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Capability maturity models for offshore organisational management

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Abstract

The goal setting regime imposed by the UK safety regulator has important implications for an organisation's ability to manage health and safety related risks. Existing approaches to safety assurance based on risk analysis and formal safety assessments are increasingly considered unlikely to create the step change improvement in safety to which the offshore industry aspires and alternative approaches are being considered. One approach, which addresses the important issue of organisational behaviour and which can be applied at a very early stage of design, is the capability maturity model (CMM). The paper describes the development of a design safety capability maturity model, outlining the key processes considered necessary to safety achievement, definition of maturity levels and scoring methods. The paper discusses how CMM is related to regulatory mechanisms and risk based decision making together with the potential of CMM to environmental risk management.

1. Introduction

All businesses need to manage the health and safety, environmental and financial risks to which they are exposed and good risk management practice is now recognised as essential at the highest business level (Turnbull, 1999). In the UK the management of safety and environment are subject to regulatory controls which aim to ensure that companies place proper and appropriate emphasis on these important issues. However, the regulatory approach has important implications for the organisation and in particular their capability to manage safety and risk.

In the safety field, ever since the 1974 Health and Safety at Work Act, the UK has been creating a "goal setting" regulatory framework (Health and Safety Commission, 2004) in which those who create the risks are made responsible for assessing and controlling them. This includes demonstrating that the risks have been reduced to a level which is acceptable or is as low as reasonably practical. In the UK environmental field, an integrated approach to pollution protection and control has been adopted (DEFRA, 2004). This regulatory regime, while not risk based, is certainly target setting in approach. Its main purpose is to achieve a high level of protection by prevention of emissions or, where this is not possible, by reducing emissions to air, water and land. The regulatory approach in this case is through the determination and enforcement of permit conditions, based on best available technology. In practice this means setting conditions for acceptable levels of discharge of pollutants and ensuring that these are not exceeded.

The success of any regulatory regime is dependent on the capability of the risk generating organisations to manage their risks. A goal setting regime, for example, will clearly demand a higher level of management capability than say a prescriptive regime in which the risk generator is largely directed by others in how to manage their risks. As regulatory regimes move towards goal setting approaches, performance measurement and capability assessment become increasingly important in the achievement of the highest levels of safety and environmental protection. The main aim of this paper is to discuss the concept of the capability maturity model of organisations and the application of the design safety capability maturity model to the offshore industry and its relevance in an increasingly goal setting regulatory environment.

2. The UK offshore safety regime

The current approach to safety in the UK is embodied in the Offshore Installations Safety Case Regulations (Health and

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Safety Executive, 1992). This regulation requires that all hazards with the potential to cause a major accident have been identified, that the risks have been evaluated and that measures are put in place to reduce the risks to a level that is "as low as reasonably practicable" or ALARP. The Safety Case Regulations were supplemented by a series of supporting regulations, one of which has particular relevance to the capability maturity approach; the Design and Construction Regulations in 1996 (Health and Safety Executive, 1996). These installations required the identification of safety critical elements (SCE) for the installation, which are those parts of an installation that could cause or contribute substantially to a major accident hazard if they failed, and those whose purpose is to prevent or limit the effects of a major accident hazard, i.e. the "measures" put in place to reduce risks to personnel. The Design and Construction Regulations also required a "Verification Scheme" to be put in place for all safety critical elements; a process which involves examination of the design or its specification by a nominated independent and competent person (ICP); an important independent check that safety has been properly addressed in the design process.

3. How safety is demonstrated

In a goal setting regime, responsibility is placed on the risk generators to demonstrate that installations are safe and formal safety assessments are an essential input to this. Historically, the process of assessing the safety of a major design has been to undertake a comprehensive technical analysis of the safety built into the design. This often involves a detailed assessment of the potential hazards and risks that the plant may experience. Such studies typically include comprehensive hazard identification reviews, often in the form of a HAZID or HAZOP, combined with the use of appropriate national and international codes and standards to guide design criteria. Ideally, the outputs from these studies inform safety decision making and enable the design team to create an installation in which the design and operating risks have been reduced to a level which is as low as it is reasonably practicable to achieve at the design stage.

In practice, however, implementations of design safety procedures involve a considerable amount of work and most importantly can only be done thoroughly when a significant proportion of the design is complete. Consequently, one of the key challenges for the Regulator and client alike is to discriminate between good and bad design safety features accurately and early in the design and construction process. However, this has proven to be difficult by conventional means. The reason why this is the case is that no matter how sophisticated the technical safety assessment tools and methods are, if they focus on assessment of the "product of design" itself, safety decisions will always have to wait for engineering details to be defined. By the very nature of the design process, this will inevitably occur late in the design process once the main design features have been agreed. Indeed the conventional advice for application of HAZOP (Chemical Industries Association, 1992) is to wait until "design freeze" when sufficient design detail will be available to support the execution of a HAZOP. While at this stage, design change is less costly than changes made during construction or operation, it is still very expensive to make any but the most minor of design changes and is often resisted by powerful project managers who are rewarded for meeting tightly controlled cost and delivery targets.

In order to provide a degree of assurance that the design process will deliver a safe product at a very early stage in a project, a radically different approach to "safety assurance" is required. Preliminary thinking within the HSE and the design safety community (based on brainstorming sessions with design engineers and HSE inspectors) doubted that further refinement of the technical and HAZOP (type) assessment processes would be capable of delivering the high level assessments needed for early safety decision making and it was felt that a more fruitful approach would be to focus on the safety management processes rather than on formal safety assessments i.e. to shift the attention away from safety assessment of "product" to the assessment of the "process" that delivers the safe product. The capability of the organisation to manage the design for safety processes then becomes critically important and has led the authors to investigate the use of management performance indicators and capability maturity models. This represents a key shift in the assurance strategy of the regulator.

4. Design safety performance indicators

In identifying and developing performance indicators it is important to recognise that an organisation's capability is directly linked to its strategy. In (Kaplan and Norton's (1996a,b) pioneering work on business metrics they demonstrated how metrics need to be linked to an overall strategy, which they define as a set of hypotheses about cause and effect. According to these authors, the use of metrics can help in a number of areas. For instance they can be used to clarify and translate vision and strategy, to communicate and link strategic objectives and measures. They can also be useful in defining plans, setting targets and aligning strategic initiatives and provide a means of enhancing strategic feedback and learning.

Phelps (2004) has outlined how metrics can be developed to drive business performance, provide clarity and support decision making. Phelps emphasises the need to focus on the value chain and the need to address both current value and future value. The outputs and drivers provide a useful list of potential metrics. For example, under the future category, key outputs and potential metrics include; value growth, survivability, opportunity and risk, while key drivers include; position (strategy partnerships and investment levels) and capability (management quality, change readiness, understanding customer trends, organisational culture etc.) These future variables are particularly interesting and relevant to the issue of metrics for safety management.

The need for safety assurance based on the measurement of management performance in a safety process is well recognised in industry (HSE, 2000) and various attempts have been made to develop safety indicators (see for example the Step Change in Safety initiative, Step Change in Safety Leading Performance Indicators: Guidance for Effective Use and OGP, 1994).

In 1999 the UK Health and Safety Executive commissioned Cranfield University to undertake a study to develop leading performance indicators relevant to design safety offshore. The initial study was a joint project led by Cranfield with support from Kvaerner Oil, Gas Ltd and Det Norske Veritas. Its prime objective was to identify a management performance measurement framework based on the development of design safety performance indicators, DSPI (Strutt et al., 1998; Strutt et al., 1999; Yates, 2000). In the DSPI framework, the "quality" of safety management processes is assessed. The first stage is to identify key tasks and procedures considered to represent best practice, based on discussion between design engineers and health and safety experts. This is followed by an assessment of the tasks actually performed and involves verification that (a) key processes and activities have in fact been carried out, (b) key processes have been performed to an acceptable standard and (c) where further actions have been identified, appropriate steps have been taken to follow them up.

In DSPI, evidence of performance is considered an essential element of proof and so an important part of the process is that of checking and scoring relevant design and safety documents generated during a project. The DSPI method, while very thorough, was considered by the research team and HSE inspectors to be relatively time consuming, requiring significant resources both to integrate the measurement procedures into project management and document management systems, and was particularly time intensive to read and score the documents particularly after the project was completed. It was considered therefore that research should be focused on finding an alternative, more resource efficient, method which could be based on interviews and discussions but which would complement the DSPI approach. Various methods were considered but the method finally selected for further development was the capability maturity model (CMM) (Sharp et al., 2002). The CMM method was attractive for a number of reasons. Most importantly, it focuses on management, people and their organisation. It requires the identification of key management processes and team behaviours that influence the creation of a system in a project or development environment: all vital issues for design safety assurance.

5. Capability maturity models

Capability maturity models (CMMs) are tools used to assess the capability of an organisation to perform the key processes required to deliver a product or a service. Significantly, they can be used, both as assessment tools and as a product improvement tool. The value of a CMM model is derived primarily from its focus on key management processes which deliver product improvements. In the context of this paper key management processes mean the combined set of management tasks and practices that are necessary for an organisation to meet strategic obligations and goals such as operational safety or environmental risk targets.

6. Origins of CMM

The idea of "management process" and the concept of "capability maturity" have their roots in the field of quality management maturity developed in the 1970s, (Crosby, 1979, 1996). Table 1 for example shows typical behaviours or management perspectives exhibited by companies at 5 levels of maturity. CMM is far more detailed but is of similar format to the Harrington process improvement levels (Harrington, 1991). The best known derivative of the quality management maturity concept is the CMM developed by the Software Engineering Institute (SEI) in the US (Paulk et al., 1993). This tool is based on five levels of maturity and identifies key process areas for software development. It was developed originally to assess the capability of an organisation to design and develop software but has since been extended and used in many different areas some of which can be found on the SEI website (http://www.sei.cmu.edu/).

One of the strengths of the capability maturity concept is that it is generic and adaptable, a fact reflected by the increasing number of CMMs in other industries (see for example Fraser et al. (2002) for an overview). This has also been incorporated into ISO 9004 (ISO 9004, 2000) as a measure of the maturity in quality assurance, as shown in Table 2.

7. Application of CMM to design safety

In the area of safety, CMM frameworks have been developed to address safety culture (Keil Centre, 2000) and design safety (Sharp et al., 2002). In this paper we describe details of the design safety capability maturity model (DCMM) and its use in assessing the capability of operators and contracting organisations involved in the design and construction of a safe offshore installation.

DCMM is based on three fundamental principles, namely that:

1. The measurement of organisation management performance will yield additional and important information over and above that obtained from formal safety assessment of the installation.

Table 1
Part of the Crosby (1979) quality management grid

Level	Stage	Management perspective
5	Certainty	"We know why we do not have problems with quality"
4	Wisdom	"Defect prevention is a routine part of our operation"
3	Enlightenment	"Through management commitment and quality improvement we are identifying and resolving our problems"
2	Awakening	"Is it absolutely necessary to always have the problems with quality?"
1	Uncertainty	"We do not know why we have problems with quality"

Table 2
Description of levels of maturity in ISO 9004 (2000)

Level	Maturity	Description
5	Best in class performance	Strongly integrated improvement process; best in class benchmarked results demonstrated
4	Continual improvement emphasised	Improvement process in use; good results and sustained improvement trends
3	Stable formal system approach	Systematic process-based approach, early stage of systematic improvements; data available on conformance to objectives and existence of improvement trends
2	Reactive approach	Problem or prevention based systematic approach; minimum data on improvement results available
1	No formal approach	No systematic approach evident, no results, poor or unpredictable results

2. The measurement of capability can be obtained at a much earlier stage in design than conventional safety assessments, which require detailed knowledge of the design architecture, its component systems and subsystems and its operating characteristics.
3. There is a progression through different levels of maturity because some organisations have greater capabilities to design for safety than others, e.g. through a combination of experience and good practices, supported by research and relevant and up to date training, etc.

The main purpose of the DCMM model is to assess the capability of an organisation to perform a set of processes, representing different perspectives of design safety management. Establishing these processes is a core activity in the development of the model. These need to capture the activities that are required to deliver a safe design and they result from discussions with a team of experts and engineering specialists. Each process is given a score reflecting the capability and maturity of the organisation in undertaking that particular process. The group of processes and scores when taken together define the organisation's capability to achieve their design safety strategy and its goals.

8. Development of DCMM

An overview of the DCMM is shown in Fig. 1. It shows 12 key safety management processes, the maturity levels and the organisational characteristics associated with each level. The development of the Cranfield capability maturity models proceeded through a series of stages as follows:

1. Identification of goals and key processes
2. Definition of maturity levels
3. Development of a CMM scoring system
4. Identification of the behavioural characteristics that define maturity
5. Development of improvement steps

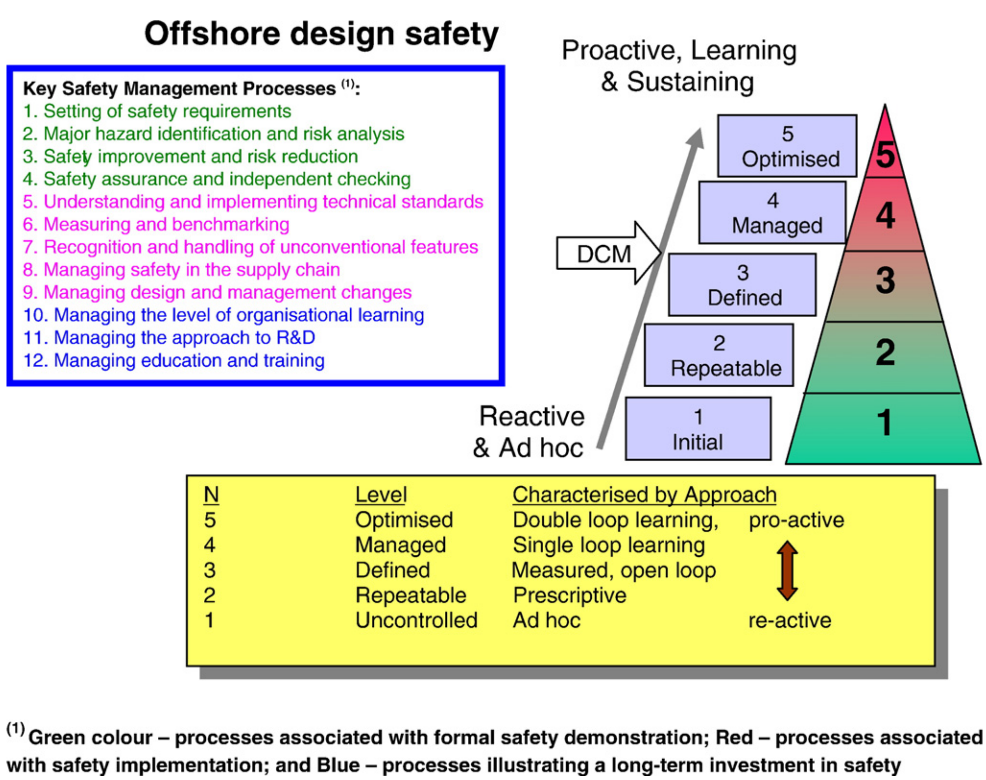

Fig. 1. Overview of design safety capability maturity model.

6. Testing the model
7. Application of the model
8. Further development of the model based on Feedback

An overview of these stages is shown in Fig. 1 and more detail is provided in subsequent sections.

8.1. Identification of goals and processes

The first step in developing the capability maturity model for a particular activity is to define the key processes and associated goals which are considered necessary to achieve the organisation's overall objective, taken to be the creation of a safe installation. Understanding and recognising organisational process goals is an important part of defining the key processes. One way of doing this is through brainstorming discussions involving engineering specialists, health and safety experts and social scientists and the use of logical argument, which consider the ordering and necessity of the identified processes. This enables an understanding of necessary activities to be built up and how these must be linked to be successful in achieving an overall strategy. Fig. 2 shows an example of a flow diagram which was created while trying to identify and map key management processes in designing for safety. Although, not all 12 eventual key processes are identified on this particular map, a number are clearly evident, including: the setting of risk acceptance criteria, the process of risk identification and assessment, the process of risk reduction, feedback and organisational learning, etc. The elements missing from this map are the medium and long term investment practices in safety such as use of technical standards, management of the supply chain, "education and training" and "research and development".

Over a period of time and iterations involving discussions with regulators and industry, twelve key safety processes were eventually identified for the DCMM. These are listed and described in Table 3. The key safety management processes are grouped into three categories. These have strategic and operational significance:

1. Processes associated with formal safety demonstration (1 to 4 in Fig. 1).
2. Processes associated with safety implementation (5 to 9 in Fig. 1).
3. Processes illustrating a longer term investment in safety (10 to 12 in Fig. 1).

The core strategy for creating a safe installation is reflected by the first four key management processes related to formal safety demonstration. These same four processes are also clearly reflected in the process flow chart of Fig. 2. They are:

- Defining safety requirements and safety acceptance criteria
- Identifying, analysing and evaluating safety related risks
- Creating and delivering a design which meets the acceptance criteria
- Providing assurance that safety goals will be met in advance of operation

The important checking role of the verification and validation process which is evident in Fig. 2 is included as a key element of the safety assurance process. The important role of feedback (for the higher maturity levels) is also shown in Fig. 2, with key links into the identification of hazards and risks and also into the design process itself.

The five implementation processes reflect safety management activities which are found to be important in practice and support the core processes. Some of these are well understood by the industry, for example, "understanding and implementing technical standards". Others are less well understood or poorly

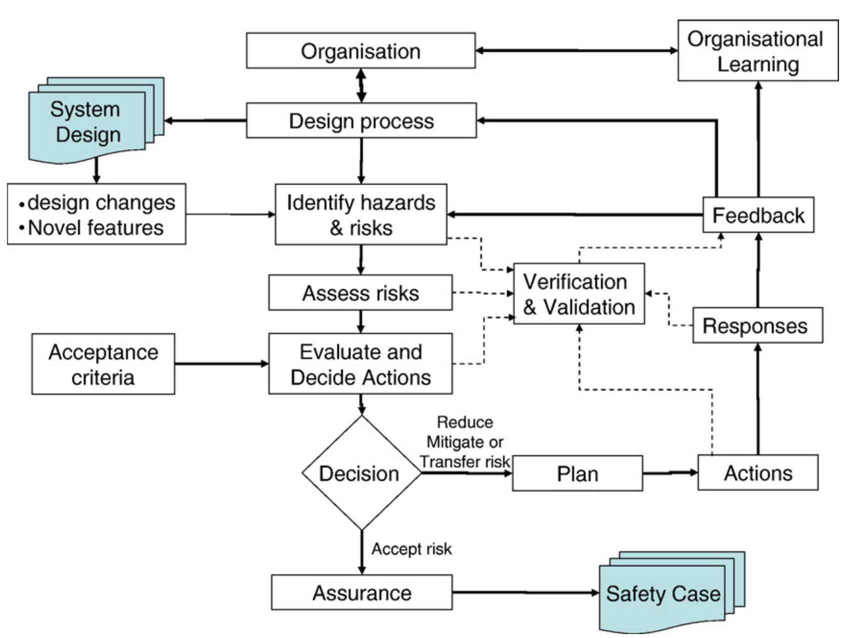

Fig. 2. Identification and mapping of management processes.

Table 3
Description of key processes used in the DCMM model

	Elements	Description of process	Category
1	Setting of safety requirements, framework and direction	How comprehensively the organisation determines safety requirements during design and defines them for clear communication. How the organisation sets a fundamental direction to achieve safety and continuously improve through incentives, culture etc.	
2	Major hazard identification and risk analysis	How well the organisation operates the process of major hazard identification and risk analysis. The completeness with which major hazards are identified and logged into the project processes.	Formal safety demonstration
3	Safety improvement and risk reduction	How well the organisation manages the activities and tasks related to making safety improvements and implementing risk reduction during the design process How well the organisation operates the process of demonstrating that risks are ALARP	
4	Safety assurance and independent checking	How well the organisation conducts its checking processes especially validation and verification.	
5	Understanding and implementing technical standards	How well the organisation uses, develops and maintains standards.	
6	Measuring and benchmarking	How well the organisations measures its own performance and compares it with that of other, comparable organisations	
7	Recognition and handling of unconventional features	How well the organisation anticipates and manages the ways, in which unconventional elements of projects benefit or compromise safety	Safety implementation
8	Managing safety in the supply chain	How well the organisation manages its supply chain partners in meeting and demonstrating design safety	
9	Managing design and management changes	How well the organisation manages change that can impact on design for safety including life cycle transitions e.g. from FEED to detail design	
10	Managing the level of organizational learning	How well the organisation adds to and uses its stock of knowledge to support design for safety	
11	Managing education and training	How well the organisation determines, acts on and exploits the need for education and training relevant to design for safety	Longer term investment in safety
12	Managing the approach to research and development	How well the organisation conducts and exploits R and D to support design for safety	

addressed, for example "identifying changes or unconventional features in design, construction or operation". These factors often introduce unexpected hazards which may go unnoticed in fast track projects unless specific action is taken to identify them. In practice, such issues are often hidden deep in the detail of a design and it is a major challenge to identify and remove them; high levels of capability are needed in practice to effectively address this topic.

Design changes or unconventional features are often hidden as a result of their origin. For example, they may be introduced through the products of 2nd or 3rd tier suppliers of hardware. The project organisation will in such cases need specific management processes to recognise unconventional features, to identify and assess changes and to manage the supply chain such that unexpected problems originating in the suppliers' products are avoided or effectively managed.

The last three safety management processes (10 to 12 in Fig. 1) relate to a company's strategy for sustaining their capability in the long term; they are fundamental and are often the areas where contractors and supplier companies are weakest.

8.2. Definition of maturity levels

The next step in CMM development was to define a set of maturity levels. The DCMM model is based on a 5 level ranking system, ranging from the lowest maturity, level 1, corresponding to initial or learner, to the highest maturity, level 5, corresponding to an optimised process or best practice. It is important to understand what these various levels actually mean as this is crucial to assessing the maturity of an organisation. In the Cranfield CMM, 5 levels were identified (Table 4) but the underlying principle of the five levels is based on a concept of how the organisation learns and responds to knowledge gained (Table 5). We have adapted ideas from the theory of action and the concept of single and double loop

Table 4
Description of DCMM maturity levels

Level	Maturity	Description
5	Optimised	The Organisation is 'best practice', capable of learning and adapting itself. It not only uses experience to correct any problems, but also to change the nature of the way it operates.
4	Managed	The Organisation can control what it does in the way of processes. It lays down requirements and ensures that these are met through feedback.
3	Defined	The Organisation can say what it does and how it goes about it.
2	Repeatable	The Organisation can repeat what it has done before, but not necessarily define what it does.
1	Initial	The Organisation has limited experience and is at a learning and development stage.

Table 5
Interpretation of maturity level

N	Maturity	Learning mode	Process characteristic and effect
5	Optimised	Adaptive-double loop learning	Processes are adapted to optimise product safety
4	Managed	Quantified-single loop learning	Processes are quantitative and influence product safety
3	Defined	Measured-open loop	Processes are defined for safety. There is partial influence on product safety.
2	Repeatable	Prescriptive	Processes are standardised but lack real influence on product safety
1	Ad hoc	Reactive	Processes are not standardised and are largely uncontrolled
0	Incomplete	Violation	

learning (Argyris and Schön, 1978) to discriminate between the higher capability levels. Single loop learning occurs when errors are detected and corrected thus permitting the organization to carry on its present policies or achieve its present objectives. Double loop learning occurs when errors are detected and corrected in ways that involve the modification of an organization's underlying norms, policies and objectives.

In the Cranfield model, CMM double loop learning is consistent with the highest (level 5) capability. That is, the organisational processes influence not only the safety of the product but they are able to adapt their management processes, and where necessary, their organisation, to optimise the delivery of the safe product. A level 4 capability is linked to single loop learning such that the safety management processes influence the designed product. This is a fundamental requirement to meeting a goal setting regime. Organisations at level 3 and below are essentially open loop. The level 3 organisation however, knows what it must do to deliver safety but finds it difficult to use the output of its processes to influence design. A level 2 organisation has the ability to standardise its management procedures and can repeat what is has done before, but the processes are not properly defined for achieving safety. They may, for example, be unclear about what safety activities need to be performed or they may have limited or inappropriate tools for safety assessment. The lowest level 1 organisations are regarded as learner organisations. They lack consistency in safety management and when safety is addressed the approach appears ad hoc and may not meet regulatory requirements. These lower levels can also be examples of setting requirements which are not done on a consistent basis.

8.3. Development of CMM scoring system

As discussed above, CMM models have typically been developed with 5 levels of capability, ranging from 1 to 5; although there is increasingly a need to introduce a sixth level by inclusion of a level 0 (see Table 5 and paragraph below). In the models developed at Cranfield University as each process is examined a level of maturity achieved is assigned and provided with a score between 1 and 5. The process maturity scores can then be collated to give an overall assessment of capability and there are various methods which can be used. One approach is to average the individual scores for each process. While this will

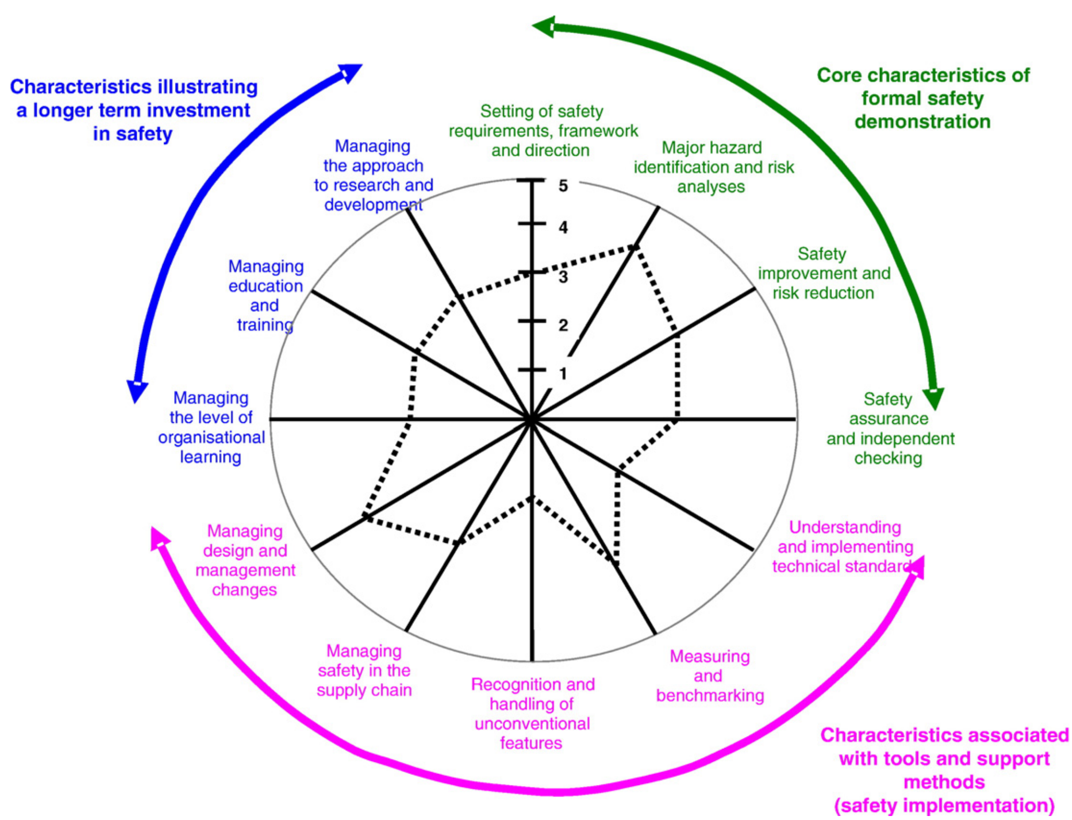

Fig. 3. CMM spider diagram.

generate an overall capability, care should be taken in its interpretation as an average could either mask important shortcomings in one or more processes or not show credit for outstanding performance in other processes. An alternative method is to restrict the overall maturity to the lowest of the process ranks. Using this method it is harder for companies to claim any credit for higher levels of capability in some processes as all the processes have to achieve the same level. For this reason it is always better to look at the overall scores say in the form of a spider diagram such as that shown in Fig. 3. This diagram clearly indicates where the strengths and weaknesses lie in the organisation's key processes.

Concerning the case for a 0th order maturity level; in the Cranfield DCMM there is an underlying assumption that the 12 key processes are present in some form and to some degree, even in a level 1 organisation. While this is true for most organisations, it may not of course always be the case, particularly for uninformed new entrants to a business area or for organisations with deliberate criminal or violation tendencies. If a key process is absent then it may be more accurate to assign a 0th order maturity level.

8.4. Identification of behavioural characteristics for processes

In order to identify a maturity level for an organisation's implementation of a process, it is necessary to understand how organisations with different maturities approach and implement a particular process. This requires that each process is described at each level of maturity. The descriptions should be concise and clear so that it is straightforward to identify the important characteristics and discriminate the capability level. These should reflect the generic discriminators, such as those outlined in Table 5, related to learning style and process characteristics effect. The generic issues listed in Table 5 provide guidance; however, there are other key behavioural characteristics which are important to consider. These include the following issues:

- Commitment to perform: addressing issues of leadership and policy.
- Ability to perform: addressing issues of man-power and time resources committed, staff competence and provision of tools to support implementation of processes.
- Methodology: addressing such issues as the procedures used to perform the various processes, the nature of the assessment tools (qualitative, quantitative) and improvement strategies.
- Organisational integration: addressing the extent to which management processes are integrated to meet overall organisational goals and commitments.
- Evidence: which addresses the strength of evidence of espoused behavioural characteristics and of processes performed.

8.5. Identification of improvement steps

The framework is based on the assumption that higher levels of maturity incorporate the requirements of lower levels. An organisation could not, for example, be at a managed level if it did not have the positive qualities associated with the defined level. This means that the best way to apply the framework is to start by applying the lowest level to the organisation in question and work up each level until the organisation fails the requirement associated with that level. For instance, an organisation is at the defined level if the first requirement it fails is one of those associated with the managed level. In the models developed by Cranfield, it was found useful to focus attention of how organisations can improve their capability. In the complete model there is a table showing how organisations can progress up the maturity ladder for each process (Table 6).

8.6. Testing the model

Testing is an important stage in the development of a CMM and serves a number of important functions. For example tests can be used to validate the model, to obtain feedback on how well the model worked in practice and to identify practical improvements. In the DCMM case, the model has been tested by HSE inspectors and by an oil company assessing an engineering contractor. Feedback from these organisations was found to be useful in adding information to the model. For example it was found that the table of improvement steps was most useful in identifying the maturity level of the organisation but that it needed more detail to help the process. As a result of the feedback, a number of amendments were made to the table of improvement steps.

There have been some adverse comments about the use of numerical scores, particularly where the scores are used in a commercial environment. It is perhaps worth pointing out that a scoring system is not necessary for CMM to be applied. The main value of a CMM audit is its ability to identify weaknesses in the management processes. It creates an explicit and motivational driver for management to change the maturity level of their team, project or organisation. During a CMM assessment process, those being assessed are exposed to the characteristics of the levels below and above their own and analyses of what separates them from the higher or lower performance. By the end of the assessment, management should know what they do well and what processes and additional practices they need to introduce or develop further. This embeds

Table 6
Steps required to improve the level of maturity

Current maturity level	General steps required to move up to next level
4 to 5	Ensure that feedback from benchmarking is used to both improve long term safety processes, organisational structure and education and training
3 to 4	Implement feedback from bench marking processes to improve safety in designed product
2 to 3	Implement documentation and procedures to ensure all safety processes are defined and recorded, and set targets and requirements
1 to 2	Ensure that previous processes are well recorded and can be repeated

motivation and improvement steps within the CMM process providing an influence and guidance to change what is usually absent from other assessment and feedback models and consequently often ignored. As an example a level 3 maturity would not include use of feedback to modify and improve the design processes. The CMM approach therefore reintroduces a key stage in the whole assessment process that has the potential to add the most value.

8.7. Application of CMM

The CMM model can be applied to a range of organisations and teams associated with a particular development and in different ways. In an offshore design project there are various organisations interacting for example; the duty holder, and their engineering contractors and hardware suppliers. Sometimes, for instance, the duty holder's organisation might score highly, but the project organisation might score poorly because of the constraints set by the particular project. The model developed by the Cranfield team has provided guidance in its report to the HSE on how different stakeholders may wish to measure their DCMM characteristics (report unpublished); the report also provides some guidance on expectations for each of these stakeholders. The three main stakeholders considered within the DCMM model are:

- The Duty Holder's Organisation
- The Design Contractor's Organisation
- The Project Organisation

The DCMM can and should be applied at each stage of the design life cycle including the design feasibility phase. Therefore, DCMM can provide a systematic framework in which people inside and outside a design organisation can make judgements about its capability. It provides an organising principle which helps direct attention to important issues, raises problems that need further investigation, and provides some structure to work out how to improve the organisation. The model also enables a set of benchmarks to be established when applied to a range of similar organisations. It can be used as a self-assessment tool or through an external independent organisation.

Having stated that the importance of DCMM is not to provide a scaling process, there are nonetheless benefits to applying scoring criteria to each of the twelve DCMM characteristic processes. From these a profile of the organisational capability can be developed, as shown, for example in Fig. 3 for an actual organisation. It should be noted that the benefit of this approach is that most of the organisations reviewed did not have a consistent or uniform level of achievement across all processes. For example many organisations had lower levels of maturity in the longer term processes such as research, education and training. The comparison across all processes gave a general indication of where such an organisation may be placed. If, for example, the organisation was one of several bidding competitively for a project then those with more favourable ratings could be at an advantage.

8.8. Further development of the model based on feedback

The final stage of the development process is model refinement based on feedback from the experience of companies as the model is used in practice. The first few implementations of the CMM model should ideally be treated as a final stage of practical testing and model validation. Indeed we have found that these models need to evolve as new or unexpected issues, difficulties or limitations are revealed through their use.

9. Discussion

Within the hierarchy of risk management, controlling risk at source is overall more effective than mitigating the consequences after the event. In the context of large design and build projects, control at source by intelligent proactive design effort is regarded by safety professionals as good design practice. Mitigation on the other hand is perceived as more burdensome in terms of resources and plant operating costs as a result of the additional time, effort and personnel required to operate badly designed plant safely. Whilst all organisations must have some capability to respond in the event of an incident, companies which only address safety through a reactive response tend to be those with a lower capability. Higher capability demands proactive as well as reactive components in a safety strategy.

DCMM is seen as a means by which a significant step forward in design safety management may be achieved. For example the UK regulator (HSE) includes the model on its web site as an example of incorporating health and safety into design. Within the DCMM assessment process, the long term objective is not simply as a performance measure but rather a mechanism for change. The real added value from the DCMM process takes place in the gap between the outcomes of the assessment and the necessary or desired end state for the management team, client, or regulator i.e. by focusing on the process that delivers the safe installation.

10. Implications for CMM in regulation

CMM is increasingly seen as an important tool within a regulatory framework, this is especially so in the UK, where there has been a strong shift since the 1970s towards goal setting regulation. In a goal setting regime, companies have a degree of freedom to decide how to control the risks they generate. However, we would argue that if a goal setting or target setting regulatory regime is to function well, a minimum level of capability of the design and construction organisation and also the installation duty holder's organisation must be achieved.

In the design safety CMM, organisational behaviour is characterised by five maturity levels, namely; learner, repeatable, defined, managed and optimised. These levels can be thought of as transitions between two polar extremes in the way design for safety is managed in an organisation, namely, reactive and proactive. At the one extreme corresponding to levels 1 and 2 we have organisations for which safety is largely based on reaction and a general "wait and see" approach. For these organisations the level of safety is at best what they have achieved in the past. Safety tasks are largely based on following standard practices and while they must comply with the law, they have largely undefined procedures for achieving compliance and tend to minimise the level of effort in safety and risk analysis and its management. Organisations at levels 4 and 5 on the other hand, have well defined safety management systems which they use to influence design at the design stage and create the safe installation. Such organisations tend to possess better capability to perform quantitative risk analyses combined with a higher degree of control over safety and an ability to define and meet acceptable levels of safety and risk. They tend to have better trained staff and allocate resources at a level sufficient to understand and act on the risks that the design process creates before the installations are operated. They tend to be more aware of relevant R and D and invest in R and D activities which lead to safety improvements at product or process level. Level 3 organisations are often in transition between and level 2 and level 4 management styles. The most significant characteristics of the level 3 organisation are their better knowledge and ability to assess risk than level 2 organisations. Their risk assessment methods however, tend to be more qualitative than quantitative and have a somewhat limited capability to make design changes which deliver higher levels of safety.

While there are shades of opinion on the minimum level of capability needed to meet the requirements of a goal setting regime, the Cranfield DCMM was explicitly defined to show compliance with regulatory authorities' expectations. Level 3 was defined as the point at which the organisation understands what it must do to meet regulatory requirements. However, where the regulations require organisations to demonstrate that all risks have been reduced to ALARP level it is arguable that level 4 should be treated as the minimum capability that the organisation should aspire to since it is at this level that analysis will influence design safety decisions.

It is interesting to consider how capability maturity impacts on regulatory policy. There are various policy principles that are held by Regulators (Pollard et al., 2004). These are:

- The precautionary principle
- The enforcement principle
- The communication and participatory principle and
- The monitoring and education principle

These regulatory principles are generally applicable, whether the regime is totally prescriptive or goal setting. However, the degree of success of a given policy mix will be sensitive to the capabilities of the duty holders and risk generators. For example, a monitoring and education principle will work far more effectively for organisations with capabilities at or above level 3 because these organisations have a higher order of organisational learning capability. Organisations below level 3 on the other hand, tend to lack proactive risk management capability and therefore often require the use of enforcement principles to force them to address safety and to implement risk assessment as part of the design process. The various regulatory principles are shown in relation to the regulatory ladder of Fig. 4 (adapted from Leinster, 2001). Although these principles were developed from an environmental regulation view point,

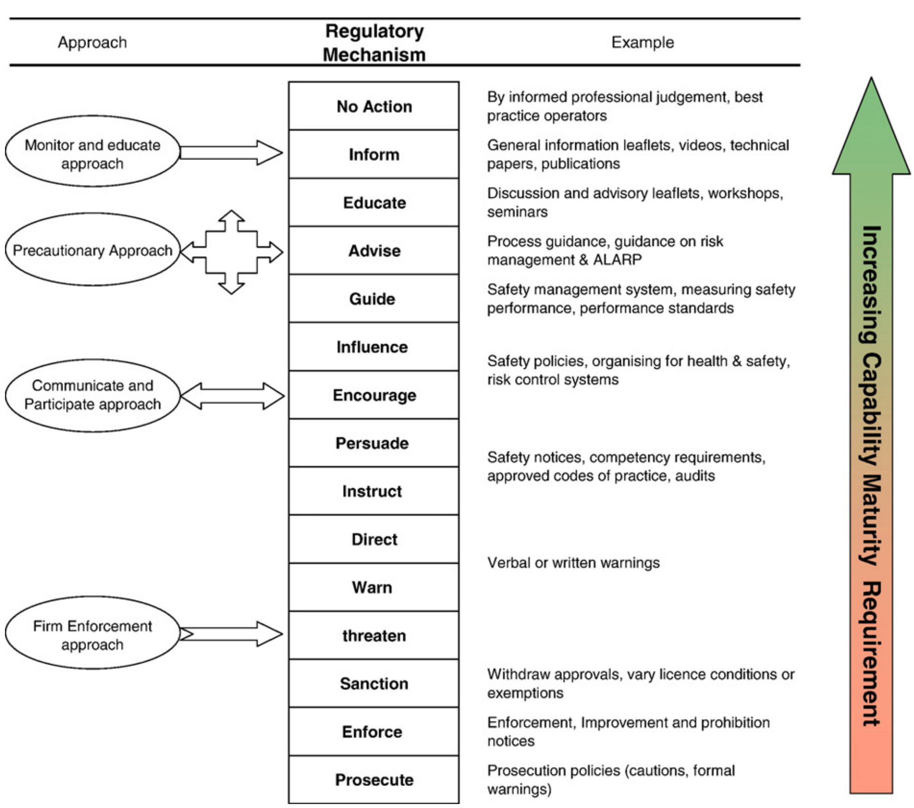

Fig. 4. Regulatory ladder (adapted from Leinster, 2001).

there are some important analogies in health and safety regulation.

11. Implications for CMM in decision making

The UK Offshore Operators Association (UKOOA, 1998) has defined a risk based framework which is widely accepted and used by organisations in the offshore oil and gas sector. These guidelines were developed in recognition of the need to make risk-related decision making more open and repeatable. The framework (illustrated in Fig. 5) provides a structured and integrated approach that enables business, technical and social factors to be considered and used to establish a sound basis for decision making.

The framework defines three broad categories of decision for a project, namely:

A. Nothing new or unusual. No major risk implications. Established practice. No major stakeholder implications. No significant economic implications.
B. Business risk or life cycle implications. Some risk trade-off. Some uncertainty or deviation from standard or best practice. Some significant economic implications.
C. Very novel or challenging project. Strong stakeholder views and perceptions. Significant risk trade-off or risk transfer and large uncertainties with possible lowering of safety standards and major economic implications.

The UKOOA framework identifies seven decision making methods in general use throughout industry, namely the use of:

1. Codes and standards
2. Independent verification
3. Good practice
4. Engineering judgment
5. Quantitative risk assessment with cost benefit analysis
6. Company values
7. Societal values

The framework and its implications for organisational capability are shown in Fig. 5 (UKOOA, 1998). In many common engineering situations in every established practice characterised by type "A" decisions, risk management can be handled largely by reference to relevant codes or current practice. Such tasks can generally be accomplished by organisations with a minimum capability of level 2. In practice, and most commonly for conventional offshore installations and operations, type "B" decisions have to be made. These typically involve the use of risk assessment and cost benefit analysis trade-offs. We would suggest that the minimum capability for this category of decision making is level 3 and ideally decision makers should have a level 4 capability, particularly where the designers have to demonstrate that all risks have been reduced to ALARP. Where new or potentially controversial activities are proposed, or where there are large risk implications and uncertainties a type "C" decision context will predominate for many key issues, particularly those involving the environment. In such situations it is more appropriate to address the concerns, views and perceptions of all stakeholders both internal and external, for example; the workforce, investors, regulatory bodies, environmental organisations and the likely public or media response. This type of activity requires the highest level of risk management capability and in particular an ability to change policies and practices that address type C decisions. It can be argued therefore that organisations with at least a level 4 or 5 capability would be needed to deal with these types of risk. Such organisations have the highest level of assessment capability but

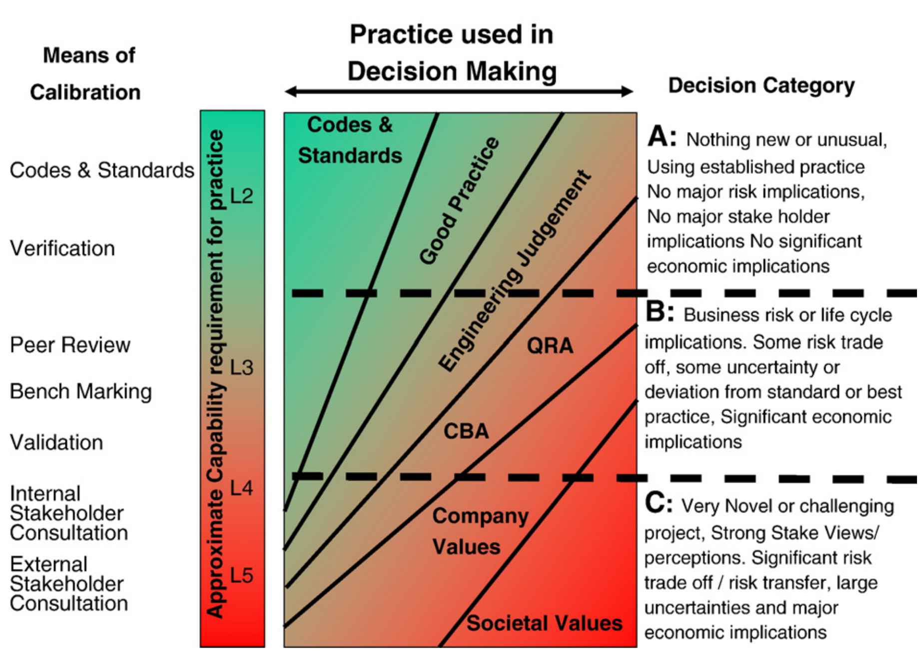

Fig. 5. Decision making framework mapped against capability level adapted from the OKOOA framework.

more importantly have single or double loop learning potential, that is to say this can both influence the design and/or adapt their own organisational behaviours to meet the challenges raised.

12. Implications for CMM in environmental risk management

While this paper has focused on CMM in safety there are major opportunities for using CMM to address environmental risk management capability. Environmental issues are increasingly important in the oil industry and most oil companies are anxious to demonstrate their responsibility in managing environmental risks. There are a number of potential pollution sources resulting from oil and gas exploration and production. These include; a variety of oilfield chemicals and solid waste, drilling mud and cuttings, flared gas, treated injection water and accidental oil spills, etc. Protection of the environment is increasingly recognised as important offshore and this trend is expected to increase in the future. The need to decommission more offshore platforms in the next few years while meeting increasing environmental standards will provide a major challenge for the oil companies.

The advances made in the development of the design safety CMM within the offshore sector are likely to have direct application to environmental risk management particularly for the operation and regulation of installations with environmental permits. Environmental regulators are showing increasing interest in both risk based regulation and self-regulation, under which the capability of operators to actively manage risk is being assessed. This will have important implications for the amount of regulatory attention given to sites and the charge regulators make of operators (Leinster, 2001; Pollard, 2001).

It is envisaged that environmental regulators will show significant interest in an organisation's capability to manage environmental risk especially where companies operate multiple sites at home and abroad. Plant level monitoring of risk management capability will provide a valuable reality check on corporate risk management statements. The operator pollution risk appraisal (OPRA) schemes introduced for the environmental regulation of the process sector in the UK offer one example of how the inherent hazards associated with unit processes and with operator performance at individual sites can be assessed to provide an overall risk profile for operators, process sectors and regions (Dahlström et al., 2003).

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