paper presents a framework for the availability assessment of subsea distribution systems during the functional design (selection) phase. This framework, which also includes all interface elements, can be started at an early stage when the definition of the system architecture is coarse and generic failure data is available and can be refined as more information becomes available, then maintained as the system ages during the operational phase. The main objective is to present a decision tool for selecting the subsea distribution system with the highest advantage in terms of availability at a very early stage of the design. The Design Structure Matrix (DSM) mapping method is used to represent the system's components and their dependencies, which is then enriched with additional reliability data to calculate availability. A case study of an actual subsea distribution system is used to demonstrate the approach.

1. Introduction

Downtime of high-value subsea installations due to equipment failures and time needed for their subsequent retrieval, repair and replacement can have a significant effect on revenue. The problem is compounded for deep-water subsea installations where all tasks must be handled remotely from a surface vessel. Reliability and availability assessments, particularly during the concept selection phase, can identify key systems, configuration, equipment and components that are likely to have a major impact on system availability (ISO 2394 and 20815). Such study can also include accidental damage (e.g. dropped object, anchor dropping and dragging etc.) that can destroy part of the system; a good architecture helps to avoid these hazards. For subsea installations, the difficulty of access makes the system architecture a primary factor that influences availability. Components are bundled together for ease of lifting and installation, considering the limit on size and weight of bundles which can be installed using available crane barges. Balancing the number of offshore lifts and accessibility of components for ease of retrieval is the hallmark of a good architecture.

Reliability is the probability that a system will operate properly for a specific period of time under specified operating conditions. System maintainability is a measure of the ability of a system to be maintained to prevent a failure occurring in the future and the ability to restore the system when a failure occurs. A system is not available if it is taken down for routine or preventative maintenance; the consequence is similar to a system that has broken down. Maintainability is a derivative of the system reliability; it is design dependent and is achieved by the highest level of availability (MIL-HDBK-217F).

System reliability, availability and maintainability (RAM) studies at the early development stage can provide a baseline to compare alternative architectures. At the concept selection phase (Yasseri, 2014) when the functional architecture is being decided, it is helpful to model the functional elements in terms of coarse-grain building blocks. The functional architecture is a high-level abstraction, which defines functional elements without reference to its physical implementation. Many methods have been proposed for the reliability analysis of systems. The most commonly used methods are Failure Mode and Effect Assessment (FMEA) (RIAC, 2010), Fault Tree Diagram (FTD) (RIAC, 2010), Reliability Block Diagram (RBD) (BS EN 61078:2006) Markov Chain (Liu et al., 2014; Koutras, 1996), and Monte Carlo Simulation (Zio et al., 2006, 2010). Each method has its own advantages and disadvantages (Dekker and Groenendijk, 1995).

Robert and Laing (2002) studied the causes and frequency of failure, by collecting data from field experience and accelerated testing. Brandt and Eriksen (2001) showed how RAM analysis can be used to quantify costs associated with subsea-well interventions and subsea repairs. Brandt (2003) applied risk and reliability techniques in combination with verification and qualification procedures. Sunde (2003) proposed a

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Abbreviation

BIV	Branch Isolation Valve
Comms	Communication cables
COTS	Commercial Off The Shelf
FMECA	Failure Mode Effect and Criticality
FPMH	Failure per million hours
FTA	Flowline Termination Assembly
FTD	Fault Tree Diagram
HFL	Hydraulic Flying Leads
HP	High Pressure
Hrs	Hours
Hyd	Hydraulic
IMR	Inspection-Maintenance-Repair
LP	Low Pressure
MEG	Mono ethylene glycol
MeOH	Methanol
MTTF	Mean Time To Failure
RAM	Reliability, Availability and Maintainability
RBD	Reliability Block Diagram
ROV	Remotely Operated Vehicle
SCM	Subsea Control Module
SDU	Subsea Distribution Unit
X-tree	Christmas tree

guideline, based on a computerized tool for the assessment of the reliability and cost of subsea process systems. Alhanati and Trevisan (2012) investigated reliability gaps in an electrical submersible pump technology for deep-water applications.

The first step in evaluating a system's reliability is to construct a graphical presentation of the system's components and their connectivity reliability-wise. This paper uses the Design Structure Matrix (DSM) (Eppinger and Browning, 2012) for this purpose. The interface DSM (Yasseri, 2015) is enriched with reliability data concerning non-graphic characteristics like k, the number of components required for the system to be deemed available i.e. the 'k' in, k-out-of-m systems (NASA, 2011 or NSWC-11, 2010), and the calculated reliability. This model is carried forward to later stages of the development when the physical architecture has taken shape, and component-specific failure rate can be obtained or calculated. The overall system availability is determined compositionally as a function of the reliability of its constituent components, and their interactions.

The primary emphasis of the reliability of the subsea system is component based. It is true that a reliable system must be composed of reliable components, but it is possible to arrange reliable component into a subsea system for which retrieving of a failed component is time-consuming, thus leading to extensive downtime and hence to a poor availability. Subsea equipment is housed in a suitable size and weight structures for the transportation and the installation purposes. Equipment may be bundled with little attention in how they can be brought back to the surface for repair. Consequently, there is a need for an approach that can consider the effect of system architecture on availability. The motivation for the use of an architecture-level quantitative assessment of availability includes the following:

- Developing techniques to analyse the reliability and performance of the system which is built from Commercially available Off-The-Shelf (COTS) components, rather than bespoke design.
- Understanding how the system reliability/performance depends on how its components are arranged (configured) and their interactions.
- Studying the sensitivity to reliabilities of components and interfaces, in search of better interface designs and packing.
- Guiding the process of identifying critical components and interfaces.
- Developing techniques for quantitative analysis that are applicable throughout the system life cycle.

2. System architecture

The system architecture is an abstract model that defines the structure and behaviour of a system (Sillitto, 2014). It defines the organization of the system's components, their relationships to each other and to the environment. It also provides a plan from which components can be procured and manufactured, such that the developed system will work together to deliver the required overall function.

Two levels of system architecture are defined; namely the functional (also known as logical) architecture and the physical architecture. Functional architecture sometimes referred to as the “conceptual design”, is an abstract view of the production system.

Functional architecture defines a solution-independent representation of the system; composed of pure functions. The depiction of components of a functional architecture represents abstractions of physical solutions. At this stage, what the component must do is quite clear but its physical properties (weight, size, material etc.) are unknown until a decision made regarding which vendor would supply them; this happens later in the project lifecycle. Physical components procured from two different vendors provide the same function but their details may be different; hence their failure rate. For example, two Subsea Control Modules (SCM) developed by two suppliers, will have many different physical characteristics, but they will also share many common functional properties. A component of a functional system thus defines functions, properties and interfaces that are common to a range of physical design alternatives. Most importantly, functional architecture remains largely independent of technology or suppliers and provides a reasonably stable baseline from which the physical architecture can be derived and manufactured.

A functional (logical) architecture is a design which includes all major components (by naming their functions) plus their relationships. The upper part of Fig. 1 shows that a system to deliver a function consists of many sub-functions. At this level, only the function of each equipment, flow, communications, connections and dependencies are identified. Each component is shown as a black box whose function is described but not its physical properties. The intention is to ensure that all components and functionality of a subsea system are accounted and well understood. Functional architecture does not include vendors’ names or equipment properties (weight, size, geometry, transportation, install-ability etc.).

As the design progresses and one of the many possible functional architecture options is chosen to be taken forward for detailing, then the physical architecture gradually emerges-the lower part of Fig. 1. The lower part of Fig. 1 is a mirror image of the upper part, and there is a one-to-one relationship between the functional components and their physical counterpart.

When vendors are selected, then gradually the physical system takes shape. As the design of components starts, their dimensions become available and the system configuration can be refined. This process starts at the select phase (Yasseri, 2014), perfected in the detail design and maintained as the project lifecycle management requires. At the detail design phase, few iterations are required until a satisfactory physical architecture is obtained.

The physical architecture has all major components and entities identified within a specific physical dimension, vendor, locations, etc., or possible solutions. It also includes all known details such as how they operate, vendor's operating instructions, configuration, materials and means of communication & control. All physical constraints or limitations are also identified, e.g. fluid flow requirements, size and availability of installation barges and physical solution for interfaces are decided. In