

ASSESSING THE IMPACT OF AGEING SAFETY CRITICAL ELEMENTS IN OFFSHORE INSTALLATIONS AND HOW THE AGEING PROCESSES IMPACT THE ROLE OF SCES TO ACT AS BARRIERS TO MAJOR ACCIDENTS

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The Energy Institute (EI) has supported and co-ordinated an oil and gas industry project to investigate potential measures for the ageing effects on Safety Critical Elements (SCEs) as defined by the offshore safety regulations Prevention of Fire and Explosion, and Emergency Response, (PFEER), and Design and Construction etc. (DCR). This investigation has led to a measurement method of business processes that can provide Leading Indicators and also a novel modification of the Failure Modes, Effects and Criticality Analysis linked with ageing processes.

This assessment process is being supplemented by research supported by the Norwegian Petroleum Safety Authority (PSA) which is looking at embedding ageing assessments into the assurance processes leading to checks on the performance of hazard barriers (as required by Norwegian safety regulations).

The paper will describe what these 2 projects have found and how between them they have developed a synergy resulting in a range of assessment approaches, produced Key Performance Indicators for ageing and have set a number of principles for defining possible life extension.

BACKGROUND AND OTHER INITIATIVES

The offshore industry in the UK and Norway has been established for several decades and the developments include a mixture of large manned installations (of various structural types) and small not normally attended installations. They were designed with a range of design lives usually based on expectations from the reservoir where they were placed. A significant number of these installations have now aged beyond their original design lifetime.

This paper reports on initiatives originated and sponsored by the Energy Institute in the UK and the Petroleum Safety Agency in Norway. These initiatives have looked at the effects of ageing on Safety Critical Elements on both supporting structures and topsides. The work undertaken by PSA additionally considers the effects of ageing in the context of barriers to Major Accident Hazards.

THE UKCS

In the UK, the Offshore Safety Case Regulations (OSCR), [HSE, 2005] have a requirement for duty holders to define SCEs with Performance Standards (PSs) in relation to Major Accident Hazards. Details of the current regime are given in the EI Guidelines [EI, 2007(i)]. In short, SCEs are any part of an installation, plant or computer programme whose failure will either cause or contribute to a major accident, or the purpose of which is to prevent or limit the effect of a major accident, including items of plant specified in Regulation 19 of the Prevention of Fire and Explosion, and Emergency Response Regulations [HSE, 1995].

Regulation 13 of OSCR 2005 requires a 'thorough review of the Safety Case' at regular intervals 'to identify ageing processes, design parameters and changes in operating conditions that may limit the life of the installation, and safety critical plant and equipment'.

Improved guidelines for managing the effects of ageing on SCEs will be useful for life extension where ageing effects become more of an issue. Life extension is a change that would warrant a revision of the Safety Case under OSCR (Regulation 14) [HSE, 2005] and equivalent Norwegian regulations. The processes for the effective management of ageing SCEs are likely to feature strongly in life extension proposals.

THE NORWEGIAN SHELF

According to Norwegian regulations, the operator must obtain consent prior to using a facility beyond the basic lifetime described in the Plan for Development and Operation (PDO) application (Section 5f of the Information Duty Regulations). Extending production life safely is one of the PSA's priority areas.

Operators must document how adequate safety is achieved in the face of continued operation of older facilities and pipelines, noting that the lifetime of a facility is described in the PDO and/or stipulated as a basis for the facility design.

Normally, all parts and components of a facility will be designed so that there is little chance of failure during the course of the planned lifetime. If all of the individual parts and components have sufficient lifetimes, then the facility as a whole will also have a sufficient lifetime. In connection with life extension, this principle must be exceeded as individual parts and components can no longer exhibit the desired low likelihood of failure in the extended years, based on design standards.

PSA expects operators to address the entire facility and document sufficient safety for continued operations beyond the expected lifetime.

OVERVIEW

Figure 1 encapsulates an overview of the ageing trends of equipment.

Where equipment has a safety critical function, at all times during the installation's lifecycle (in both the UK and Norwegian sectors) minimum acceptability criteria must be set, below which the PSs of an SCE must not fall.

The Performance Indicators (PIs) concern the measurement of how well the effects of ageing are being managed; when processes are being managed well, Performance Standards will be maintained in the face of ageing.

AGEING MECHANISMS AND EFFECTS

The effects of ageing have been considered in a broad sense, that is, the degradation of a system/component with use and the degradation or increasing inappropriateness of a system/component with time.

Aspects of ageing are shown in Table 1; the "General Ageing Descriptors" column contains what might be considered the more colloquial understanding of ageing.

Understanding ageing categories and mechanisms ensures that a comprehensive assessment of the effects of ageing can take place, suitable management processes are identified and meaningful PIs are defined.

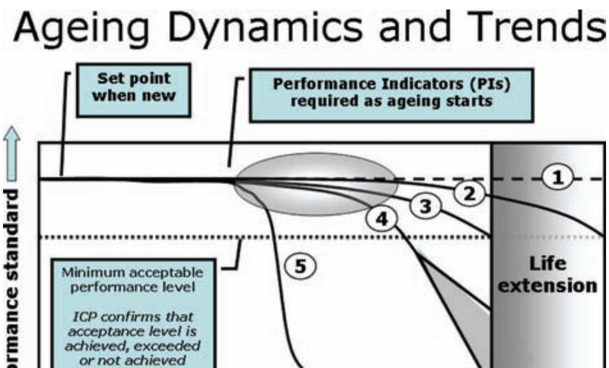

Figure 1. Overview of ageing trends. Where line 1 represents design set point when new; line 2 represents performance degradation that survives through life extension; line 3 represents performance degradation that survives to end of design life; line 4 represents performance degradation requiring repair/replacement prior to design life but still following the "bath tub" wear out curve; and line 5 represents rapid degradation before end of design life

PROCESSES FOR MANAGING THE EFFECTS OF AGEING

The processes for managing the effects of ageing fall into 3 different categories, whereby each is carried out at different levels within an organisation.

Senior management is responsible for high level management processes setting objectives, strategy and the culture of an organisation.

Middle management (or supervisory levels on the installation) is responsible for planning and organising the implementation of installation based activities.

Plant operatives (maintenance and operations teams) are responsible for implementing day-to-day maintenance, replacement and repair.

The last 2 categories have been termed Risk Control Systems.

The concept of Risk Control Systems was introduced by the Chemical Industries Association [HSE, 2006] as a means for developing leading and lagging indicators for process safety. Each Risk Control System focuses on a specific risk and defines actions and activities undertaken in order to control that risk. Control systems may include integrity assurance measures, such as inspection but will also include procedures and competencies.

The opportunity for developing Leading Performance Indicators seems to be greatest at the higher level management processes; although some may be derived from activities at both Middle Management and at the Plant levels. All the main elements of management processes at each of these levels follows the familiar Deming cycle, both within each set of processes and on handover between management levels. This is illustrated in Figure 2.

Table 2 shows one example sub-process of each of the main 6 senior management processes and Table 3 shows examples of leading and lagging indicators for typical SCEs.

SENIOR MANAGEMENT PROCESSES FOR MATURITY MODELLING

The authors identified 6 senior management processes.

- P1 Developing a strategy/policy for the management of ageing SCEs
- P2 Planning the management of ageing SCEs, based on agreed strategy and policy and performance indicators
- P3 Implementing schemes to gather performance and tests data for performance indicators on the condition/management of SCEs
- P4 Assessing how well the SCEs are performing with respect to current hazards, using performance indicators, based on data gathered from Process 3
- P5 Setting out and implementing appropriate remediation schemes to ensure SCEs meet the required Performance Standards
- P6 Assuring and verifying that the ageing SCEs are performing either as isolated systems or in concert with other SCEs

Table 1. Brief description of ageing mechanisms

Brief description of ageing mechanisms	General ageing descriptors	Further descriptive notes
Specification superseded (by technology – equipment obsolescence)	Failure to adapt to change Obsolescence Improvements in technology and standards (exacerbated by loss of people, experience and expertise)	This ageing aspect concerns the specification and choice of equipment type based upon an equipment technology which is deemed to be no longer valid, i.e. no longer functional, discredited or obsolete. Note, that this may include; • The cessation of suitable spares for the equipment • Growing evidence of systematic breakdowns & reliability failures • Shortcomings identified under particular operating phases/ conditions Example impacts might be; • Deluge valve internals no longer available (especially elastomeric throated valves) • Cracking of TEMPSC hoist points arising from partial launch tests • Poisoning of gas detectors due to the offshore operating environment (where they prove excessively sensitive to fumes/ particles from regular maintenance)
Specification superseded (by technology – incident/ consequence analysis)	Improvements in technology and standards Loss of people, experience and expertise	This ageing aspect concerns the specification and choice of equipment type based upon an analysis method or technology which is deemed to be no longer valid. Note, this may include; • Fire and explosion calculation methods • The durations of resistance of material to jet fire impingement • The calculated extent of gas dispersion Example impacts might be; • Blast walls inadequate due to low over-pressure calculations from older software • PFP construction not suitable for flame erosional characteristics • Inappropriate placement of gas detectors
Specification superseded (by events)	Failure to adapt to change Improvements in technology and standards	This ageing aspect concerns the potential changes to Major Accident Hazards which may render the Performance Standards of SCEs inadequate. Most carefully, it should be applied to the accumulation of "creeping" changes whereby minor modifications to the process creates a potentially major change. Example impacts might be; • Increased fire loads potentially causing breach of key systems • H_2S break-through into producing wells but with no H_2S detection systems or NACE rated pipe work • Mothballed equipment containing residue hydrocarbons
External degradation	Physical deterioration	This ageing aspect concerns the more traditionally acknowledged understanding of ageing whereby external conditions in the environment or action resulting from operations and maintenance cause a degradation of the exterior of equipment. A key issue with this form of ageing is that it is generally time-dependent rather than use-dependent and will be easily identifiable without disassembly or performance testing, indeed, the performance may be unaffected, certainly in the early stages of ageing.

(*continued*)

Table 1. Continued

Brief description of ageing mechanisms	General ageing descriptors	Further descriptive notes
		Example impacts might be; • Rust or other oxidation build-up on external surfaces • Chipping and marking from maintenance work on adjacent equipment • Accumulated damage from scaffolding • Paint spray in sensitive areas, e.g. switch units or junction boxes from periodic repainting
Internal degradation	Physical deterioration	This ageing aspect concerns another more traditionally acknowledged understanding of ageing whereby the continued functioning of the equipment causes wear-out of internal materials and components. A key issue with this form of ageing is that it is use-dependent ands that the physical degradation due to wear may not be easily identifiable without disassembly or performance testing. Example impacts might be; • Valve stem seal leakage • Flange degradation and seepage • Bearing wear on rotating machinery • Internal erosion on pipe walls and fittings (e.g. on bends or restrictions, orifice plates, intrusive measuring devices)

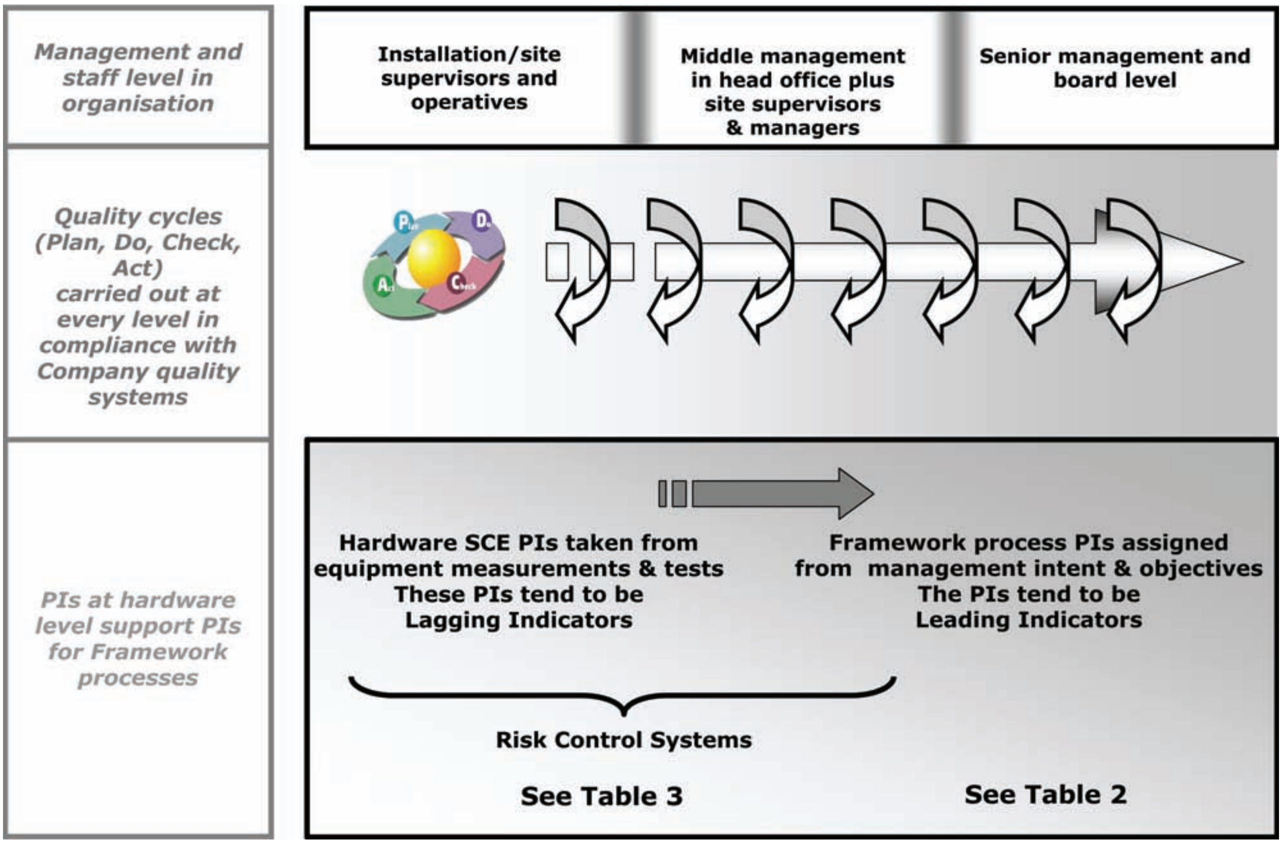

Figure 2. Illustration of application of management processes

Table 2. Examples of leading and lagging performance indicators relating to the processes and a selected sub-process for the management of ageing SCEs (items in italics are taken from the KP3 initiative) [HSE, 2007]

Sub-process descriptions	Potential PIs leading	Typical deliverables or outputs	Potential PIs lagging	Typical deliverables or outputs
Process P1:-Development of a corporate strategy/policy for the management of ageing SCEs within the organisation as a whole.				
a. Define top level strategic goals for management of ageing SCEs for generic hazards	1. Develop company objectives with respect to ageing installations (and SCEs) 2. Monitor industry trends and review feedback from interested parties (stakeholders) 3. Establish a programme to compare company objectives against competitors to define 'best in class'	1. Company mission statement referring to managing ageing installations 2. Company annual returns 3. Company publicity literature 4. Corporate Safety plan referring to managing ageing installations	1. Number of queries from regulators and employees regarding company position on asset status 2. Increasing number of deficiencies in ageing SCEs reported from assets	1. Company safety alerts 2. Audit reports 3. QA feedback 4. Stakeholder queries & responses
Process P2:-Planning of the management of ageing SCEs based on the agreed strategy and policy and the defining of suitable performance indicators.				
a. Interpret the strategy for a particular installation and its SCEs.	1. Issue asset/project specific strategy documents before start of project or acquisition of asset	1. Project/asset HSE plan 2. Project/asset HSE management system 3. Safety case 4. Modules within documents describing approach to ageing SCEs	1. Project queries from stakeholders due to absence of strategy statements	1. MoM 2. Safety queries 3. HSE project inspections & queries
Process P3:-Implementing of schemes to gather performance and test data for performance indicators on the condition/management of ageing SCEs.				
a. Undertake activities to measure data for PIs, e.g. tests on SCE with respect to PSs, analysis of effectiveness of SCE control systems.	1. Testing regime and schedule established early in the project/asset life and clearly communicated 2. Testing team with responsible competent	1. Maintenance records 2. Production reports 3. Production forecasts 4. SCE compliance checks 5. ICP WSE reports	1. Decreasing level of performance of ageing systems and components in functional tests 2. Increasing SCE unreliability	1. Maintenance records 2. Production reports

	individuals appointed early in the project/asset life and clearly communicated 3. Increasing percentage of functional tests completed to schedule		or unavailability due to ageing 3. Increasing failure rates for ageing SCEs	
Process P5:- Setting out and implement an appropriate remediation schemes to ensure SCEs meet the required Performance Standards				
a. Set out and implement an appropriate remediation scheme to ensure SCEs meet the required PSs *Including;* *Carrying out of 'defined life repairs'*	1. Programme upgrades based on increasing risk levels and requirements to maintain risk control established early in the project/asset life and clearly communicated 2. Performance Standard monitoring programme established early in the project/asset life and clearly communicated 3. *Establish a scheme for identifying 'defined life repairs' early in the project/asset life and clearly communicated*	1. Maintenance plan 2. HSE plan 3. Maintenance records	1. Maintenance and upgrade programmes falling behind schedule 2. No improvement in performance of ageing SCEs noted after maintenance and upgrade programmes have been set in place 3. *Implementation of defined life repair scheme falling behind schedule*	1. Maintenance records 2. HSE plan
Process P6:-Verifying and Assuring that the ageing SCEs are performing both as isolated systems or in concert with other SCEs				
a. Verify and/or Assure and verify that the ageing SCEs are performing, both as isolated systems or in concert with other SCEs	1. Establish early on a comprehensive scope of work in conjunction with the ICP with specific consideration of ageing SCEs as components and whole systems	1. Safety plan 2. Safety management system 3. Safety case 4. WSE	1. Monitor the number of disagreements between the duty holder and appointed ICP 2. Increasing numbers of failures/near misses & incidents attributed to ageing (using Root Cause Analyses)	1. MoM 2. Safety records 3. LTI reports 4. RIDDOR reporting 5. Board management reports

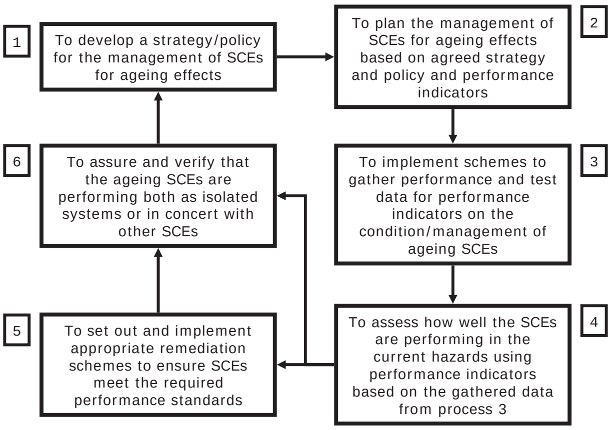

Figure 3. Maturity model processes

Figure 3 shows these processes within a process flow model. The Performance Indicators describe a level of performance according to a maturity level of the success of each process. Further details of maturity levels may be found in EI 2007(ii), Hart 2008 and Wintle 2009.

Each of these processes has sub-processes and these in turn can be measured via a Performance Indicator. For the full details readers should refer to the completed report from the Energy Institute when it becomes available but some examples in Table 2 provides more detail.

The Performance Indicators for the senior management processes more readily yield leading indicators. The Risk Control Systems can be measured by both leading and lagging indicators although leading indicators are more difficult to extract. Examples for 2 types of SCEs are illustrated in Table 3.

It should be noted that the management processes apply to structural systems as well as topside systems. The research initiatives generated by PSA have tended to focus on structural systems and the previous publications referenced have described the way in maturity modelling has been applied to the processes required to maintain structural integrity.

For the successful outcome of the management processes for structural integrity, a robust and damage tolerant structure the proper structural safety is required and is not restricted to the occurrence of single component failures. To be robust and damage tolerant means that the structure must have an acceptable probability of failure due to extreme loading in intact condition or with a single member or joint failure.

Therefore, the management processes and Risk Control Systems must:

– Establish indicators for robustness and damage tolerance. The indicators should ensure that failure due to wave overload (accounting for possible wave-in-deck impacts) is acceptable in intact condition and with one member failed. The damage tolerance and robustness of a jacket structure can be evaluated by barrier analysis, and indicators for barriers can be established. Acceptance criteria for these indicators must be developed based on common practice and structural risk and reliability analyses.

– Evaluate the necessary inspection intervals needed to prevent a single failure from developing into a critical failure and multiple joint and member failures from occurring.

USING BARRIER THEORY TO ASSIST MANAGING AGEING SCES AND ACHIEVING LIFE EXTENSION

The degraded SCEs are generally part of a complex of systems that work together to avoid or protect against the Major Accident Hazards. As installations approach the final stages of their lifetime, it may prove intractable to

Table 3. Examples of leading and lagging indicators for 2 typical SCEs

Typical safety critical element	Leading PIs (examples)	Lagging PIs (examples)
Hydrocarbon containment	• Increasing percentage of scheduled CUI inspections outstanding • Increasing number of pipes repaired or awaiting repair • Increasing percentage cathodic protection checks not completed to schedule	• Increasing percentage lost product (production loss and leakage) due to loss of containment faults • Number and extent of HC leaks detected • Number of cracks detected
Gas, smoke and fire detection and alarm systems	• Number of locations identified where alarms were inaudible due to ageing alarms and increased noise from additional equipment	• Increasing percentage time systems are unavailable • Number of failures of detection systems to perform on demand during emergency or under test

restore one particular barrier to an acceptable level of performance. One option may be to use cost benefit analysis to demonstrate that nothing need be done for a particular SCE although discussions with colleagues in the regulators and verifiers have indicated that this is an undesirable approach as uncertainty in future markets for oil and gas have on occasion resulted in desirable remedial work being deferred. Managing uncertainty in market prices as well as uncertainty in equipment degradation may be a step too far! In such cases, an option may be to make use of the other protective barriers and improve their performance to make-up shortcomings. This approach then becomes an embedded component of the 6 management processes.

It should be noted that not all barriers are "hard", for example, inspection and verification can in turn become safety barriers to prevent and find failures and repair them when they have occurred.

By using the "complete" system, the opportunities for successfully achieving life extension are enhanced. In the Norwegian sector both the PSA in Norway and the industry have initiated a number of activities linked to ageing and life extension on the Norwegian shelf.

The life extension approach must be documented and the steps to achieve adequate safety in connection with continued operation of older facilities and pipelines justified. Ageing installations can no longer exhibit the desired low likelihood of failure of individual parts and components in the extended years.

As part of the continued safety assessment (in both the UK and Norway), an evaluation should be carried out to determine what could happen if one of these parts fails, whether this will lead to catastrophic results, or whether there is sufficient overall robustness that such a failure can be tolerated until the part or component has been repaired? These questions in connection with lifetime extension must be addressed and they may require reference back to the comprehensive and holistic approach using barriers.

Based on earlier work looking at the use of maturity modelling to manage continued structural integrity, further research work was carried out to develop an approach to life extension, this work is reported in references [Sharp, 2008] and [Wintle, 2008]. In addition, audits were carried out of the Structural Integrity Management of an operator of a Norwegian Continental Shelf asset which showed signs of ageing and with a possible approach to life extension being considered [Galbraith, 2007]. The feedback from this audit informed the sub-processes and specifically addressed life extension. New sub-processes, the associated descriptions of maturity levels and the available improvements steps were defined. The modified processes and sub-processes are described in Table 4 below.

Table 4. Modified sub-processes (used in Structural Integrity Management) and their application to ageing and life extension

Main process	Sub-processes	Ageing	Life extension
1. Develop overall SIM philosophy & life cycle condition monitoring strategy	1.1 Development of SIM philosophy		✓
	1.2 Definition of high level acceptance criteria		✓
	1.3 Definition of ageing effects	✓	
	1.4 Allocation & management of resources	✓	✓
	1.5 Understanding of structural performance, strengths and limitations	✓	✓
2. Establish long term inspection programme and emergency preparedness	2.1 Definition of long-term platform specific inspection programmes	✓	✓
3. In-service inspection programme and offshore execution	3.1 Inspection planning	✓	
4. Data logging, evaluation and assessment	4.1 Evaluation, analysis and assessment of inspection data	✓	
	4.2 Assessment for life extension	✓	✓
5. Implementation (design and execution) of repair and mitigation measures	5.1 Determine requirements for repair and mitigation measures	✓	
6. Integrity assurance and reporting, evaluation of effectiveness of SIM	6.1 Assurance of integrity	✓	✓
	6.2 Evaluation of effectiveness of inspection programme	✓	✓
	6.3 Management reporting	✓	✓

CONCLUSIONS

In the work carried out for both sponsors, there has been much interest in looking at Leading Performance Indicators. The authors have reported in previous Hazards papers on the success of Maturity Modelling and it is our view that Maturity Modelling again provides the most suitable candidate for Leading Performance Indicators. Indeed, one of the follow-on activities from managing the effects of ageing SCEs is by suitable maintenance and this formed the subject of a paper by the authors at Hazards XX [Hart, 2008]

In this project, a number of activities have been identified that can be used to manage the effects of ageing on SCEs and structures (whether SCEs or not). For each of these activities it is possible to identify Performance Indicators to determine how well these activities are being carried out. The activities undertaken by senior management have been combined into a maturity model and represent a method of defining effective leading Performance Indicators to supplement more convention measures of performance.

The consideration of the use of barrier theory has been used to assist the steps required to develop life extension strategies and additional management processes have been identified which enhance both management of the effects of ageing and life extension.

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