Rahim Yousif
University of Torino, Torino, Italy and Det Norske Veritas, Stavanger, Norway

Refsdal Ingbjørn
StatoilHydro, Bergen, Norway

Kenett Ron
KPA Limited, Raanana, Israel, University of Torino, Italy and NYU - Poly Center for Risk Engr, NY, USA

The 5C model: a new approach to asset integrity management

Keywords

5C model, asset integrity, technical integrity, asset management, asset integrity management

Abstract

As organizations grow more complex in operation and more global in scope, assets and technical integrity become key success factors. A company's asset integrity business process needs to be mapped in order to 1) provide a proper overview of operation and business processes, 2) identify all critical interfaces and 3) ensure that all gaps and overlap in processes are eliminated.
Achieving asset integrity requires companies to sustain their activities and identify the hazards, weaknesses and objectives of their strategic assets. Technical integrity emphasizes a complete overview of technical conditions and related information, and the ability of the companies to document the technical state of its assets. It is based on an integrated view of the current state of operations, and the identification of all critical interfaces, in order to ensure that all gaps and unnecessary overlaps in processes are eliminated.
Companies look increasingly at their asset integrity management system as a means to extend the life of their assets, beyond the original design conditions and production capacity.
Establishing an asset integrity management system requires the documentation of the company's technical integrity management, a strategy and the processes for carrying it out, identifying gaps; selecting corrective interventions and conducting follow up actions.
The paper will discuss various aspects of asset integrity management, including its planning and implementation. We begin with an introduction to asset technical integrity, provide some theoretical backgrounds, present a model we call 5C and conclude with a summary and discussion.

1. Introduction to asset technical integrity

Asset technical integrity refers to a condition where the technical state of assets incorporates in all related operations and business processes as one process. Such integration ensures that there will be no harm done to people, property or the environment and this reduced risk exposure of the firm. Technical integrity can be also described as the overall state of safety in terms of functionality, operability and reliability [2]. Conducting and assuring technical integrity of any facility or plant involves designing, maintaining and operating facilities with cost effective high performance processes. It also involves delivering quality products and services to customers, best value of investments for stakeholders and high corporate image and social responsibility.

The objectives of strategic asset technical integrity documentation are:

- controlling the asset safely
- high effectiveness in the production process
- effective use of human resources
- extending the lifetime of the asset
- keeping core business functions and controls within the asset.

The word *integrity* has its roots from the Middle English integrite, from old French, from Latin integrits (soundness) and from integer (whole, complete).

Asset integrity has been studied in variety of publications and studies, mostly related to petroleum industries. Many studies have referred in asset integrity to the issue of technical integrity and to the specific issues of material integrity and issues of inspection. It is known as an effective system for managing the integrity of systems, pipes, pipelines and equipments throughout the full life cycle for all phases; design, concept, and engineering, construction, installation, operations and decommissioning. The operation phase including all elements related to the maintenance strategy, maintenance activities, repairs, modifications and alternations, inspections and integrity assessments.

HSE stated that asset integrity can be defined as the ability of an asset to perform its required function effectively and efficiently whilst protecting health, safety and the environment. Asset integrity management is the means of ensuring that the people, systems, processes and resources that deliver integrity are in place, in use and will perform when required over the whole lifecycle of the asset [6].

OGP relates the asset integrity to the prevention of major incidents, and defines it as an outcome of good design, construction and operating practices. It is achieved when facilities are structurally and mechanically sound and perform the processes and produce the products for which they were designed [13].

In the next sections, we discuss how asset integrity can be designed, implemented and maintained.

2. Design of asset integrity processes

We begin by a literature review of existing management models used in oil and gas companies, and present experiences gathered over several years of consulting work. This is complemented by direct face to face interviews conducted with technical systems and discipline managers, in a large oil company in Norway, operating in the North Sea continental shelf.

Asset integrity management is a core element in companies' total management systems, strategies and activities. It is based on maintaining plant assets in required safe and productive condition for the desired life of those assets. Assets attain the status of integrity by incorporating aspects of a plan, design, operations, maintenance and inspection, to maximize the value of investments both in and from these assets.

Before considering which factors and state descriptors are needed to understand the asset integrity one needs to look at all operations and activities conducted in the life time of the plant or the asset. The core element of operation management is based on the Maintenance Management Systems, how they are managed and how they interact with other business processes. Wireman states that maintenance planning is the most essential part of any company's effort to permanently improve the maintenance organization [16].

Proper asset maintenance requires proactively planned maintenance programmes. Such programmes are often viewed by management as an expense since they are mainly focused on prevention. Maintenance and inspection are, for most part, costly, invasive and detract from production if not specified and planned correctly [1]. A proper maintenance strategy of plant equipment can significantly reduce the overall operating cost and increase the efficiency and productivity of the plant.

Leadership is a key function in improving understanding, simplification, challenge and learning in major hazard control and ultimately in performance [6]. An effective methodology includes one or more Key Process Indicator (KPI) for each objective stated in the company policy [4]. The selected KPIs should be aligned with the risk-based management process for the facility. These specific KPIs may then be used to aid the management of steps in the asset integrity management process [13].

In the late 1990s, the Norwegian Petroleum Directorate developed a management tool for maintenance management and management of operations in the Norwegian oil companies.

The model has been tried by several major oil companies operating in Norway and elsewhere (see *Figure 1*).

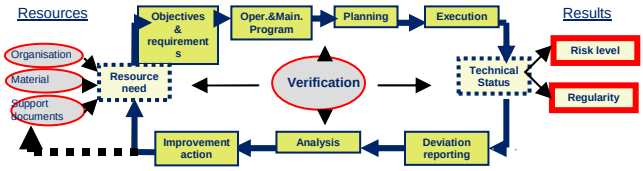

Figure 1. Maintenance management loop (Source: Translation from NPD 1998)

Asset integrity management requires understanding the risk of operations depending on classifying the events based on their probabilities and consequences. Hazard identification and risk assessment are invariably linked to a safe operating envelop [1]. The events with high probability and low consequences are best managed through existing maintenance management processes and systems. Events with low probability and high consequences require more proactive actions in hazard identification, risk assessment, risk analysis and risk communication and management.

The elements of a Maintenance Management System, as a major part of the total asset integrity management system, should cover all important equipment (pressure vessels, piping, rotating equipment, instrumentation, safety systems, etc., with regular tests and overhauls. Particularly important is the checking of special safety devices [12] it must be successfully integrated to achieve the required objectives.

Such objectives include the following:
• Eliminating all potential hazards
• Reducing critical incidents and near miss incidents
• Maintaining the condition, functionality and operability of the machinery inventory
• Reducing failure incidence or Mean Time Between Failures (MTBF)
• Reducing downtime after failure or Mean Time To Repair (MTTR)
• Increasing maintenance personnel skills and work experience
• Increasing the plant/systems/equipment reliability and availability.

To implement asset integrity we introduce a new model, called the 5C model presented next.

3. The 5C model for asset integrity

Following interviews with several technical system and discipline manager we organised the asset integrity process in five major pillars. These pillars are: Competence, Compliance, Coordination, Communication and Control (See *Figure 2*). They form major indicators for evaluating the state of the asset. These elements form the 5C the model presented in this paper.

The 5C model can be used as a simple evaluation tool for defining the state of integrity in any asset, at any time, based on the size and type of the operations carried in the asset. It ensures a high level of efficiency as it can be carried out by available resources in the asset without the need for extra resources outside the companies' reach and ownership. On the other hand, the model is easy to use and clearly indicates where the gaps are and how to reallocate resources based on the knowledge gathered within the organization.
Based on the 5C model, the main elements of the asset are mapped including gaps or backlogs. These are considered as undesired events, which require focused actions to bring the operations back to the normal state, determined by its goals and requirements. The model highlights and proposes the required improvements.

Asset Integrity				
Competence	**Compliance**	**Communication**	**Collaboration**	**Control**
Management software	Legislations & requirements	Company portal	Daily briefing meeting	Daily follow up
KPI	Management documents	Reports	Production meeting	System review
Incident reporting	Standards	Technical integrity seminars	Finance meeting	Internal verification
Production management	Design requirements	Unit/section/ department meetings	Plant status meeting/plant board meeting	External verification
Design & drawings		Meeting structures	Discipline network	Deviation reporting
None conformance			Integrated operations	Investigation& Root cause analysis
Special software			Contractors & service providers	

Figure 2. The 5C model for asset integrity

Events related to asset integrity can be described by a general construct that captures the knowledge accumulated by the organization. The main events which contribute to the integrity level of the asset are mapped into *Cause-Event-Action-Outcome* (CEAO) chains. Causes of events related to asset integrity can be categorised in a Reference Framework consisting of the 5 Cs and 6 horizontal dimensions listed below [8], [9]:

- Strategy and goals. Strategy and goals are the medium- and long-term goals to be achieved and the plans for realising these goals. The strategy and goals for the enterprise system and the implementation project should match the business goals and strategy.
- Management. The management aspect deals with setting priorities, assigning resources and planning and monitoring processes.
- Structure. Structure involves the relationships between elements of the organizational system, such as processes, people and means. Structure includes tasks, authorities and responsibilities, team structures, process structure and structure of the enterprise system.
- Process. Process involves the steps that are needed to perform the focus process of each dimension: the primary business process and relevant support and management processes, the project process and the enterprise system design and adaptation process.
- Evaluation. This aspect refers to the state and the function of the organisation and plant based on required functions and outcomes according to the resources used and skills needed to perform the tasks in all previous dimensions.
- Social dynamics. The aspect social dynamics refers to the behaviours of people, their norms and rituals. Social dynamics often become

visible in informal procedures and (lack of) communication.

The 5C model reference framework presented in *Table 1* is used to classify causes of events unveiled in an asset integrity assessment. Filling the table can be done by a tally of causes listed in the different cells. Alternatively a poster with the table is used as a white board where post-it notes are positioned using an Affinity Diagram brainstorming exercise.

Table 1. The 5C model reference framework

	Competence	Compliance	Communication	Coordination	Control
Strategy and goals					
Management					
Structure					
Process					
Evaluation					
Social dynamics					

A CEAO chain is a mapping of an event driven problem and related actions. It contains of the following items: An Event is defined as a problem created by a gap between current conditions and standards or specifications, Events are sometimes outside the control of the organization. A Cause is an underlying reason, leading to the event. For each event, it is possible to specify one or several causes, which are linked to the event through a parent-child relationship. An Action is the solution taken to resolve the event; it includes method of performing or means used. Each action is connected to Outcomes. The mapping of causes of the CEAO chains into the reference framework leads to different clusters of CEAO chains. Each cluster belongs to a focus cell in the framework [9]. Identifying such clusters is critical to enhanced asset integrity assessment and mitigation plans development.

Definition of a Cause-Event-Action-Outcome (CEAO) chain
- Cause – something that caused the event in the eyes of the interviewee
- Event – something that needed action
- Action – to change the course of the project
- Outcome – positive or negative result

The 5C model, with the mapping of CEAO chains, helps identify risks and how they are managed. The model and process of its implementation are managed by understanding the main elements of 5C within the asset, in order to help prevent problems, minimize operation risks and reduce costs. We now expand on the 5 components of the 5C model.

4. Competence

Schroder [15] defines competences as "personal effectiveness skills". Others consider competences as being linked to personality and therefore, within the context of the intended research on input factors, potentially impact on the understanding of managerial performance and effectiveness. Nordhaug and Gronhag defined the concept of competence as one of the most diffuse terms in the organisational and occupational literature [10]. This definition of competence refers to a set of skills that an individual must possess in order to be capable of satisfactorily performing a specified job or task. In a recent publication for OGP emphasizing those tasks should be designed in consistence with the knowledge, skills, and physical capabilities of the person or team [13].

Relevant competences are clearly required by construction, operations and maintenance technicians working directly on an asset. Suitable competences are also required by technical authorities, supervisors and managers. Regulators and other independent bodies who have oversight of major hazard assets also need suitable competences [13]. The company may increase the competence level through promoting continuous training, improved training, and follow up. There is a requirement to provide engineers with focused training to ensure that they have a clear understanding of the importance of ensuring technical integrity of design of process plants [3].

Different types of competence dealing with different issues for interest of the asset management. Cognitive and functional competences are related with professional activities while social and meta-competences are dealing with persons and individuals. The competence covers the social, management and leadership abilities to deal with the tools and equipments, as the use of these tools and equipments may vary among individuals.

Mapping the competence is based on the competence of all employees to conduct the tasks they are designed for according to their function in the company, and to achieve best possible expected outcomes. The model summarized the competences needed on the issues related to the daily operations in any asset are competences in; using management software's, drawing management tools and other specific required software's, defining and follow up KPIs, and the competence on the incident reporting, production, deviations and monitoring systems.

5 Compliance

Technical Integrity management of assets has been adopted historically by the industry where there has

been a series of local regulations, industry standards or corporate requirements are followed. The compliance to the laws, legislations, procedures and standards should be shared with all other partners, contractors and sub-contractors operating in the asset.

Optimum utilization of all company assets, including personnel, depending on their availability, operability and conformance to established standards [7]. And based on the Norwegian experience with companies' compliance to the legislations; there is clear need to supervise how operators discharge their compliance responsibility. They have a duty to ensure that contractors are familiar with key requirements for the work to be done and the associated risks [14].

The companies' compliance with design and specification is leading to avoid risk of failure due to inappropriate or ineffective design. It is minimized by the careful selection of materials and the application of valid standards, procedures and design management controls [7]. These design standards can be well-known international standards or the companies own norms and standards based on the long range accumulated knowledge and best practice. Through analyses and assessments, companies must decide if the level of risk is acceptable and the standards are sufficient [14]. The companies' own guidelines to the compliance with technical requirements and regulations refer to norms and standards which companies can use to achieve compliance and ensure technical integrity of the assets. However, they must still decide whether these are good enough for the activity concerned.

In our model, specified the compliance elements based on the new industrial era with new applied management systems, companies are obliged to comply with the existing rules and regulations at all levels as:

- National regulation
- National and local legislations
- Company's own management documents
- International standards and recommendations
- Design requirements

If the companies' find difficulties to follow the normal procedures and requirements, the management establishes procedural exceptions to keep the asset running and aware of these exceptions or non-conformities' which should be documented properly and available.

6. Collaboration/Communication

Companies' are in need to improve the collaboration and build trust across all levels in the company; internally, externally and among all parties. This can be achieved by systematic collaboration internally with all other units and externally with stakeholders, operators, contractors, suppliers and authorities. The asset integrity is assured by enhancing the team work spirit and adapting the mechanism for culture change from adversary to team or change the culture from working individually and being a single task focused to being part of a team. When the people meet regularly and trust each other, they're more likely to easier identify communication barriers, share an open safety culture and to report deviations, problems and shortcomings without fear of reprisals.

Increased communication and collaborative information sharing will uncover higher percentage of weaknesses, near misses and incidents and enhances the cooperation between employees, management, partners and regulatory authorities and builds consensus from the top to the bottom of the company.

The company has to find and discover the best practice for collaboration based on gathered knowledge, own experiences and others experience. The best practice has to help us in identifying best methods for the conducting operations, to achieve the desired outcome in asset integrity to meet the expectations of all partners.

Learning is achieved by identifying and sharing best practice, and by having processed to enable the learning to be embedded [6]. Sharing the knowledge and internal and external communication can be improved by designing inter-communication railroads by enhancing on thematic meetings, seminars and team building, which will help to build consensus and foster two-way communication.

All stakeholders and parties involved in the asset need to demonstrate that they have adequate planning processes in place to manage the supply of resources as financial, personnel and equipments to meet the demands in the production and management.

The asset technical integrity elements and indicators should be represented at daily status meeting as well as in planning meetings to help keep focus on integrity activities. The asset strategy and plan need to be disseminated and need to be understood and agreed with all stakeholders and people involved in various operations.

Stakeholders are expecting to be provided with correct information and on systematic manner. When they trust information, they can better focus on their contribution and the resources for the success of their investments, the company and its operations. In addition to the internal partners, the consideration needs to be given also for communication with any relevant external parties such as communities

around, regulatory authorities and HSE inspection authorities.
The results from asset integrity work and follow up works needs to be fed back into asset plans in a suitable format and interval. The lessons learned from interventions, events and programs should be disseminated. Employees should be briefed and debriefed to identify the phases and enable them to identify large and small issues. Information sharing should be based on a system enables everyone to update the process and information in the area of responsibility by using the formal process instead of just dumping the information in the database.

7. Coordination

Any asset as an organization consists of various units and activities, these activities need to be coordinated with the unit and across all other units. From an organizational perspective, routines are one form of coordination operating within and between parts of an organization [5]. This applies developing procedures and routines for coordinating the tasks and activities across all the whole company. Asset activities and operations can involve a range of different contractors including; inspection, maintenance, scaffolding …etc. all of which have different managers and reporting to different duty holders. Contractors may have their own plans, planning engineers, planning systems and inspection routines, all of which need to align with the asset plans. These can be done by engaging contractors and other service providers and make their active participation in risk-sharing and decision-making processes.
The asset integrity requires a long range plan to ensure the continuity and short range plans in the plant should change with very little notice, it is therefore, important to have one plan and operation procedures in order to enable all partners in the work at the plant; including the contractors to be included in required activities, plans and operations carried out by different stakeholders. Reliable coordination of activities and having trustful contractor relationships will do maximise the opportunities for safe operations.
The asset integrity management requires a long term planning a head of certain activities and tasks such as starting new production lines, over side work, turnover and shutdown. These activities' results in increased demand for specific competent manpower and equipment, therefore, long term engagement, planning and commitment are essential to secure the required resource and assure the quality of the operations carried out during that period.

8. Control

Asset technical integrity is managed and maintained through clear strategies; these strategies describe the control methods to be used, for example; corrosion, erosion, mechanical failure, fatigue, or chemical effects throughout asset's life cycle.
The asset integrity will inevitably be achieved through the application of appropriate verification schemes [2]. Verification schemes contain testing, inspection, and maintenance together with the associated documentary evidence and certification of technical condition and integrity are some of the essential aspects of such schemes.
The process of control, assessment and monitoring can be done on regularly bases; internally, externally or by the third party auditors, the process should include the following key elements:

- daily follow up of the operations based on routine control
- systematic control
- identify the potential hazards and threats from procedures, plant equipment and operations to the personnel, the facilities, the surroundings, the environment and the asset.
- identification of the necessary actions and intervention to mitigate and control the hazards in order to lower each element of the risks to a level, which is "As Low is Reasonably Practicable" (ALARP)
- conducting root cause analysis based on identifying the root cause of failures related to factors as human, technology and organisation
- evaluating the performance standards and assure that they are continually maintained

Proactive response, active leadership and learning from experiences, leads to fewer regulations and to avoid avoiding litigation. Better understanding of risks and factors contributing to increase the risk level leads to find better solutions and performance improvement of higher level of asset integrity. These can be done to achieve the main strategy and company goals in improved safety, improved production, cost savings and use of resources.
The company should demonstrate explicitly the commitment to safety, help engineers to design, construct, establish and maintain safer systems. To be proactive in safety management, focus on evidence based solutions, prevent injuries and eliminate all factors contributing to the accidents and catastrophic losses. In the case of deviations and incidents, the company should seek for applying root cause analysis and take appropriate actions to eliminate hazards and triggered risks.

The root cause analysis should be used as a toll to find and highlight possible future hazards. Asset integrity through high focus on creating the safety as a business benefit by prevention work time lost and makes it a major factor contributing to bottom line, not just as an extra cost. Cost savings in medical coverage's, insurance/legal claims - fewer claims paid out; fewer sick leaves due to physical and psychological impacts, injuries and loss of life.

9. Conclusion

Asset integrity can be considered as a key indicator for the successful management strategy and implementation. Management is expected to provide the vision, values and commitment necessary to create and sustain a culture which customer expectations, company objectives, and the aspirations of the individual can be met. This requires a leadership, a competent organization with adequate resources and systems, and clear definition of roles, responsibilities and accountabilities at all levels [7].

The asset integrity is based on the integrity of all units, plants and installations. They should be kept at the intent of the original design. A long-term maintenance policy should be established for this purpose. Many major incidents resulted from maintenance and inspection not being carried out correctly or not at all [1]. The focus should be on preventive maintenance, based on measuring the condition of the equipment and of relevant systems (OECD, 2008). Asset integrity management must ensure the integrity of the components for those operations which are critical to safety, to production or to control/mitigate equipment or system malfunctions. As well as those equipments and instruments are the most critical and fundamental control measures for safety and production.

Assuring technical integrity is an essential requirement of any process plant design, whether it is for a completely new facility or a small modification to an existing facility. The process will ensure that there is no harm caused to people, property or damage caused to the environment and society. The overall asset integrity management process may address a much wider base of assets and may be concerned with health, safety, and environmental, occupational, and production as well as quality objectives.

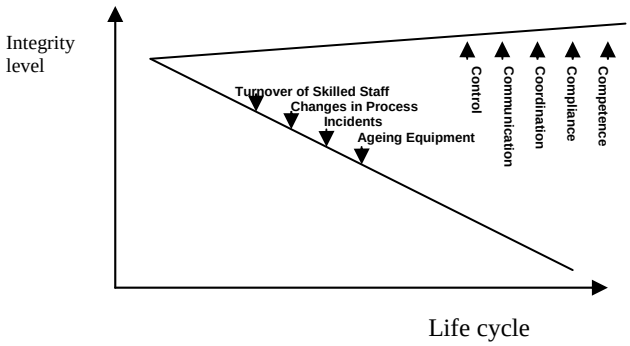

Figure 3. Factors sustaining asset integrity

The 5C model provides a universal list of variables that helping us to identify specific factors according to a context (see *Figure 3*). One of the advances of the model is that it considers all required function, from both technical and discipline managers, to carry out their daily duties. Furthermore, it can be interpreted as a checklist or a guideline that may influence the effect of any new interventions and expected outcome. The model accounts also for different types of skills, operations and requirements and any other factors which come into consideration, based on the technical state of the facility or the life cycle.

A theoretical framework has been developed by direct interviews with technical managers in an operating company, which seems have offered a solution to the problems, they are facing in their daily duties. Therefore, with respect to the adaptability of the model and possibility of changes in the content: It will be a useful tool to help the management, for identifying the asset integrity state and existing gaps but the model cannot be used directly in order to define the inner structure of any organisation.

Asset integrity leads to increase operation efficiency, improve safe operations and to decrease repair costs. Likewise, leads to gain knowledge and benefiting from obtaining the correct information on real problems and pursuing real solutions, cost effectively, rather than focusing on an undefined problem and cause.

Knowledge sharing is a critical to any operations in the asset, the integrity management reporting as a main element in knowledge sharing can be improved using online systems. A good integrity management system should be a live document, adapting to changes during the maintenance, operation and modification of the system. It is important that asset and technical integrity information and reports produced at suitable intervals with details on asset condition compared with its required performance standards identifying where the corrective actions are required and how it will be implemented.

As the asset integrity management is based on combining people, technology, and operational procedures makes it possible to have various combinations based on the company's objectives and policies. Our model for asset integrity management is about highlighting and ensuring that the fundamental elements for improving the culture and operating processes within the company are aligned with the technical integrity requirement and services are provided in an integrated model.
The human resources participating in achieving asset integrity and delivering the integrated services need to have an ownership feeling in order to feel they play an equal part in achieving a common company's goal. These can be supported by a set of procedures and processes define roles and responsibilities that are commonly understood and people are committed to it throughout the organisation.

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