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Affected Publication: API Recommended Practice 17N, *Recommended Practice on Subsea Production System Reliability, Technical Risk, and Integrity Management*, Second Edition, June 2017

Addendum 1

Withdraw Annex E in its entirety, and replace with the following:

Annex E (informative)

New Technology Qualification

NOTE This annex was conditionally included to provide interim guidance until the next edition of API 17Q is published. API 17Q, Second Edition, is now published and therefore, this annex has been withdrawn. API 17Q has been completely rewritten from the First Edition, providing more detailed guidance for the industry on new technology qualification, including qualification of modified/extended technology. See API 17Q for more information on this subject.

Withdraw Annex F in its entirety, and replace with the following:

Annex F (informative)

Application of Test Statistics

NOTE This annex was conditionally included to provide interim guidance until the next edition of API 17Q is published. API 17Q, Second Edition, is now published and therefore, this annex has been withdrawn. API 17Q has been completely rewritten from the First Edition, providing more detailed guidance for the industry on new technology qualification, including qualification of modified/extended technology. See API 17Q for more information on this subject.

Recommended Practice on Subsea Production System Reliability, Technical Risk, and Integrity Management

API RECOMMENDED PRACTICE 17N
SECOND EDITION, JUNE 2017

ADDENDUM 1, MAY 2018
REAFFIRMED, APRIL 2023



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Introduction

Reliability and integrity can have major environmental, safety, and financial impacts for all organizations involved in designing, manufacturing, installing, and operating subsea equipment. The complexity of technical and organizational challenges in subsea projects and operations requires continual attention to detail to achieve high reliability and integrity performance.

Equipment reliability is important both to system integrity and to production. For example, poor seal reliability in a flow line connector may result in loss of containment with the potential for environmental damage. Valves that fail to close on command may prevent isolation and compromise safety. Valves that fail to open on command may compromise production.

Budget and schedule constraints can lead to limited information and time for making decisions. This can introduce varying levels of uncertainty that have the potential to affect equipment reliability, integrity, and associated operational risks. In particular, any potential failures that lead to loss of containment or loss of production should be thoroughly investigated and actions taken to manage the risks that such events generate.

This recommended practice (RP) provides a structured approach that organizations can adopt to manage technical uncertainty throughout the life cycle of a subsea system. This may range from the management of general project risk through to the identification and mitigation of potential equipment failure modes, affecting integrity or production.

Most organizations will find much that is familiar and recognized as good practice. Some sections of the annexes may only be of interest to the reliability and integrity specialist. The basic approach, however, is simple and consistent and when applied correctly has the potential to greatly reduce the financial, safety, and reputational risks, arising from potential failures, throughout the life cycle of subsea systems.

Although this RP is focused on subsea production equipment, the guidance is generic and may be easily adapted to address the design of subsea hardware used for drilling operations including the subsea blowout preventer and lower marine riser package.

Recommended Practice on Subsea Production System Reliability, Technical Risk, and Integrity Management

1 Scope

This recommended practice (RP) aims to provide operators, contractors and suppliers with guidance on the management and application of reliability and integrity management (RIM) engineering techniques in subsea projects and operations within their scope of work and supply. It is applicable to:

- standard and nonstandard equipment (within the scope of API 17A);
- new field developments, further development of existing fields and field upgrades;
- all life cycle phases from feasibility through design, manufacture, and operation to decommissioning.

NOTE API 18LCM^[1] gives additional guidance on general requirements for life cycle management of equipment.

This RP is **not** intended to replace individual company processes, procedures, document nomenclature, or numbering; it is a guide. For example, this RP does not prescribe the use of any specific equipment or process. It does not recommend any actions, beyond good engineering practice. However, this RP may be used to enhance existing processes, if deemed appropriate.

2 Normative References

The following normative documents contain provisions that, through reference in this text, constitute provisions of this standard. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. For undated references, the latest edition of the normative document applies.

API Recommended Practice 17A, *Design and Operation of Subsea Production Systems—General Requirements and Recommendations*

API Recommended Practice 17Q, *Technology Qualification for Subsea Equipment*, Second Edition

NOTE API 17Q, Second Edition is planned for publication in 2017. Annexes E and F are included in this document to provide interim guidance and will be removed once API 17Q, Second Edition is published. For all references in the text to API 17Q, the reader should refer to these annexes until API 17Q is published.

API Recommended Practice 75, *Recommended Practice for Development of a Safety and Environmental Management Program for Offshore Operations and Facilities*

API Recommended Practice 580, *Risk-Based Inspection*

BS¹ IEC² 62198:2001, *Project risk management—Application guidelines*

DNV-RP-A203³, *Technology Qualification*, July 2013

IEC 61508, *Functional safety of electrical/electronic/programmable electronic safety-related systems*

¹ British Standards Institution, Chiswick High Road, London, W4 4AL, United Kingdom, www.bsi-global.com.

² International Electrotechnical Commission, 3, rue de Varembe, P.O. Box 131, CH-1211 Geneva 20, Switzerland, www.iec.ch.

³ DNV GL, Veritasveien 1, 1363 Hovik, Norway, www.dnvgl.com.

ISO 14224 ⁴, *Petroleum, petrochemical and natural gas industries—Collection and exchange of reliability and maintenance data for equipment*

ISO 20815, *Petroleum, petrochemical and natural gas industries—Production assurance and reliability management*

3 Terms, Definitions, Acronyms, and Abbreviations

3.1 Terms and Definitions

For the purposes of this standard, the following terms and definitions apply.

3.1.1

availability

The ability of an item to be in a state to perform a required function under given conditions at a given instant of time, or over a given time interval, assuming that the required external resources are provided.

NOTE The term “ability” is often interpreted as probability.

3.1.2

availability requirements

Appropriate combination of reliability and/or maintainability performance characteristics that need to be achieved to meet project requirements.

3.1.3

common cause failure

Failures of different items resulting from the same direct cause, occurring within a relatively short time, where these failures are not consequences of one another.

NOTE Components that fail due to a shared cause normally fail in the same functional mode. The term common mode is, therefore, sometimes used. It is, however, not considered to be a precise term for communicating the characteristics that describe a common cause failure.

3.1.4

confidence interval

A confidence interval is a term used in inferential statistics that measures the probability that a population parameter will fall between two set values.

NOTE The confidence interval can take any probability values, with the most common being 90 % or 95 %.

3.1.5

configuration management

CM

A management process that establishes and maintains consistency of a product's attributes with the requirements and product configuration information (i.e. product design, realization, verification, operation, and support) throughout the product's life cycle.

3.1.6

critical systems

Critical systems are those for which a failure will lead to major accidents (i.e. safety critical systems), loss of containment (i.e. environmental critical systems), or significant loss of production (i.e. production critical systems).

⁴ International Organization for Standardization, 1, ch. de la Voie-Creuse, Case postale 56, CH-1211 Geneva 20, Switzerland, www.iso.org.

3.1.7**downtime**

The time interval during which an item is unable to perform a required function due to a fault, or other activities (e.g. during maintenance).

3.1.8**environment**

The internal, external, and operational conditions to which equipment are exposed.

NOTE This includes physical, chemical, biological, and usage conditions (i.e. seawater environment, water depth, seabed conditions, reservoir conditions, pressure, temperature, etc.).

3.1.9**failure**

Termination of the ability of an item to perform a required function.

NOTE 1 After failure, the item has a fault.

NOTE 2 Failure is an event, as distinguished from a fault, which is a state.

3.1.10**failure data**

Information related to the occurrence of a failure event.

3.1.11**failure impact (effect)**

Consequence of a failure on a system, on an equipment function, on the economy, on human safety, or on the environment.

3.1.12**failure mechanism**

A process (physical, chemical, human, or other) that leads to a failure.

NOTE Most failure mechanisms involve more than one process and may involve a chain of events and processes.

3.1.13**failure mode**

The effect by which a failure is observed on the failed item (i.e. the loss of a required functionality, e.g. loss of containment).

3.1.14**fault**

State of an item characterized by inability to perform a required function, excluding the inability during preventive maintenance or other planned actions, or due to lack of external resources.

NOTE A fault is often a result of a failure of the item itself but the state can exist without a failure.

3.1.15**frequency**

(a) The number of occurrences of a specified event or class of events per unit time, cycles, or other measures.

(b) The ratio of the number of times an event occurs in a series of trials of a chance experiment relative to the number of trials of the experiment performed.

NOTE 1 Definition (a) is assumed wherever the term frequency is used, unless otherwise stated.

NOTE 2 In this RP, definition (b) is equivalent to the definition of probability.

3.1.16**function**

The intended purpose of an item to perform a specific task or capability.

3.1.17**hazard**

A situation with the potential for harm or loss of system or damage to the environment, the term includes danger to persons arising within a short timescale (e.g. fire and explosion) and also those that have a long-term effect on a person's health (e.g. release of a toxic substance).

3.1.18**human error**

That which involves deviation from an intended action due to slips, lapses, or mistakes.

NOTE Human error can also be the result of processes with inadequate procedural controls.

3.1.19**human factors evaluation**

Use of various methods (e.g. function and task analysis, human-system interface reviews, training reviews, procedure reviews, incident investigations) in order to identify sources and potential effects of human error.

3.1.20**installation hardware**

The system or equipment used to install subsea production hardware.

3.1.21**integrity**

The ability of a system of components to perform its required function while preventing or mitigating incidents that could pose a significant threat to life, health, and the environment over its operating life.

NOTE The term "ability" is often interpreted as probability.

3.1.22**integrity management**

The systematic implementation of the activities necessary to ensure that critical systems are properly designed and installed in accordance with specifications, and remain fit for purpose until they are decommissioned.

3.1.23**maintainability**

The ability of an item under given conditions of use, to be retained in or restored to, a state in which it can perform a required function, when maintenance is performed under given conditions and using stated procedures and resources.

NOTE The term "ability" is often interpreted as probability.

3.1.24**maintenance record**

Set of data that contains all failure, fault, and maintenance information relating to an item.

3.1.25**maintenance-free operating period****MFOP**

The specified time that a system is expected to operate without a specified failure event that demands a maintenance intervention, where failure occurrence is to a given level of probability.

3.1.26**package**

A named system, subsystem, or defined set of components considered as a single entity for the purposes of a design study or for procurement (e.g. subsea tree, control system).

3.1.27**performance**

A measure of how well an item performs a required function (e.g. the rate at which a valve closes on demand).

3.1.28**probability**

A number between zero (0) and one (1) expressing the likelihood that a specific event will occur.

NOTE Probability is usually expressed as the ratio of the number of actual occurrences to the number of possible occurrences.

3.1.29**process**

An arrangement of tasks directed toward a specific objective.

3.1.30**production availability**

The ratio of actual production to a reference (e.g. planned) production level over a specified period of time.

3.1.31**qualification**

The process of confirming, by examination and provision of evidence, that equipment meets specified requirements for the intended use.

3.1.32**redundancy**

Existence of more than one means to perform a required function (e.g. by duplicating items).

NOTE Redundancy is one means of achieving fault tolerance.

3.1.33**reliability**

The ability of an item to perform a required function, under given conditions of production, environment, and usage, for a required time interval.

NOTE The term "ability" is often interpreted as probability.

3.1.34**reliability and maintainability data****RM data**

Data collected to support analysis of reliability, maintainability, and availability of systems.

NOTE Reliability and maintainability (RM) data is the term applied by ISO 14224. ISO 20815 refers to reliability data instead.

3.1.35**risk**

The potential for the realization of unwanted, negative consequences of an event.

NOTE Risk may be measured in several ways (e.g. as the probability of occurrence of an unwanted event during a given time or as the product of the frequency of occurrence of an adverse event and a numeric measure of the consequences of the event).

3.1.36

specification

The document in which function, performance, design, and operating requirements are defined, together with associated reliability and integrity goals and requirements.

3.1.37

system availability

The ratio of time a system is functional or in a functional state (uptime) to the total time it is required or expected to function.

NOTE System availability can be specified at field system, package, or subsystem level.

3.1.38

technical risk

Risk associated with the achievement of a technical goal, criterion, or objective that applies to undesired consequences related to technical performance, human safety, mission assets, or environment.

3.1.39

uncertainty

A state of having limited knowledge where it is impossible to exactly describe the existing state or future outcome(s).

3.1.40

uptime

The time interval during which an item is functional.

3.1.41

validation

Confirmation, through the provision of objective evidence, that the requirements for a specific intended use or application have been fulfilled.

NOTE 1 The term “validated” is used to designate the corresponding status.

NOTE 2 The “use or application” conditions for validation can be real or simulated.

3.1.42

verification

Confirmation, through provision of objective evidence, that specified requirements have been fulfilled.

NOTE 1 The term “verified” is used to designate the corresponding status.

NOTE 2 Confirmation can comprise activities such as:

- performing alternative calculations;
- comparing a new design specification with a similar proven design specification;
- undertaking tests and demonstrations; and
- reviewing documents prior to issue.

3.2 Acronyms and Abbreviations

For the purposes of this document, the following acronyms and abbreviations apply.

ALT	accelerated life testing
AUV	autonomous underwater vehicle
BOP	blowout preventer
CAPEX	capital expenditure
CCFA	common cause failure analysis
CFD	computational fluid dynamics
CM	configuration management
CP	cathodic protection
CRO	control room operator
DfRI	design for reliability and integrity
DPIEF	define, plan, implement, evaluate, and feedback
EC	eddy current
ESDV	emergency shutdown valve
ETA	event tree analysis
FAT	factory acceptance test
FEA	finite element analysis
FEED	front-end engineering design
FFOP	failure-free operating period
FMECA	failure modes, effects, and criticality analysis
FRACAS	failure reporting and corrective action system
FTA	fault tree analysis
GOR	gas-oil ratio
HALT	highly accelerated life test(ing)
HASS	highly accelerated stress screening
HAZID	hazard identification
HAZOP	hazard and operability study
HIPPS	high integrity pressure protection system

HISC	hydrogen-induced stress corrosion cracking
HP	high-pressure
HPU	hydraulic power unit
ILI	in-line inspection
IM-FMECA	integrity management failure modes, effects, and criticality analysis
ITMM	inspection, testing, monitoring, and maintenance
KP	key process
LCC	life cycle cost
LMRP	lower marine riser package
LP	low-pressure
MATIC	manufacture, assembly, testing, installation, and commissioning
MBS	multibeam sonar
MCS	Monte Carlo simulation
MFL	magnetic flux leakage
MFOP	maintenance-free operating period
MOC	management of change
MTBF	mean time between failure
MTTF	mean time to failure
MTTR	mean time to repair
NPV	net present value
OEM	original equipment manufacturer
OPEX	operating expenditure
OREDA	offshore reliability data
PARLOC	pipeline and riser loss of containment
P-FMECA	process failure modes, effects, and criticality analysis
PRM	project risk management
PRS-FMECA	preparedness response scheme failure modes, effects, and criticality analysis
QA	quality assurance
QC	quality control
Q-FMECA	qualification failure modes, effects, and criticality analysis

RAM	reliability, availability, and maintainability
RBD	reliability block diagram
RBI	Risk-based Inspection
RCA	root cause (failure) analysis
RCFA	root cause failure analysis
RCM	reliability centered maintenance
RCMM	reliability capability maturity model
R&D	research and development
RDT	reliability demonstration testing
RIAD	reliability and integrity assurance document
RIM	reliability and integrity management
RM	reliability and maintainability
ROTV	remotely operated towed vehicle
ROV	remotely operated vehicle
SCC	stress corrosion cracking
SCM	subsea control module
SIL	safety integrity level
SIT	system integration test
SOL	safe operating limit
SQP	standard qualification program
SSIV	subsea isolation valve
SSS	side-scan sonar
TQP	technology qualification program
TRAR	technical risk assurance review
TRC	technical risk categorization
TRL	technology readiness level
USV	underwater safety valve
UT	ultrasonic transducer

4 Document Outline and Application

4.1 General

Users of this RP should gain a better understanding on how to manage an appropriate level of reliability and integrity through the life cycle of their systems. Industry-wide users should be able to:

- recognize the trade-off between upfront reliability, integrity, and engineering effort vs. operational integrity management and maintenance effort;
- effectively manage and respond to regulatory requirements or guidance (see API 75) related to or affecting subsea equipment reliability and integrity performance;
- provide better assurance of future reliability and integrity performance of subsea systems;
- effectively manage the risks from using novel equipment (including standard equipment in novel applications) and standard equipment;
- schedule projects and operational activities, including maintenance and intervention, with sufficient time to address all the technical risks.

Overall, application of this RP should lead to a better understanding of technical risk and, therefore, greater confidence in delivering economically or technically challenging developments.

Reliability and integrity are best addressed through industry-wide cooperation in terms of best practice, managing failures that occur and the collection and analysis of performance data. This RP aims to provide a common framework and language for developing common understanding and cooperative progress within the subsea oil and gas industry for the specification and demonstration of reliability and integrity achievement.

The achievement of improved subsea equipment availability and integrity requires good engineering and management processes, practices, and behaviors at an organizational level to manage and minimize the potential for equipment failure.

The focus of this RP, however, is on specific activities (or tasks) that can be implemented within projects and operations to achieve immediate and tangible improvements to system performance.

4.2 Document Road Map

Figure 1 below shows a flow diagram of how the document may be read by different users as well as a brief description of what can be found in each section. Given that some users may be familiar with the First Edition of API 17N, the flow diagram provides an insight into where an experienced user of the document may want to refer, i.e. the annexes. A new reader, however, is recommended to read through the document's main body to understand the philosophy and its application to subsea asset life cycles. Managers may wish to refer to Annex B for guidance on the KPs and preparation for their implementation within a company or project.

NOTE 1 More detailed guidance on technology qualification has been moved from API 17N to API 17Q, Second Edition.

NOTE 2 API 17Q, Second Edition is planned for publication in 2017. Annexes E and F are included in this document to provide interim guidance and will be removed once API 17Q, Second Edition is published. For all references in the text to API 17Q, the reader will need to refer to these annexes until API 17Q is published.

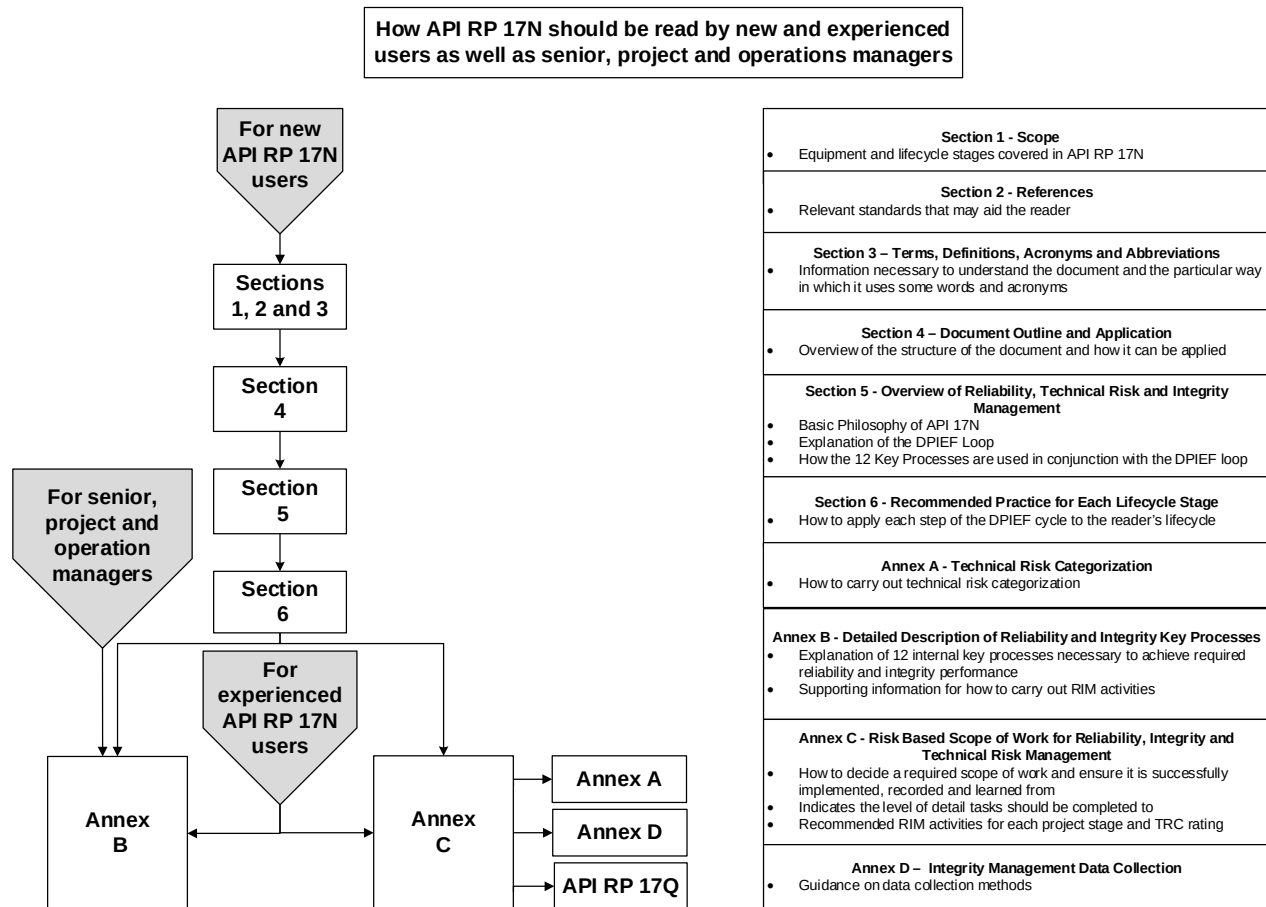


Figure 1—API 17N Road Map

4.3 Project and Operation Applicability

The RP is provided as a guide to RIM for the whole of the subsea industry. It is intended to be applicable to all project scopes and existing assets, including:

- field developments using field proven or fully qualified hardware;
- field upgrades to replace obsolete equipment, extend life of field, or tie back new wells into existing infrastructure;
- new technology development projects;
- field developments in which existing technology is used under extended operating conditions;
- field developments involving new technology.

The philosophy of this RP is to prioritize RIM efforts based on the level and source of technical risk. More detailed reliability and integrity effort is recommended for projects/equipment involving high technical risk and for underperforming assets.

For projects/equipment involving low technical risk (e.g. some projects using field proven or fully qualified hardware), little additional reliability and integrity effort beyond existing good engineering and management practices is expected. However, the guidance within will provide additional considerations for increasing the RIM performance.

4.4 Equipment Applicability

4.4.1 General

This RP applies to all subsea equipment, including:

- subsea equipment and hardware, including related control systems;
- installation facilities and tools;
- system interfaces (e.g. chemical injection interface with a production system);
- subsea intervention and maintenance.

4.4.2 Subsea Equipment and Hardware

From the sand face downhole to the top of the riser, plus the hydraulic power unit (HPU)/master control station (and other subsea-specific surface equipment) and typically including wellheads (both subsea and mud line casing suspension systems) and trees; pipelines, jumpers, flowlines, and end connections; processing equipment; controls, control lines, and control fluids; instrumentation; templates; and manifolds and production (including water injection) risers (both rigid and flexible).

4.4.3 Installation Facilities and Tools

Risks associated with installation facilities, equipment, tools, and procedures should be addressed to ensure that:

- construction, installation, and commissioning procedures will not adversely affect the reliability and integrity of permanently installed equipment;
- unreliability and unavailability performance of required tools and equipment do not impact start-up schedules and hence the production availability.

4.4.4 System Interfaces

Hardware interfacing risks, especially those that also represent boundaries between different organizations, should be identified and addressed.

4.4.5 Subsea Intervention and Maintenance

Considers performance history of the hardware that has been used or can be used to better scope interventions.

Intervention methods, tools, workover, and inspection risks should be addressed such that:

- intervention and maintenance procedures will not adversely affect the reliability and integrity of permanently installed equipment;
- unreliable performance of required tools and equipment do not impact production availability or intervention efficiency.

Although this RP is focused on subsea production equipment, the guidance is generic and may be easily adapted to address the design of subsea hardware used for drilling operations, including the subsea blowout preventer (BOP) and lower marine riser package (LMRP).

4.5 Life Cycle Stages

This RP covers all stages of a subsea system life cycle, including:

- Feasibility;
- concept selection;
- front-end engineering design (FEED);
- detail design;
- manufacture, assembly, testing, installation, and commissioning (MATIC);
- operation;
- decommissioning.

4.6 Company Documentation

Figure 2 shows a typical example of a document hierarchy that may be used for the implementation of reliability, technical risk, and integrity management within a company. The diagram shows a high-level strategy document communicating company intent. This should refer to high-level technical practice documents addressing requirements for projects and operations. Together these documents set out the roles and responsibilities of individuals and groups within project and operation teams.

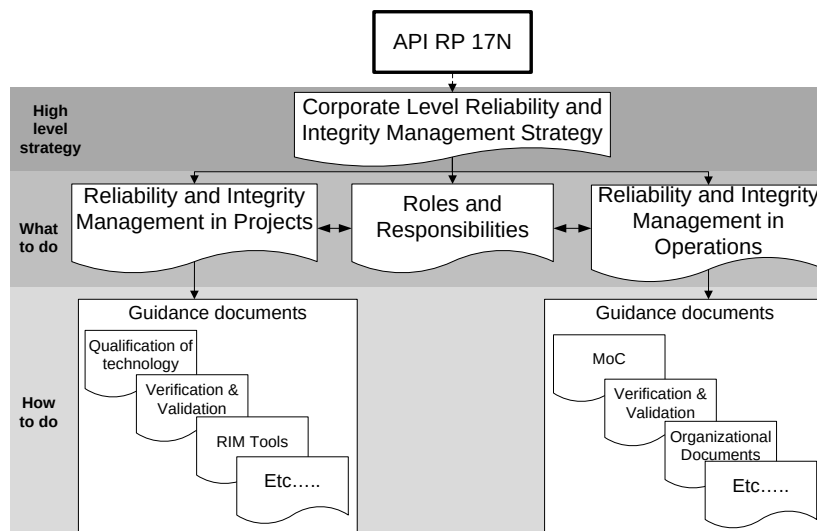


Figure 2—How API 17N Applies to a Company's Reliability, Technical Risk, and Integrity Management Documentation

The technical practice documents are typically supported by a series of guidance notes and/or manuals that contain detailed information on how to carry out tasks identified by the project or operations teams in order to achieve the required levels of reliability, technical risk, and integrity. Individual documents would also contain guidance on KP implementation, though some of these may well have wider applicability than reliability, technical risk, and integrity management and therefore need input from other teams within the company.

API 17N provides guidance on developing an appropriate framework for companies to establish their reliability, technical risk, and integrity management strategy.

5 Overview of Reliability, Technical Risk, and Integrity Management

5.1 General

This section summarizes the basic philosophy behind this RP and explains the reliability and integrity assurance loop (DPIEF loop; see Figure 3) that is the basis behind all the RIM activities described in this document, where DPIEF stands for:

- define;
- plan;
- implement;
- evaluate;
- feedback.

This assurance loop is applied at each life cycle stage of the subsea system (see Section 6 and Annex C):

- feasibility (see 6.5 and C.2);
- concept selection (see 6.5 and C.3);
- FEED (see 6.5 and 6.4);
- detailed design (see 6.5 and C.5);
- MATIC (see 6.6 and C.6);
- operations (see 6.7, C.7, and C.8);
- decommissioning (see 6.10).

Early life stages of field development projects are focused on operator-led activities with involvement from engineering contractors increasing as the project progresses. Supplier activities are generally introduced during FEED and continue during detailed design and MATIC.

5.2 Underlying Philosophy

API 17N is based on the 12 “key” RIM processes listed in 5.9 and described in detail in Annex B. These processes, if adopted, can provide an organization with the basis for a well-organized and rigorous system for the management of reliability, technical risk, and integrity.

The underlying philosophy is based on a belief that:

- the achievement of system reliability and integrity will add value to a field development through maximization of equipment reliability, minimization of intervention for maintenance or replacement of failed equipment, and by preventing events that may cause harm to people or damage the environment;
- the achievement of equipment reliability, integrity, and system availability is primarily founded on the implementation of good reliability and technical risk management practices formally integrated with good subsea engineering using the best available analytical tools and techniques to inform engineering decisions throughout the project life cycle;
- reliability and integrity are core business values that companies are seeking to achieve.

Senior management should ensure that the framework followed adheres to company policy, core company values, and statutory and regulatory requirements and that appropriate levels of authority for decision-making have been agreed.

For practical purposes, the 12 KPs are implemented as a number of integrated RIM activities.

The core activities in the reliability and integrity assurance cycle are comprised of the five basic activities illustrated in Figure 3. These activities are applied during each stage of a subsea system's life cycle and encourage a “stop and think” approach such that:

- clear objectives are set for the work;
- appropriate activities are selected that will meet the objectives;
- there are sufficient time and resources to carry out the activities and analyze results;
- there is confirmation that the activities have been completed correctly and fully evaluated and audited;
- evidence is collated and documented to provide reliability and integrity assurance;
- lessons are learned to improve future asset design, delivery, and operation.

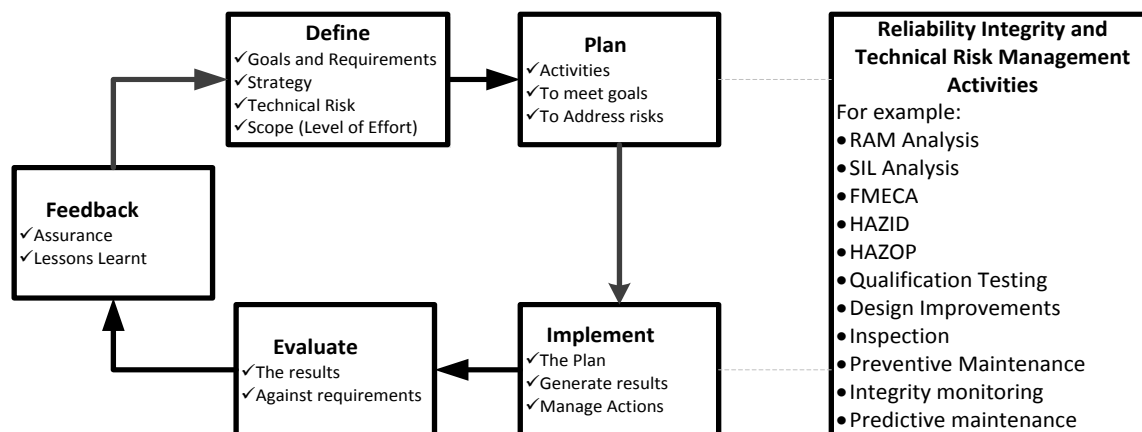


Figure 3—DPIEF Reliability and Integrity Assurance Cycle

Much of this is good organizational practice, but in addition, the reliability, integrity, and risk management focus is on removing potential causes of poor reliability and loss of integrity, with continuous improvement achieved at every step.

5.3 Assessment and Management of Risk

5.3.1 General

The assessment and management of risk is fundamentally important to integrity management and also supports achievement of production availability requirements. Identification of risk should include health, safety, financial, environmental, and reputational effects.

The key elements of risk assessment and management are outlined in Figure 4.

NOTE More detailed guidance on risk management is addressed by other standards such as ISO 31000 [2].

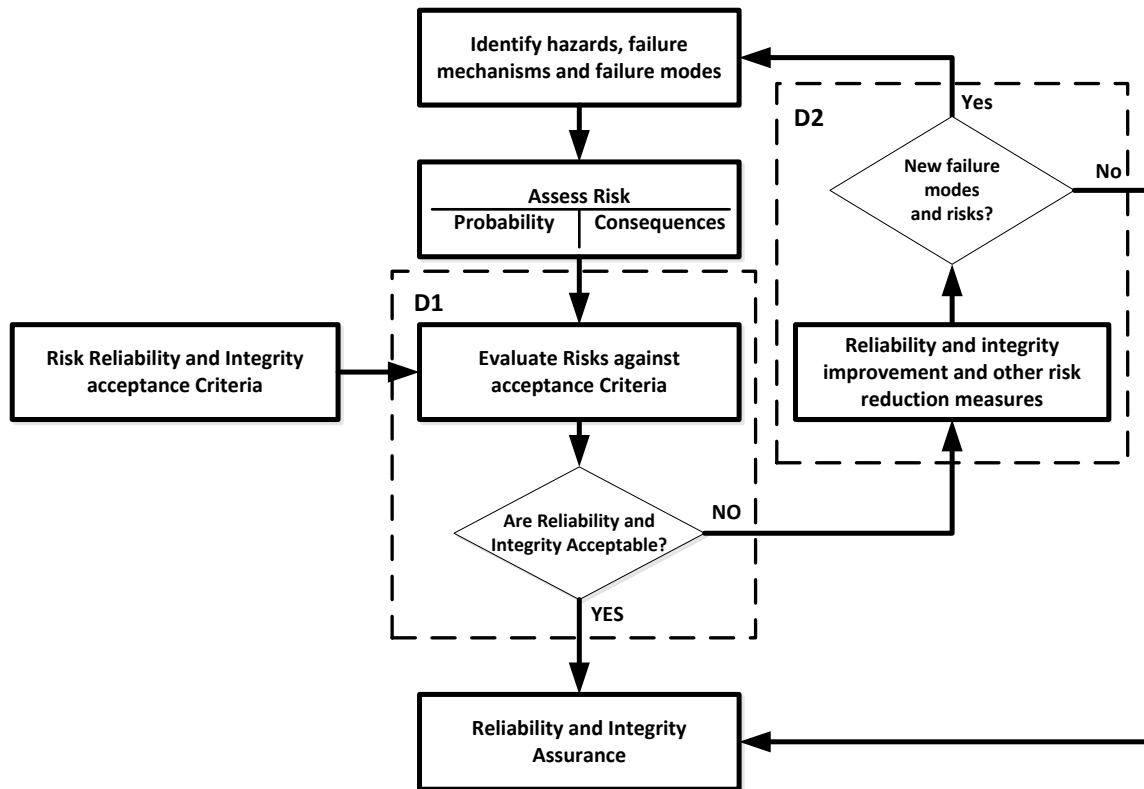


Figure 4—Assessment and Management of Risk

The key elements of risk assessment and management should involve the following.

- Identification of potential failure events and hazards:
 - hazards should include evaluations for hardware, software, the environment, and human error.
- Risk assessment for each hazard, failure mechanism, or failure mode, which will generally involve:
 - estimating the probability of failure events;
 - estimating the consequences of failure should the failure mode or hazard be realized;
 - identification of barriers, mitigation means, and emergency response plans (e.g. using bowtie analysis).
- Evaluation of the risks against risk acceptance criteria set by the company responsible for managing the risk.
- Where the risks are unacceptable, identification of actions to improve reliability and/or integrity and reduce or manage risk.
- Evaluation of the effectiveness of the barriers in place (safeguards and mitigation means).
- Where the risks are acceptable, provide feedback and assurance to senior management, customers, and other stakeholders as needed.

5.3.2 Risk Management Strategies

Possible risk management strategies can typically include:

- eliminate or reduce the probability of hazards, failure modes, and failure mechanisms in design, MATIC, and operations;
- improvements to inherent reliability, reduction of probability of failure through the project life stages;
- detection of the causes of potential failures and taking measures to prevent failures occurring during operations;
- detection and reduction of the likelihood of failures in operation for both the system and operational processes;
- mitigation of consequences should failure be realized;
- development of emergency plan responsiveness.

5.3.3 Key Risk Management Decisions

There are two key decision points (Figure 4) in the management of reliability, integrity, and risk:

- (D1) evaluation of risk against risk acceptance criteria;
- (D2) reliability/integrity improvement and risk reduction.

These together with cost-benefit analysis are the key elements of the evaluate step of the DPIEF assurance cycle (see 5.7).

5.4 Define Step of DPIEF Cycle

5.4.1 General

Define activities should include:

- identification of all required functions, or combination of functions, of an item that is considered necessary to provide a given service;
- accountability and competency of personnel to drive reliability, integrity, and risk management throughout the life cycle;
- input of relevant lessons learned from previous projects and operations;
- identification and categorization of technical risk and uncertainty;
- identification of technology readiness for any new or modified technology to be developed during the project stage and deployed in operations;
- identification of project and operations RIM goals and requirements;
- prioritization of reliability, integrity, and technical risk management effort for the asset.

5.4.2 Input of Lessons Learned

This may be provided as a review document for the project team or as a workshop process involving inputs from experienced engineers [including operations engineers, service provider(s), and supplier(s)] or both. A

company lessons learned database is a useful resource for this activity in addition to service provider(s) and supplier(s) input.

Lessons learned include, but are not limited to:

- process improvements based on previous positive or negative outcomes;
- evaluation of incident reports and corrective actions related to both system and human failures.

5.4.3 Assessment and Categorization of Technical Uncertainty and Risk

The risk assessment effort should be tailored to the level and source of technical uncertainty and risk for the system life cycle stage being considered. Assessments should seek to identify changes from previous projects/assets (change factors) that introduce uncertainty in the ability of the equipment to operate reliably in the field.

The parameters considered as potential sources of uncertainty should include:

- required operating environment (in terms of pressures, temperatures, water depths, production fluids, and seabed conditions, etc.) relative to previous experience;
- the relative novelty of technology to be used in each concept;
- how system configuration deviates from previous practice;
- company and industry experience of using similar systems in similar applications;
- current expected concept reliability and integrity compared with project reliability and integrity goals and requirements;
- how system operations deviate from previous practice.

The tools used for the assessment of technical uncertainty and risk may take different forms during different stages of the life cycle, for example:

- a simple high-level technical review may filter out equipment with technical uncertainty during early design stages such as concept selection and FEED;
- consequence/severity analysis can be used to identify equipment with the greatest impact on production or safety and environment;
- assessment of the potential causes of failure, the consequences of potential failure and the likelihood for each failure [e.g. by integrity management failure modes, effects, and criticality analysis (IM-FMECA), root cause (failure) analysis (RCA), process FMECA (P-FMECA)];
- human factors evaluations can identify sources of human error from FEED through to decommissioning and can identify the possible effect of those errors on reliability and integrity;
- technical risk reviews can be used to identify where equipment is being designed beyond current experience.

The technical risk and uncertainty categorization tool recommended by this RP is described in Annex A. This also provides an indication of the level of RIM effort that may be required by the project/operations team to manage the technical risk and uncertainties.

5.4.4 Goals and Requirements

It is important for the project and operations teams to be clear on what they and the asset are aiming to achieve and why. This includes:

- production requirements, i.e. the ability to maintain uptime and minimize downtime;
- integrity requirements, i.e. the ability to contain production fluids, isolate equipment, and remain fit for purpose over the life cycle of the system, while protecting safety, health, and environment;
- risk acceptance criteria, i.e. the limit of acceptable or tolerable risk.

Goals identify the reliability performance the project team **would like to achieve**.

NOTE It is unlikely that integrity goals will be defined for a project as these are more likely to be defined as regulatory requirements.

Requirements identify the reliability and integrity performance that the asset is required to achieve in order to meet the business and regulatory objectives.

Reliability and integrity goals and requirements should be:

- consistent with company and/or client business requirements for production, safety, and environment;
- used to drive the design and system developments;
- fully supported by senior management, project teams, operations teams, vendors, and contractors.

Goals and requirements may be expressed in words (qualitative) or numerically (quantitative); see B.3.

At each life cycle stage, the overall project goals and requirements should be reviewed and verified by the project and operations teams.

The level of equipment (project, package, subsystem, etc.) that the goals and requirements are applied to should be developed in line with the life cycle stage as summarized in 6.3.

5.4.5 Strategy to Be Used

The strategy is the general approach the project and operations teams will take to achieve the stated goals and requirements in a way that adds value to the asset.

- **Reliability Strategy.** Achieve a required level of performance or system availability by extending the life of equipment before failure or maintenance.
- **Maintainability Strategy.** Achieve a required level of performance or system availability, for example by minimizing the time to restore failed equipment to an operable state.
- **Standardization Strategy.** Achieve acceptable reliability and integrity through use of field proven or standard equipment as far as practicable.
- **Risk Mitigation Strategy.** Use operational mitigations, such as spare capacity and rapid intervention responses, to reduce the effects of system failure and human error.
- **Integrity Strategy.** Identify the processes (barriers and means of mitigation) that will be instituted to maintain integrity during operations (i.e. the integrity management processes).
- **Obsolescence Strategy.** Identify equipment that are likely to become obsolete within the life cycle of the asset and develop an obsolescence management plan.

There will inevitably be a trade-off between different strategies to achieve the overall goals and requirements set. An example of such a trade-off for a high integrity pressure protection system (HIPPS) system would be that between integrity (fail-safe) and production availability and how this impacts the design process.

This RP recommends implementing a reliability, integrity, and technical risk management program or incorporating the essential elements of such a program into a broader project and asset management program, which has the ability to address some, or all, of the above.

5.4.6 Identification of Scope of Work

The scope of work for any given life cycle stage is the list of activities that will address the identified technical risks and the specified goals and requirements for the equipment with the system scope. This may include, but is not limited to:

- system production availability analysis to determine the extent to which design configurations meet economic production targets;
- system reliability and integrity assessments to identify the probability of system failures (e.g. failure of the chemical injection system, the probability of failing to shut-in a well, shutdown a complete system or start up a system, etc.);
- consequence/severity analysis to identify critical systems;
- FMECA to identify and, where practicable, design out potential failure modes;
- obsolescence assessments to identify equipment that may become obsolete during the field life;
- safety integrity level (SIL) assessments for safety critical subsea equipment (e.g. HIPPS);
- design reviews to expose equipment and systems at various stages of design to the opinion of subject matter experts;
- testing and analysis to develop understanding of and demonstrate potential for functionality and reliability;
- reliability centered maintenance (RCM) to develop a robust subsea maintenance and integrity management system during operation;
- defining processes to be implemented for life of field to assure integrity, such as Risk-based Inspection (RBI) processes;
- human error assessment [e.g. as part of hazard and operability study (HAZOP);
- hazard identification (HAZID), or P-FMECA] to evaluate design, manufacturing, and operational processes for the likelihood of human errors and to identify means of mitigating the potential for error. For more information on human error evaluation, see Reference [3].

All activities should:

- be appropriate for the level of risk identified;
- be realistically achievable within the time frame of the wider project schedule;
- add value to the project;
- be cost effective;
- be consistent with the project goals, requirements, and strategy;
- include input from relevant departments involved with the product's life cycle.

5.5 Plan Step of DPIEF Cycle

The RIM plan establishes the detail of how the scope of work is to be accomplished. A plan should be developed for each stage in the subsea life cycle and should cover such areas as:

- the specific activities to be carried out (analyses, assessments, reviews, etc.);
- resources to be used (people, software/hardware tools, etc.) and time period that each resource is required;
- roles, responsibilities, and accountability for all personnel involved at all relevant management levels;
- deliverables for each activity;
- any requirements for verification and validation;
- schedules and milestones.

As projects proceed the organizations involved will change, for example when suppliers are selected and at project handover to operations. The RIM plan should clarify which organization will do what, within each activity, in terms of:

- specifying requirements;
- completing the work;
- verifying that the work meets the requirements;
- identifying physical and organizational interfaces.

The plan should only contain what is achievable within the schedule and budget constraints. If it is necessary to omit previously identified activities, this should be with clear justification and understanding of the potential consequences (of carrying unmitigated risk).

5.6 Implement Step of the DPIEF Cycle

The process of implementing the activities at each life cycle stage should include the following activities:

- breaking down the plan into a series of tasks or actions;
- tracking and close out of plans to ensure completion;
- verification and checking against stated goals and requirements to provide assurance that the identified technical risk has been addressed to a sufficient degree for the project stage.

Implementation of the plan is supported, through the application of good management practices as described by the KPs in Annex B.

Throughout the life cycle, implementation activities are intended to provide assurance that:

- potential failure modes that could affect system performance have been analyzed and managed;
- all design decisions are consistent with the reliability, availability, maintainability, and integrity goals and requirements;

- qualification of equipment has addressed function, performance, reliability, integrity, integrity manageability, and maintainability required by the business and is at an acceptable level of progress to proceed to the subsequent life cycle stage;
- all identified lessons learned from previous projects and operations have been incorporated;
- the supply chain is fully integrated into the reliability, integrity, and technical risk management program;
- the achieved reliability, availability, maintainability, and integrity performance will allow production, financial, and company performance goals and requirements to be met.

5.7 Evaluate Step of the DPIEF Cycle

As the plans are implemented and results are delivered at each life cycle stage, they should be analyzed and evaluated against the specified goals and requirements and risk acceptance criteria (see Figure 4) to identify actions for the next stage in the life cycle, and for management of emergent risk, for example:

- evaluation of reliability, availability, and maintainability (RAM) analysis results against performance availability objectives to select best design configuration at concept selection stage;
- evaluation of results from qualification tests and activities during FEED and detailed design for new technologies to be used in the project against acceptance criteria;
- evaluation of inspection and integrity monitoring results during operation against acceptance criteria;
- evaluation of residual risks that cannot be completely eliminated;
- evaluation of the capability of a company to manage reliability and integrity in a project or operations [e.g. using a reliability capability maturity model (RCMM) audit; B.12.4.2].

Risk acceptance criteria used by the project team should be agreed with the operations team and be in line with overall business policy. The method of risk evaluation and associated risk matrix should be consistent throughout the life cycle.

The technical risk categorization (TRC) level should be revisited to identify changes to the original assessment arising from any new information as the design evolves. New technical risks generally require additional action management; these risks should be addressed and managed through appropriate strategies to meet defined risk acceptance criteria (discussed in 5.3.2).

5.8 Feedback Step of the DPIEF Cycle

5.8.1 General

The feedback step should include:

- feedback of lessons learned;
- operator's technical risk assurance review (TRAR);
- reliability and integrity assurance documentation (RIAD).

For all life cycle stages, the feedback and assurance step is used to provide documented evidence to:

- support decision-making at each life cycle stage (e.g. as part of the decision support package);
- assist other projects at earlier stages.

5.8.2 Lessons Learned Feedback

A review of the work done may include a review to identify and record any lessons learned that may be of value to future projects, such as:

- technical risks, failures, or unwanted events that were not anticipated, but could have been;
- risks that were overestimated and why;
- successes that can be applied to other projects (opportunities);
- suggested improvements on how to complete specific activities (resource, processes, schedule, etc.);
- results of audits.

Feedback aims to capture and distribute lessons learned such that they are usefully utilized. A key interface is that between the project team and the operations team. Important lessons learned in operations should be communicated to future project teams to enable operational reliability and integrity experience to be an input to the design process.

5.8.3 Operator's TRAR

TRARs may be used by an operator to identify any residual risks that may have been overlooked or insufficiently addressed by an equipment vendor's risk assessments.

Reviews should be performed for equipment with high levels of technical risk:

- new technology;
- equipment undergoing major design changes or major changes in operations;
- high-level reviews are performed at the end of FEED before detailed design;
- detailed reviews are performed toward the end of detailed design before manufacture.

5.8.4 RIAD

Throughout the life cycle, typically at the end of each life cycle stage, a documented record should be produced. The RIAD should cover:

- activities performed and completed;
- evidence in the form of a summary of results with links, as appropriate, to detailed reports;
- key findings from studies performed (e.g. testing and analyses);
- decisions made and implemented measures;
- claims related to the reliability and integrity goals and requirements;
- assurance that the technical risks identified for each package can be managed within the project schedule and budget.

The RIAD provides documented assurance that the technical risks and uncertainties have been addressed.

Assurance claims should only be based on the evidence reported in the RIAD and should clearly outline the extent to which reliability and integrity goals and requirements have been met.

5.9 KPs for RIM

There are 12 organizational KPs that support delivery of reliability and integrity and implementation of the DPIEF cycle. The majority of organizations in the subsea industry practice many of these KPs in various forms; however, this RP provides information on key features of each process that promote good reliability, integrity, and risk management practice.

The relationship between the DPIEF cycle and the 12 KPs is shown in Figure 5.

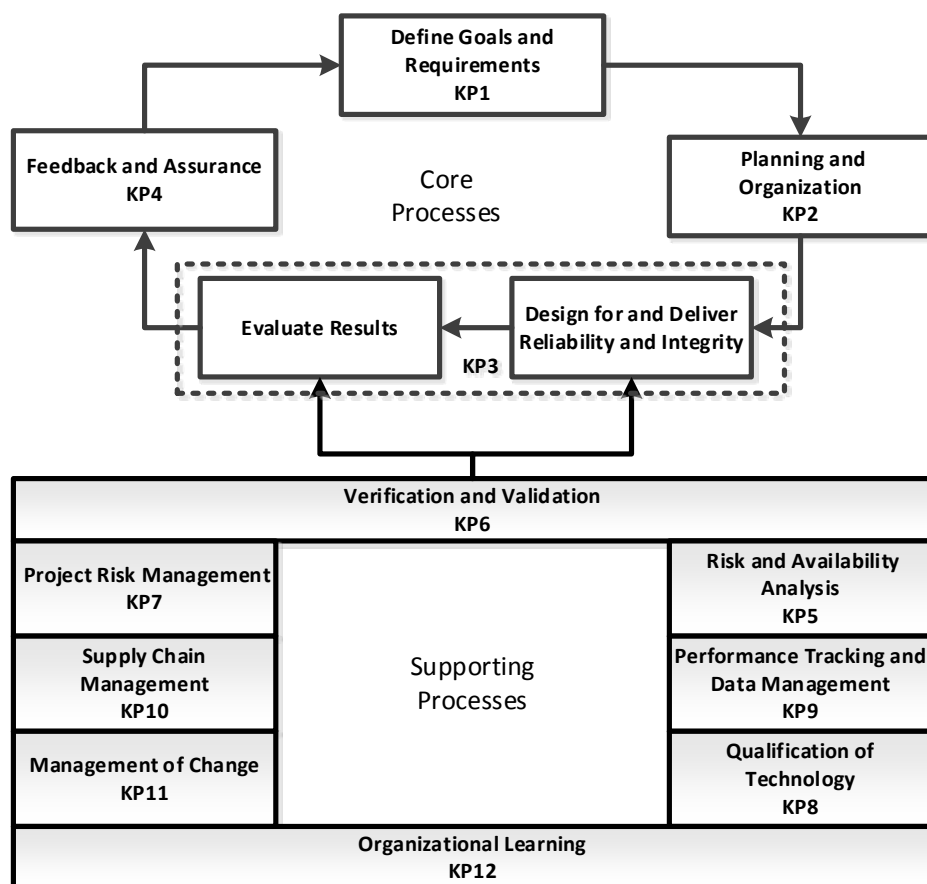


Figure 5—KPs for RIM

KP 1—Define Goals and Requirements ensures that the project and operational goals and requirements are fully aligned with overall business performance and regulatory objectives and provides the focus for delivery of reliability and integrity assurance.

Table 1—Operator Business Requirements and Reliability/Integrity Implications

Operator Business Requirements	RIM Focus
High production availability	Reliability: maximize uptime
	Maintainability: minimize downtime
Best value field development	Maximize production
	Minimize operational expenditure (OPEX)
High level of integrity assurance	Containment: low probability of loss of containment
	Isolation: low probability of failure on demand

The trade-off between the purchase cost and the operational expenditure should be formally recognized when considering the need for reliability and maintainability improvement (see B.3 for more details). Requirements related to the trade-off between automated design and human operational processes need to be assessed to evaluate the risks of human error compared to a more complex design.

Each organization should clearly define the authority level at which goals and requirements need to be agreed.

KP 2—Planning and Organization allocates leadership and resources to the required RIM activities such that they add value to the asset overall and do not adversely impact on schedule requirements. The activities identified should be considered an integral part of the engineering process and integrated with conventional engineering tasks in the project/asset management system. The right resources are identified for detection and correction/mitigation of issues throughout the cycle (see B.4 for more details).

KP 3—Design for and Deliver Reliability and Integrity is the key process for delivering reliability and integrity of subsea installations (see B.5 for more details). Information gathered from reliability and integrity assessment activities should be evaluated during the design process to drive the design's ability to achieve and deliver the specified availability and integrity requirements. Decisions on what actions to take require a good understanding of both failure mechanisms and how inappropriate actions taken during the design, manufacture, assembly, test, and installation phases contribute to failure in operation.

KP 4—Feedback and Assurance is the process of communicating the information pertaining to reliability, integrity, and technical effectiveness of the system to other members of a project/operations team and to senior management. The key output from the reliability and integrity assurance process is the RIAD (see B.6 for more details).

KP 5—Risk and Availability Analysis provides RIM support by identifying failure modes/logic, consequences, and the frequency of occurrence. Analysis and models usually focus on function, hardware, or process. The specific type of assessment will depend on the amount of information available (this will depend on the life cycle stage), the subject of the analysis, and the source of technical uncertainty. The output from the analyses enables clear prioritization of required activities and actions to minimize risk and optimize reliability/availability (see B.7 for more details).

KP 6—Verification and Validation confirms that any given activity is the correct one and that it has been carried out correctly (see B.8 for more details).

KP 7—Project Risk Management (PRM) addresses nontechnical budget and technical risks throughout the project life cycle (or field upgrades during operations) to enable all risks to be identified, quantified, managed, and preferably eliminated (see B.9 for more details).

KP 8—Qualification of Technology is the process by which systems are examined and evidence is provided to demonstrate that the technology employed meets the specified requirements for the intended use (see B.10 for more details).

KP 9—Performance Tracking and Data Management collects and organizes reliability and integrity performance data from all life cycle stages of every subsea asset to support asset management and the assessment of reliability, integrity, availability, and production efficiency (see B.11 for more details).

KP 10—Supply Chain Management plans, manages, and adds efficiency and value during planning, sourcing, procurement, conversion, and logistics management activities. Supply chain management ensures that reliability, integrity, obsolescence risks, and technical risk management goals, requirements, achievements, and lessons learned are communicated within and between all organizations (including all suppliers) involved in the life cycle (see B.12 for more details).

KP 11—Management of Change (MOC) ensures that any changes in the project (to scope, design, plan, process, etc.) or in operations (procedures, remedial intervention, field upgrades) are consistent with the

reliability, integrity obsolescence risk, and technical risk management goals and requirements. It also ensures that the change and impacts are fully assessed and managed (see B.13 for more details).

KP 12—Organizational Learning provides a common framework to capture an organization's learnings over an asset's life cycle and communicate them back into the organization to be adopted by later projects and operations teams. The lessons learned usually cover the whole life of the asset from strategic thinking and decision-making, through project execution and asset operation and should include both good and bad practice (see B.14 for more details).

These KPs provide a supporting environment for the reliability, integrity, and risk management activities. When the appropriate process is identified, further information and guidance is available within Annex B. When these processes are implemented across an organization, the reliability, integrity, and technical risk management effort for each subsea system is reduced (good practice that otherwise had to be specified now happens automatically).

Figure 6 provides a summary of the life cycle stages for which different KPs are relevant or may be relevant under some circumstances.

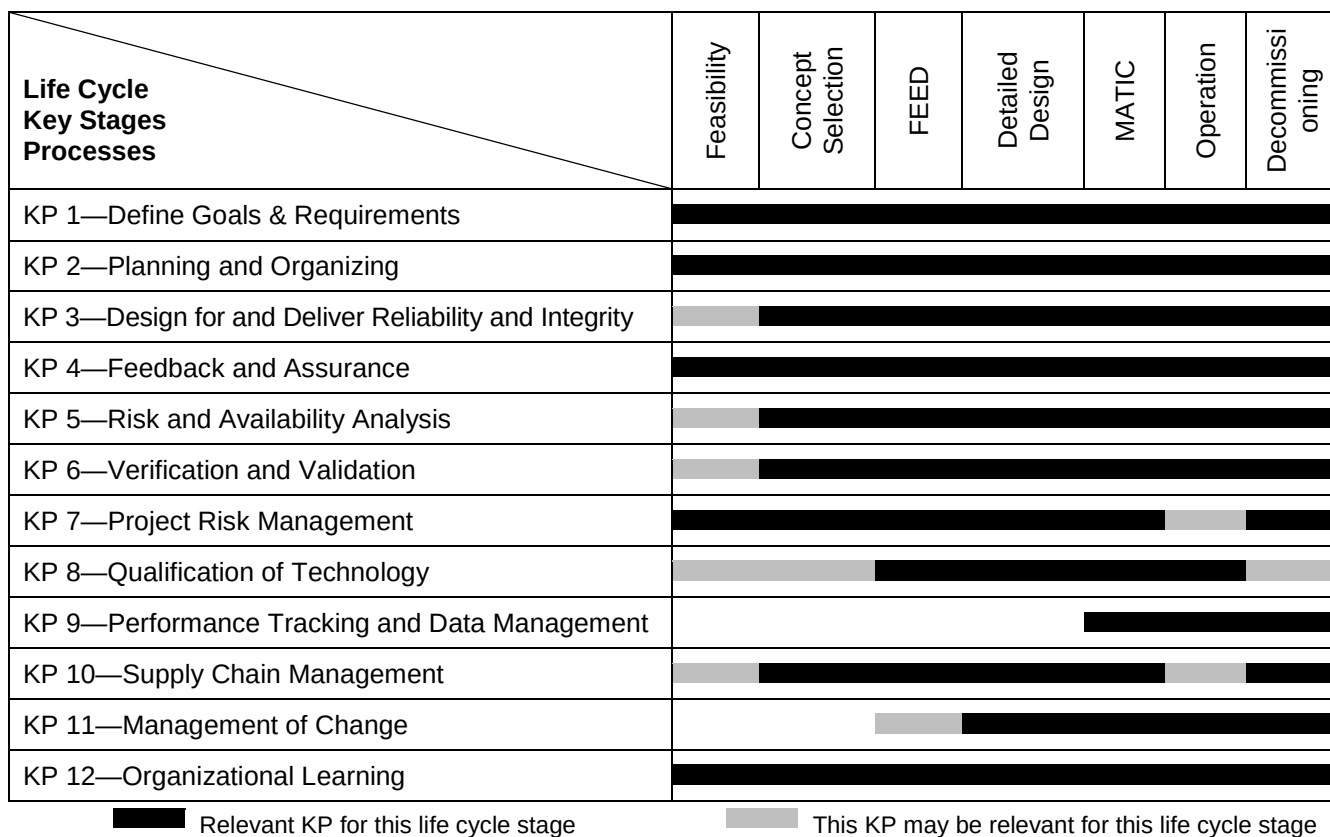


Figure 6—Summary of the Life Cycle

6 Recommended Practice for Each Life Cycle Stage

6.1 General

This section provides a general approach to achieve the desired reliability, integrity, and risk management performance at each stage of the subsea asset life cycle. Further details are provided in Annex C.

6.2 Configuration Management (CM)

CM is not formally addressed in this RP as a separate process. However, the main key elements of a CM process are captured in the current 12 KPs (see Annex B).

CM is a system engineering process that embodies rules, procedures, techniques, methodology, and resources to assure that:

- the configuration of the system and/or item (its physical and performance attributes) are fully documented;
- changes made to any item during design, MATIC, operations, and decommissioning are beneficial and are implemented without adverse consequences;
- changes are managed until incorporated in all affected items.

NOTE Many companies may already have CM as a defined process that can be integrated with the recommendations in this RP. For more information on CM, see Bibliographic Items [4], [5], and [6].

6.3 Application of the DPIEF Assurance Cycle

The life cycle of a subsea system involves a number of stages through which the system is developed and operated. As the life cycle progresses, the subsea system becomes better defined and the focus of the DPIEF cycle at each stage (see Table 2) should change accordingly.

The activities during the project stages of the life cycle are focused on designing-in reliability, integrity, and their manageability. During operations, the focus is on integrity management, production availability, data collection, and understanding root causes of failure. Importantly, operations teams should input into project activities during the design life cycle to ensure operational aspects are addressed.

Table 2—Project and Asset Life Cycle Focus and Considerations

Life Cycle Stage	Focus	Considerations
Feasibility	Project-level view	Considers the overall system challenges to project performance (location, environment, new technology, resources).
Concept Selection	System-level view	Considers the reliability, integrity, and risk implications of technology and operational processes for the different possible system configurations.
FEED	Package-level view	Considers what requirements need to be specified on individual packages to meet overall system goals (e.g. well, manifold, umbilicals, human error), including reliability, integrity, and integrity management requirements.
Detailed Design	Subassembly- and component-level view	Considers the reliability and integrity risks associated with individual components (e.g. gate valves, connectors, sensors).
Manufacture, Assembly, Testing, Installation, Commissioning	Procedural-level view	Considers how procedural control can be used to prevent errors and the introduction of defects that can reduce reliability and integrity performance of the equipment after manufacture. This also includes collecting performance data during testing and installation to improve future projects.
Operations	Procedural-, system-, and component-level view	Considers how procedural control can be used to prevent errors and equipment failures affecting system reliability and integrity performance throughout operations, including interventions. This includes measuring and maintaining actual performance data and taking actions to continuously improve future performance.
Decommissioning	Procedural- and component-level view	Considers how procedural control can be used to prevent errors affecting integrity performance for the decommissioning process. This may also consider the reliability and integrity of components given increasing demand for reuse.

This RP recommends adopting the approach in Figure 7 to apply the DPIEF assurance cycle to the different life cycle stages.

The “double DPIEF loop” shown in operations, is included due to the repetition of the “normal operations loop” (right-hand side loop). Design, by comparison, proceeds iteratively from start to end (at commissioning/hand-over). It is therefore necessary to include a separate “corrective action loop” (left-hand side) within the operations stage to clearly distinguish between normal operations and corrective action.

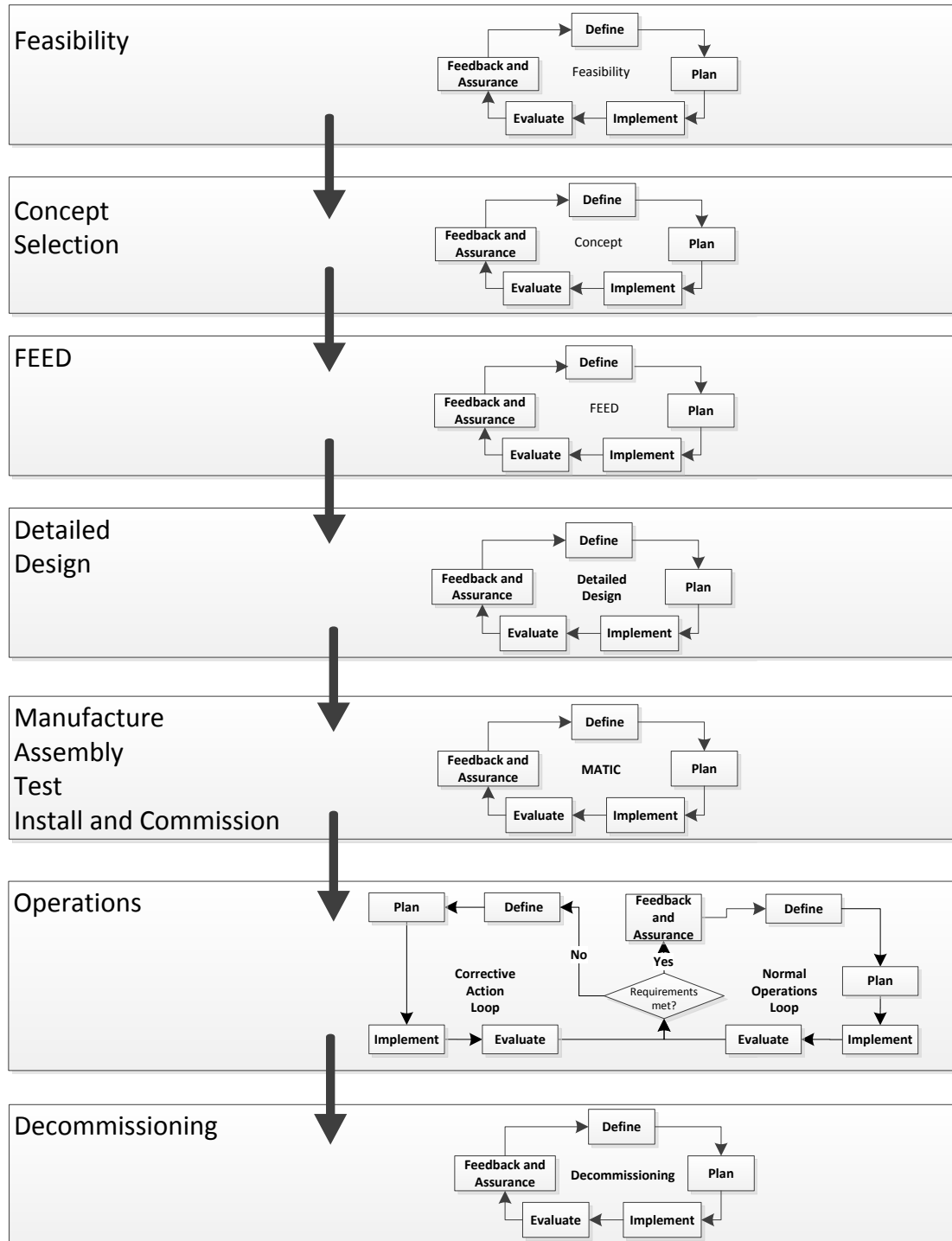


Figure 7—Application of DPIEF Cycle to the Subsea System Life Cycle

The level of RIM effort associated with the reliability, integrity, and risk management activities at each life cycle stage should be consistent with the level of risk identified for the given subsea system and field. This RP recommends the use of TRC for identifying the level of risk and uncertainty (see Annex A).

NOTE Other industry standards (e.g. DNV-RP-A203) use alternative risk categorization and novelty assessment schemes and may be used by some organizations instead of TRC.

Annex C provides specific guidance on application of the DPIEF cycle at each life cycle stage. However, the specific activities required (e.g. application of system reliability analysis) may depend on both the level and source of technical risk as identified by the TRC. Annex C also provides additional guidance on recommended activities at each life cycle stage depending on the risk category.

Regardless of technical risk, there are four activities and associated documentation that should be continuously updated throughout the life cycle and are an integral part of implementation of the DPIEF assurance cycle:

- TRC;
- technology readiness level (TRL);
- statement of goals and requirements;
- RIAD.

In order to achieve consistent outcomes across all projects and assets, organizations should create a generic scope of work for each life cycle stage for each technical risk category. This should then be refined to make a specific scope for the project/asset application.

6.4 Timing of the DPIEF Loop in the Asset Life Cycle

The DPIEF loop is applied at every stage of the asset life cycle; however, the actual time at which a team may initiate activities relevant to a stage will vary. For example, the operations team may usefully initiate definition of operational requirements by providing input to the project team as early as concept selection (see Figure 8).

6.5 Design Stages

From a reliability and integrity perspective, the intent during the design stages may be summarized as:

- create the required inherent reliability, availability, maintainability, and integrity in the design;
- provide evidence of the above through analysis, testing and use of historical performance data.

Annex C provides detailed guidance of RIM activities appropriate for each design stage of the life cycle as indicated in Figure 8.

6.6 Manufacture, Assembly, Testing, Installation, and Commissioning (MATIC)

From a subsea reliability and integrity perspective, the intent during the MATIC stages is to:

- ensure that the levels of reliability, availability, maintainability, and integrity designed into the subsea production system are not compromised by the MATIC activities;
- that any nonconformances, system faults, or human errors in the design itself or introduced during the MATIC stages are identified and corrected. Ideally these should be implemented and managed before production start-up or as soon as possible thereafter.

Section C.6 provides detailed guidance of RIM activities appropriate for the MATIC stage.

		Feasibility	Concept Selection	FEED	Detailed Design	Manufacture Assembly Testing	Installation Commissioning	Operations	Decommissioning
Feasibility (See C.2)	D								
	P								
	I								
	E								
	F								
Concept Selection (See C.3)	D								
	P								
	I								
	E								
	F								
FEED (See C.4)	D								
	P								
	I								
	E								
	F								
Detailed Design (See C.5)	D								
	P								
	I								
	E								
	F								
Manufacture, Assembly, and Testing (See C.6)	D								
	P								
	I								
	E								
	F								
Installation and Commissioning (See C.6)	D								
	P								
	I								
	E								
	F								
Operations (See C.7 and C.8)	D								
	P								
	I								
	E								
	F								
Decommissioning (See 6.10)	D								
	P								
	I								
	E								
	F								

Figure 8—The Relative Time in the Asset Life Cycle That Each Stage of the DPIEF Loop Should Be Applied

6.7 Operations

6.7.1 General

From a reliability and integrity perspective, the intent during the operations stage may be summarized as:

- achieve and sustain the level of reliability, availability, maintainability, and integrity that is inherent in the design;
- sustain production without compromising system integrity;
- ensure that equipment reliability and integrity performance do not deteriorate beyond acceptable levels over time;
- provide evidence of the above through in-service inspection, monitoring, testing, and appropriate maintenance and repair or replacement strategies.

Any failures of equipment that lead to loss of production or loss of containment have very significant business consequences once production starts. In addition, there can be health and safety consequences associated with failure mitigation and repair activities. Subsea failures will generally require intervention to repair or replace failed items and the simplest intervention task becomes a difficult and expensive task if it has to be conducted on a subsea facility. Whether the intervention is carried out by diver, remotely operated vehicle (ROV), or wire-line, an expensive, dedicated vessel must mobilize, transit to site, carry out the task, return, and demobilize, so that the “on hire” period is significantly longer than the duration of the actual task. For this reason, it is best to minimize the requirement for intervention on any subsea facility.

6.7.2 Reliability and Integrity Assurance in Operations

6.7.2.1 General

The RIM process for the operations stage is shown schematically in Figure 9. The application of the DPIEF loop to the operations stage includes both a normal operations loop and a corrective action loop. The IM-FMECA is the key tool used to determine the initial inspection, testing, monitoring, and maintenance (ITMM) plan and the subsequent updating of the plan following periodic RIM campaigns.

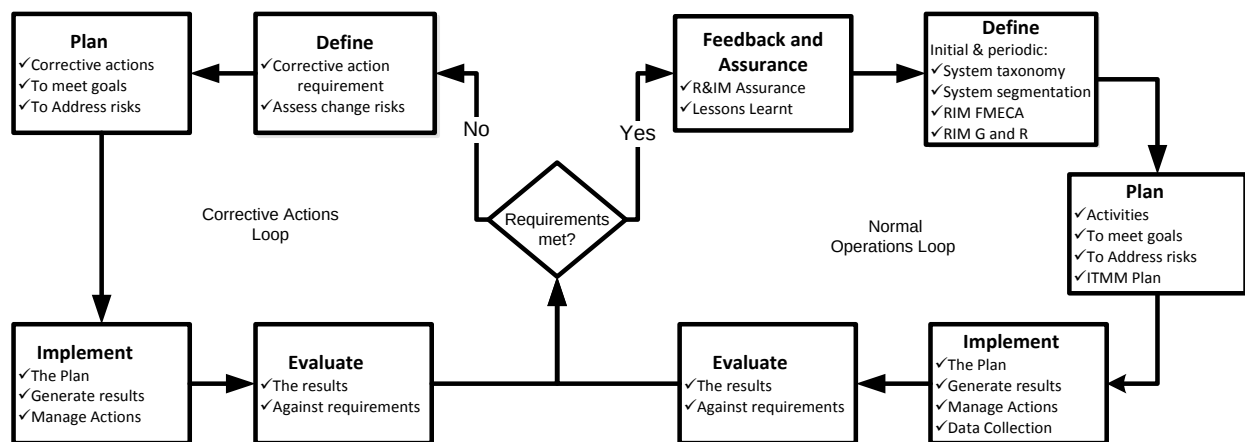


Figure 9—Double DPIEF Loop in Operations

6.7.2.2 Normal Operations Loop

The normal operations DPIEF loop applies to the periodic (typically annual) integrity management campaigns. The define and plan steps for the first iteration of the DPIEF loop should be completed during MATIC stage and handed over to operations. Subsequent iterations and changes to the define and plan stage outputs depend on the results obtained during the implementation of the plan during the integrity management campaigns.

The development of an effective RIM system for operations should be started as early as concept selection with operations personnel being involved in the selection and design process to ensure:

- lessons learned from previous operations are integrated into the design;
- the operations team understand the design assumptions for the system performance and what mitigations or safeguards were accounted for in the design;
- the operations team agrees on risk acceptance criteria with the design team and plays a role in the evaluation stage in projects.

Operations team inputs and interactions should be gradually increased and sustained throughout the design life and through the MATIC stages.

C.7 provides detailed guidance of appropriate RIM activities during normal operations.

6.7.2.3 Corrective Action Loop

The corrective action loop should be initiated whenever significant remedial measures or corrective actions are required. The corrective actions follow their own DPIEF loop and in many cases may be considered as a small project.

The identification and reporting of failures in the normal operations loop and the documentation of corrective actions undertaken in the corrective action loop may be formally integrated into a FRACAS (failure reporting and corrective action system) database. This may be usefully linked to an asset-specific IM-FMECA database.

The corrective action loop is further addressed in C.8.

6.8 Field Upgrades and Field Extensions

Typically field upgrades and extensions, such as a single- or two-well tieback to an existing system, should be considered as small projects. As such they should follow the existing guidance for projects in Annex C.

If the equipment to be installed is similar to existing equipment [e.g. using standard trees and subsea control modules (SCMs) of the same design as the existing system], the level of additional reliability effort should be modest provided that the existing system has already been studied to assess reliability and integrity (e.g. FMECA studies for the particular design of SCM and christmas trees already exist). However, the minimum RIM activities that should be carried out for any field extension are:

- TRC and TRL checks for the additional hardware;
- update RAM analyses to include the extended system architecture;
- update IM-FMECA and preparedness response scheme (PRS)-FMECA to identify any additional spares or integrity management activities or any threats to integrity or reliability related to the new location and the specific environment.

6.9 Life Extensions

As new reservoirs are discovered or new methods are developed to extend the life of existing reservoirs, there is an increasing requirement to extend the operational life of existing offshore installations and subsea infrastructure beyond the original field life. At the end of a system's design life, although most components and structural items of equipment will have suffered some level of degradation, in many cases, the actual level of degradation will be less than that allowed for at the design stage because most equipment is designed conservatively, with large safety margins. This therefore provides an opportunity for life extension.

The continued operation of equipment beyond field life introduces increased risk of failure and therefore demands particular attention to the management of reliability and integrity through inspection and monitoring of degradation.

Before extending equipment life the following should be undertaken.

- A thorough assessment of the condition of the equipment to be used with particular attention paid to critical systems. This provides the baseline for moving forward into the extended life period.
- Detailed risk assessment of critical systems to identify the risk of failure over the extended period of life. This may include:
 - updates to the existing field IM-FMECA;
 - assessment of the remaining life of critical systems (see NOTE) and its comparison with the extended life required by field business case;

- identification of equipment with insufficient remaining life, which will need to be replaced at the start of, or during the extended life period;
- updates to the ITMM program for all equipment, including updates to the ITMM frequency over the remaining life.

NOTE The assessment of the remaining life of a degrading system or item of equipment may be undertaken as a probabilistic assessment in which an estimate is made of the life at which the probability of failure exceeds the acceptable probability as defined by company or regulatory risk acceptance criteria. Acceptable probability can also be defined in terms of acceptable safety margin (Reference [7]).

ITMM frequencies should be consistent with the increasing failure rate of ageing equipment and structures and with the risk acceptance criteria.

The RIM activities outlined in C.7 and in Annex D may be used to support RIM of life extension work.

6.10 Decommissioning

6.10.1 General

In general, the decommissioning of a field constitutes a project and, as such, the entire process outlined in this RP applies. However, on completion of decommissioning the following specific issues should be addressed.

6.10.2 Feedback of Life Performance

When a field is decommissioned, subsea facilities can (in some geographical areas, have to) be recovered to shore for reuse, recycling, or disposal. As part of this process there is additional value to be gained by providing original equipment manufacturers (OEMs) with access to retrieved items to enable additional learning on long-term equipment performance. This is an opportunity to determine the extent to which components, which were inaccessible on the seabed, were overengineered—i.e. have remaining capacity at end of field life (which may, anyway, exceed design life). This might include:

- measuring wall thickness of components such as manifold headers or valve bodies;
- investigating corrosion/erosion at elbows or tee connections;
- carrying out accelerated testing of solenoids or directional control valves to see how many further cycles are required to failure;
- carrying out electrical testing on, and dissection of, umbilicals and power cables to assess the remaining life;
- assessing polymer degradation in flexible flowlines and risers.

Such investigations will help to define the late end of the “bathtub” curve for a number of components, and may help to reduce the costs associated with overengineering systems.

6.10.3 RIM Review

At decommissioning, the effectiveness of RIM can be reviewed from the whole life perspective. This is an opportunity to determine, in light of the state of the overall system and its components at end of life, what other data, had it been available, would have improved the management of reliability and integrity. Maintainability shortfalls can be documented. It is also an opportunity to review statistics such as mean time between failures, or mean time to repair (MTTR), in terms of variability over field life and to assess reasons so as to produce more reliable data and benchmarks for the future.

6.10.4 Feedback of Costs

Operators are encouraged to capture costs on completion of decommissioning to support future life cycle cost (LCC) assessments, since this is the only time that accurate decommissioning costs can be confirmed. These costs should be put in the context of the extent to which the field life, and reservoir performance, matched original expectations. It is only by accurately cataloguing such data that LCC models can be calibrated and improved.

Annex A (informative)

Technical Risk Categorization (TRC)

A.1 General

This annex provides an example of one method of categorizing technical risk to enable an appropriate level of reliability, integrity, and risk management activities to be defined at each project stage.

NOTE Other industry standards (e.g. ISO 20815 and DNV-RP-A203) use alternative risk categorization schemes and may be used by some organizations instead of TRC.

A.2 TRC

TRC is common to all project stages of the life cycle (from project categorization in feasibility through to component TRC in detailed design, and tooling/handling and procedural risk categorization during manufacture and installation). It occurs toward the beginning of every project stage and is a qualitative assessment of a number of “change risk” factors that can influence the uncertainty of failure. It is also reviewed toward the end of each project stage as part of the “evaluate” step in the DPIEF assurance cycle.

TRC should be implemented as a formal assessment process structured to ensure consistency across different projects and should:

- consider all sources of technical uncertainty that could impact the ability to achieve required performance using the five “change risk” factors (reliability, technology, architecture/configuration, environment, and organization);
- provide a qualitative “score” of technical uncertainty based on the perceived deviation from previous experience to facilitate prioritization of RIM and technical risk mitigation effort [e.g. the method presented here uses categories A (very high), B (high), C (medium), and D (low)];
- adjust the level of TRC focus from an overall project assessment to a detailed component assessment as the project develops from feasibility to design and manufacture;
- enable assessment of both the subsea equipment and the associated procedures used, for example, during manufacture and installation.

The levels of technical uncertainty for each change risk factor are illustrated against some typical keywords for the design stages (feasibility through to detailed design) in Table A.1 and for tooling and procedures used through the MATIC stages in Table A.2.

It is essential that TRC be carried out by experienced engineers who understand the project engineering scope at each project stage.

A.3 Ground Rules

TRC should not be an onerous activity. It is intended to be a high-level review process to help identify priorities. The following ground rules are used to facilitate the TRC process.

- Define the component, package, system, or procedure that the TRC is to be applied to.
- Consider the defined component, package, system or procedure against each change factor using the keywords (in either Table A.1 or Table A.2) as a guide to the types of changes that may affect the TRC for that change factor.
- If there is any doubt as to which technical risk category applies, select the higher category (and investigate the uncertainty). The selected category for each change factor should be accompanied by a

brief explanation/justification of the category to aid future understanding and support identification of appropriate risk management activities.

- The overall TRC for the project, component, package, system, or procedure is the highest of the individual categories for each factor, except where this factor is Organization. In the case of having the highest TRC risk/uncertainty category as Organization, the team carrying out the TRC may address the organizational risks and then reduce the TRC to the highest equipment related category.
- The definitions in Table A.1 and Table A.2 are general and are intended to be applied at project, system, package, component, and procedure levels although some interpretation for each project stage and project scope may be necessary. Detailed project knowledge may supersede the general guidance with recorded justification.
- Once a TRC has been defined for the component, package, system, or procedure, Table A.3 can be used as a template to help define the level of effort that is likely to be required in relation to reliability, integrity, and risk management at each stage of the asset life cycle. Section A.4 has more detail on how to do this.

This categorization activity does not consider criticality—i.e. the consequences associated with potential failure of an item. The recommended level of reliability and integrity effort and scope of work may, therefore, be revised if it does not add value or does not indicate a high enough effort (e.g. a novel sensor may result in a Category A (high technical risk), but its failure may have little effect on overall system operability).

NOTE “Technical risk” in the context of TRC refers to uncertainty and not the combined effect of probability and consequence (the implied consequence is inability to perform as intended). The recommended level of effort/work scope may be omitted if it is not perceived as cost beneficial/value added based on the severity of the potential failure (similarly greater effort may be necessary where there is high severity associated with the potential failure). It is not recommended that such a cost-benefit screening is applied prior to the TRC activity (i.e. the absolute minimum level of assessment should be the TRC).

A.4 Level of Effort

Table A.3 provides an example for the relative reliability, integrity and risk management effort that is likely to be required at each stage of the asset life cycle for the reader's defined level of technical risk and uncertainty. This type of table can be filled in by the person/team leading reliability through the asset life cycle, to indicate the effort at different life cycle stages.

For the case shown below, as the detail of the project increases, so too does the required reliability, integrity and risk management effort. Even at the earlier stages where effort may be lower, the reliability effort is still very important to ensure effective definition and delivery of the reliability and integrity requirements through the project stages.

Table A.1—TRC for Equipment

	Technical System Scale and Complexity			Operating Envelope	Organizational Capability
	Reliability	Technology	Architecture/ Configuration	Environment	Organization
Key-words	- Reliability requirements - Maintainability - Availability - Failure modes - Risk - Uncertainty	- Materials - Dimensions - Design life - Design concept - Strength limits - Temperature limits - Corrosion - Duty cycle	- Equipment - Layout - Interfaces - Complexity - Diver/ROV - Deployment/ - intervention - Tooling	- Field location - Water depth - Seabed conditions - Reservoir conditions - Environmental loadings, strains, and stresses - Test location - Storage	- Location - Company - Contractor - Supply chain - Design - Manufacture - Install - Operate - Maintain
A Very high	Reliability improvements (technology change): A significant reliability improvement requiring change to the technology involved.	Novel technology or new design concepts: Novel design or technology to be qualified during project.	Novel application: Architecture/configuration has not been previously applied by supplier.	New environment: Project is pushing environmental boundaries such as pressure, temperature, new part of world, severe meteorological conditions, or hostile on land test location.	Whole new team: New project team, working with new suppliers in a new location. Little or no relevant expertise. Limited resources/capacity to perform tasks.
B High	Reliability improvements (design change): Significant reliability improvement requiring change to the design but no change to the technology.	Major modifications: Known technology with major modifications such as material changes, conceptual modifications, manufacturing changes, or upgrades. Sufficient time remains for qualification. Non-mature for extended operating environments.	Orientation and capacity changes: Significant architectural/configuration modifications such as size, orientation, and layout; changes fully reviewed and tested where viable. Large scale, high complexity.	Significant environmental changes: Many changes noted; extended and/or aggressive operating environment; risk requires additional review.	Significant team changes: Project team working with new supplier or contractor within supply chain; key technical personnel changes from previous project. Loss of relevant expertise. Loss of resources/capacity to perform work on multiple projects concurrently.
C Medium	Minor reliability improvements: Reliability Improvements requiring tighter control over quality during manufacture assembly and fabrication.	Minor modifications: Same supplier providing a copy of previous equipment with minor modifications such as dimensions or design life; modifications have been fully reviewed and qualification can be completed.	Interface changes: Interface changes, either with different equipment or control system changes; where appropriate, configuration has been tested and verified.	Similar environmental conditions: In line with a previous project or no major environmental risks have been identified.	Minor team changes: Small or medium organization; moderate complexity; minor changes in contractor/supplier and project team. Little or no loss of ability to perform functions. Collaboration and integration across activities.
D Low	Acceptable reliability: No reliability improvements required, existing quality assurance (QA) and control is acceptable.	Field proven technology: Same supplier providing equipment of identical specification manufactured at same location; provide assurance no changes have occurred through the supply chain.	Unchanged: Architecture/configuration is equivalent to previous specifications; interfaces remain unchanged, with no orientation or layout modification.	Comparable environmental conditions: Environment is comparable to recent project with no new environmental risks.	Comparable team as previous: Core project team, contractors, suppliers, and supplier's supply chain remain unchanged; applies throughout project life cycle. Well integrated and effective collaboration across team with demonstrated capability.

Table A.2—TRC for Procedures

	Technical System Scale and Complexity			Operating Envelope	Organizational Scale/Complexity
	Reliability	Technology	Architecture/ Configuration	Environment	Organization
Key-words	General • Procedure • Reliability Requirements • Failure modes • Verification/quality control	General • Tooling • Materials • Measurement and control • Tooling qualification • Tooling calibration and certification Man & Assembly* • Product material Inst & Comm** • Diver/ROV Testing • Assembly design/function Intervention • Maintenance • Replacement	General • Interfaces • Layout • Accessibility • Procedure reversibility • Dimensions Man & Assembly* • Interfaces • Man-machine • Machine-material • Man-material • Assembled equipment Inst & Comm**, Testing, and Intervention • Interfaces • Man-tooling • Tooling-assembly • Man-assembly • Integrated equipment	General • Storage • Procedure loads • Procedural conditions Man & Assembly* • Manufacturing and treatment temperatures, pressures, and fluids Inst & Comm**, Testing & Intervention • Post-commissioning conditions • Field location • Water depth • Seabed conditions • Currents • Test temperatures, pressures, and fluids	General • Location • Sub-suppliers • Personnel Inst & Comm**, Testing & Intervention • Roles and responsibilities
A Very high	New reliability concept: A significant reliability improvement requiring conceptual change to the procedure or tooling involved.	Novel technology or new design (tooling/product/procedure) concepts: Novel design or procedure to be qualified during project.	Novel application: Procedures (new or existing) have not been previously applied to these interfaces or geometries.	New environment: MATIC processes implemented under environmental conditions that are extended beyond previously applied levels such as temperature, pressure, or handling loads.	Whole new team: New team, working with new suppliers in a new location.
B High	Major reliability improvements: Major reliability improvement requiring change to the tooling or procedure.	Major modifications: Known designs (tooling/product) or procedures with major modifications.	Major application modifications: Major changes to procedure or interfaces/geometries to which procedures apply.	Significant environmental changes: Many changes to environmental conditions in which MATIC processes are undertaken, which requires additional review.	Significant team changes: Project team working with new supplier or contractor within supply chain; key technical personnel changes from previous project.
C Medium	Minor reliability improvements: Reliability improvements requiring tighter quality or procedural control.	Minor modifications: Same supplier using previously demonstrated tooling/procedures with minor modifications; modifications have been fully reviewed.	Minor changes: Minor changes to procedure or interfaces/geometries to which procedures apply. Changes reviewed and justified as minor.	Similar environmental conditions: Similar environmental conditions for MATIC processes as previous project or no major process operating envelope risks have been identified.	Minor team changes: Small or medium project organization; moderate complexity; minor changes in contractor/supplier and project team.
D Low	Acceptable reliability: No reliability improvements required and existing quality assurance (QA) and control is acceptable.	Field proven technology: Same supplier using previously demonstrated tooling/procedures; provide assurance no changes occurred.	Unchanged: Interfaces and geometries identical to previous applications; procedures remain unchanged, with no orientation or layout modification.	Comparable environmental conditions: Environment is comparable to recent project with no new environmental risks.	Comparable team as previous: Core project team, contractors, suppliers, and supplier's supply chain remain unchanged; applies throughout project life cycle with demonstrated capability.

*Man & Assembly—Manufacture and assembly.

**Inst & Comm—Installation and commissioning.

Table A.3—Example Level of Effort Expected for Different TRC Risk Levels Throughout the Asset Life Cycle

Technical Risk & Uncertainty	Feasibility	Concept Selection	FEED	Detailed Design	MATIC	Operation
A (Very high)	H	M	H	VH	VH	H
B (High)	H	M	H	H	H	M
C (Medium)	L	L	M	M	M	M
D (Low)	L	L	L	L	M	L