FURTHER DEVELOPMENTS OF THE CAPABILITY MATURITY MODEL TO MONITOR ACTIVITIES SUPPORTING THE OFFSHORE INDUSTRY

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The Cranfield University has been developing applications of organisational behaviour as part of projects for the Health & Safety Executive in the UK and the Petroleum Safety Agency in Norway. These approaches include a Design Safety Performance Indicator and the development of Distributed Cognition Models for Human Factors Failures in the Operating and Design Processes, both of which have been presented at past Hazards Symposiums.

The authors and the HSE have seen these models as part of a general suite of tools providing measures or indicators of organisational behaviour that can be used to provide a leading indicator of performance in a range of areas. This paper describes the latest developments of one of the suite's most powerful and adaptable tools, the application of Capability Maturity Modelling.

The measurement method assesses an organisation's processes in a given endeavour and identifies an assigned level of maturity; the method categorises the relative roles of groups of processes and indicates potential improvement steps to enable organisations to move up the maturity scale.

The paper describes recent applications that the authors have developed and by way of confirmation of the wide ranging adaptability of the tool, reports on the testing the model has undergone.

BACKGROUND

Cranfield University has been developing tools that can be used to identify and assess leading indicators in design safety. The tools started with a Design Safety Performance Indicator (DSPI) which in a later phase of the project was supplemented by the application of a Capability Maturity Model. There has also been an investigative tool looking at distributed cognition of the personnel, this has latterly been more commonly referred to as "Distributed Assumptions" and was reported by Busby et al[1] at an earlier Hazards. The development of tools has continued with further developments of applications of Capability Maturity Modelling, this was developed in parallel with DSPI but in some ways has yielded more promising results and shown itself to have wider applications.

This paper will review the history of the developed tools and describe their potential roles and will then describe the further work that has been carried out on maturity modelling.

THE DRIVERS FOR EARLY SAFETY ASSESSMENT

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. 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 should be reduced to a level which is as low as it is reasonably practicable.

However, implementations of design safety procedures involve considerable amounts of work and most importantly can only be done thoroughly when a significant proportion of the design is complete. Consequently, a key challenge for the Regulator and Client alike is to discriminate between good and bad designs early in the design process; 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, if they focus on assessment of the "product of design" itself, safety decisions will always have to wait for engineering details to be defined. Indeed the conventional advice for application of HAZOP (CIA[2]) is to wait until there is sufficient design detail to support the HAZOP. At this stage, although design change is less costly than during construction or operation, it is still very expensive to make any but the most minor of changes and this is often resisted by project management teams for whom schedule and cost are the priority.

In order to provide an early assurance that the design process will deliver a safe product, a radically different approach was required. Preliminary thinking doubted that further refinement of the technical 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. The use of the resulting tools represents a key shift in the assurance strategy of the regulator.

DESIGN SAFETY PERFORMANCE INDICATORS (DSPI)

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[3],[4] 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 objective 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.

In his book Smart Business Metrics, Phelps[5] outlines 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 (HSG 65[6]) and various attempts have been made to develop safety indicators, (refer to the Step Change in Safety[7],[8] initiative and the E&P Forum/OGP Guidelines[9]).

In 1999, the UK Health and Safety Executive commissioned Cranfield University to undertake a study to develop leading performance indicators relevant to design safety. The initial study was a joint project led by Cranfield with support from Kværner Oil and Gas Ltd and DNV. Its prime objective was to identify a management performance measurement framework based on the development of design safety performance indicators, DSPI (Strutt et al.[10],[11], Yates[12]). 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. This is followed by an assessment of the tasks actually performed and involves:

- verification that key processes and activities have in fact been carried out;
- assurance that they have been performed to an acceptable standard; and
- confirmation that, 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 an important part of the process is checking and scoring relevant design and safety documents generated during a project. The DSPI method, while very thorough, was considered by both 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 particularly time intensive to read and score the documents. The DSPI model also was specifically focussed on an active project and through discussions with HSE inspectors; it became evident that some form of inspection/assessment that could be usefully carried out prior to the commencement of a project would be especially helpful. It was therefore considered that research should be focused on finding an alternative method which could be based on interviews and discussions but which would complement the DSPI approach and thus start to form a suite of assessment tools able to suit a range of situations. Various methods were considered but the method finally selected for further development was the capability maturity model (CMM), (Sharp et al[13]). 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 the key management processes and team behaviours that influence the creation of a system in a project or development environment.

DISTRIBUTED COGNITION OR DISTRIBUTED ASSUMPTIONS

The second part of the suite of tools was Distributed Cognition, this tool was based on detailed accident investigation and analysis and looked to identify lessons for designers from those analyses.

The Distributed Cognition project looked at the Human Factors failures in operating and design processes, and fundamentally considered human error not as an "uncontrollable and random event" but as the inevitable result of unintentionally developing or allowing an error-forcing environment.

In public dissemination, the project has been hampered by an erudite name, one that is entirely appropriate to those with psychology training but that is rather daunting to engineers, hence the name change to distributed assumptions.

The project focussed on providing rules to assist designers and operators to eliminate constraints and behaviour that would ultimately yield "error forcing" conditions.

From a review of failures associated with previous projects a number of observations were raised:

- that failures were in the human processes not just in physical equipment;
- that available cues for information or response had been missed or misread;
- that the design processes and the designers should look at operators as people.

This project endeavoured to provide a set of templates to help structure the testing of assumptions to help review processes rather than products, thus assisting those with design responsibility to identify human failings as starting point. These templates assist individuals to solve problems by bringing together rationales and conflicts that have arisen from:

- their own thinking;
- observing and learning from other people's behaviour;
- understanding custom and practice in their sector; industry or company;
- interrogating organisational procedures;

- describing and defining the context of the problem;
- reviewing the basis of the rules one must obey; and
- applying the tools to be used.

When problem solving fails (and when, for example, they have an accident) we should not simply look at what has gone on in someone's mind and we should not think of 'human error' as a product of a limited brain.

The key application of distributed assumptions was to understand how cognition was allocated, it was concluded that assumed knowledge was assigned in the following ways:

- To artefacts;
  - To special and general tools;
  - To guides and instructions;
  - To task and procedures;
- To culture;
  - To common assumptions;
  - To normal practices;
- To others;
  - To copied strategies;
  - To shared work;
- To history;
  - To reused designs;
  - To extrapolated standards.

It should be remembered that the project started by reviewing the background to, and causes of, real accidents. These analyses identified a number of flawed assumptions underlying distributed problem solving, which when acted upon (or when they constrained action) contributed to an accident. The flawed assumptions proved to be a valuable component of the ultimate model and some of the summarised categories can be seen in Figure 1 which represents a "screen dump" from the computerised version of the model. The flawed assumption categories were defined as follows.

- That different people have common goals
- That different people have common knowledge
- That what is available is appropriate
- That emergent priorities are reasonable
- That task provides enough cues for trial & error
- That absence and failure are not confounded
- That practices are completely general
- That processes are infallible

In addition to these "flawed assumption" categories, a number of environmental factors were identified. As noted above, the investigation of previous accidents considered the

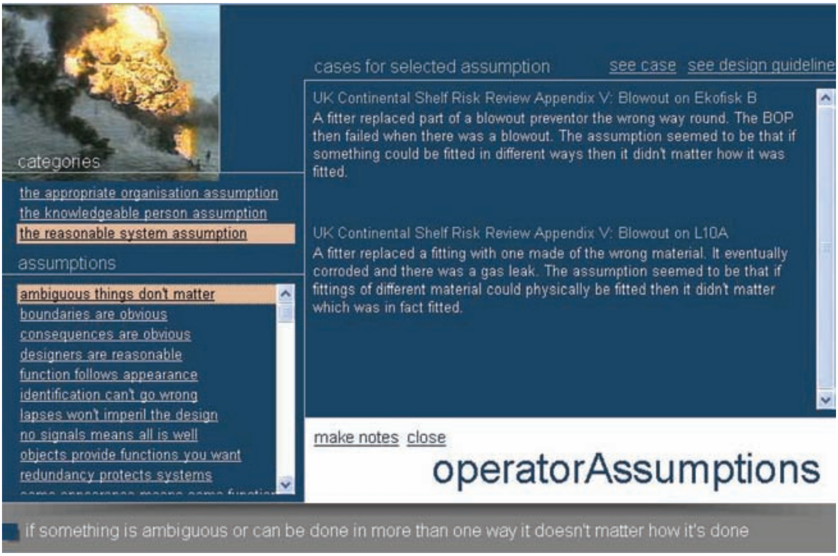

Figure 1. Sample screen from computerised Distributed Assumptions model, illustrating some assumption categories

influencing of "error-forcing" aspects of the individual's environment (in its wider sense) and a number of environmental factors or categories of influence were identified, these are:

- society (e.g. regulation detracts from individual responsibility);
- industry (e.g. equipment suppliers reluctant to disclose problems);
- project (e.g. manpower run-down precludes late changes);
- organisation (e.g. distribution of information outside controlled lists);
- discipline (e.g. loss of rationale for reused designs);
- team (e.g. operators' consensus to operate non-optimally);
- individual (e.g. bias towards confirming existing beliefs).

The distributed assumptions model proposed a way of looking at contributions to accidents and accidental behaviour, the database is with HSE and is intended to be published in the near future. Presentations to potential users highlighted that this particular tool would also be valuable for assisting accident investigation itself as well as contributing to accident avoidance by informing the design community.

CAPABILITY MATURITY MODELS

The latest tool within the suite of investigative tools for organisational behaviour is the further development of Capability Maturity Modelling. This tool was developed more or less alongside DSPI, but has latterly been developed and tested further and, to our view, represents the most valuable and flexible addition to this armoury of leading indicator assessments so far.

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

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[14], [15]). 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[16]). The best known derivative of the quality management maturity concept is the capability maturity model (CMM) developed by the Software Engineering Institute in the US (Paulk[17]). This tool 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[18]. The capability maturity concept is generic and adaptable, a fact reflected by the increasing number of CMM models in other industries. Fraser[19] gives an overview. It has also recently been incorporated into ISO 9004[20] as a measure of the maturity in quality assurance, as shown in Table 2.

Table 1. Part of the Crosby Quality Management grid (Crosby[14])

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"

APPLICATION OF CMM TO DESIGN SAFETY

In the area of safety, CMM frameworks have been developed to address safety culture (Keil Centre[21]) and design safety (Sharp[13]). 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:

1. that the measurement of organisation management performance will yield additional and important information over and above that obtained from formal safety assessment of the installation;
2. that 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. that 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 organisational processes, representing different perspectives of design safety management. Each process is given a score reflecting the capability and maturity of the organisation in undertaking that particular process. The group of processes and

Table 2. Description of levels of maturity in ISO 9004[20]

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

scores when taken together define the organisation's capability to achieve their design safety strategy and its goals.

DEVELOPMENT OF THE DCMM

An overview of the DCMM model is shown in Figure 2. It shows 12 key processes, the maturity levels and the organisational characteristics associated with each maturity 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 CMM scoring system.
4. Identification of the behavioural characteristics that define maturity.
5. Development of improvement steps.
6. Testing the model.
7. Application of the model.

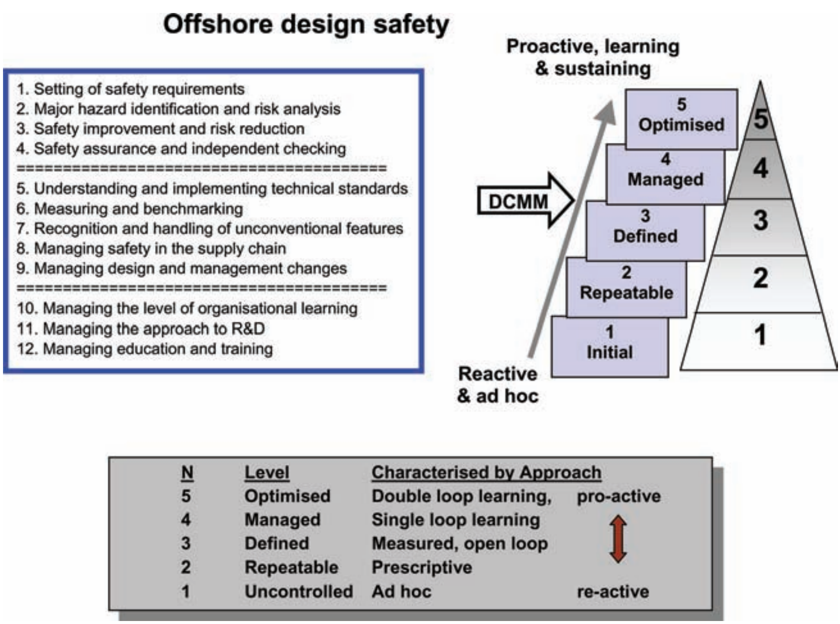

Figure 2. Overview of design safety capability maturity model

Identification of goals and processes

The first step in developing the capability maturity model for a particular activity was to define the key processes (which we term core characteristic processes) and associated goals which were considered necessary to achieve the organisation's overall objective. In the case of DCMM this is taken to be the creation of a safe installation. Figure 3, 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 of key processes are clearly evident, including:

- the setting of risk acceptance criteria;
- the process of risk identification and assessment;
- the process of risk reduction;
- feedback;
- organisational learning etc.

The elements missing from this map are the long term investment practices in safety such as "education and training" and "research and development".

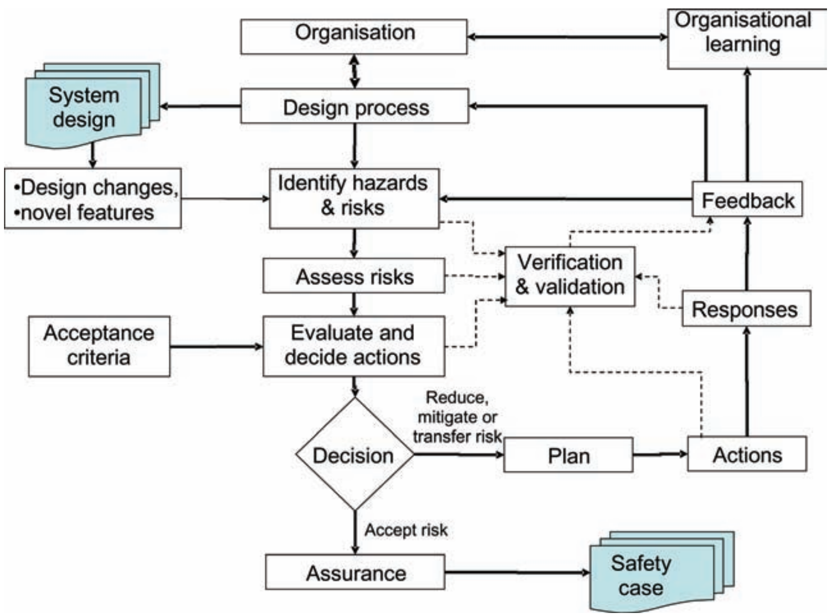

Figure 3. Identification and mapping of management processes

Over a period of time and iterations involving discussions with regulators and industry, 12 key safety processes were eventually identified for the design safety CMM. These are listed and described in Table 3. The key processes are grouped into three categories. These have strategic and operational significance:

1. core characteristic processes associated with formal safety demonstration (4 of);
2. medium tern processes associated with continuing safety implementation (5 of);
3. long term processes illustrating an investment in safety (3 of).

Table 3. Description of key processes used in the DCMM model

	Elements	Description of process	Category
1	Setting of safety requirements, framework & 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.	Formal safety demonstration
2	Major hazard identification & 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.	
3	Safety improvement & 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 & independent checking	How well the organisation conducts its checking processes especially validation and verification.	
5	Understanding & implementing technical standards	How well the organisation uses, develops and maintains standards.	Safety implementation

(*Continued*)

Table 3. *Continued*

	Elements	Description of process	Category
6	Measuring & benchmarking	How well the organisation 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.	
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 & 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.	Longer term investment in safety
11	Managing education & training	How well the organisation determines, acts on and exploits the need for education and training relevant to design for safety.	
12	Managing the approach to research & development	How well the organisation conducts and exploits R&D to support design for safety.	

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 Figure 3. 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 Figure 3 is included as a key element of the safety assurance process.

The five implementation processes reflect continuing safety management activities which are found to be important in maintaining the core characteristic processes; that is, “keeping the job going tomorrow” while the core processes “got the job done today”.

Some of these are well understood by the industry, for example, "understanding and implementing technical standards". Others are less well understood or poorly addressed, for example; identifying changes or unconventional features in design, construction or operation. This can often introduce unexpected hazards which may go unnoticed in fast track projects unless specific action is taken to identify them. In practice, changes or unconventional features are often hidden deep in the detail of a design and it is a major challenge to identify them, high levels of capability are needed to successfully address this topic. 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 processes 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.

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 system, ranging from the lowest level 1, corresponding to initial or learner, to the highest maturity, level 5, corresponding to an optimised process or best practice. It was important to understand what these various levels actually meant as this was crucial to assessing the maturity of an organisation. In the Cranfield DCMM, 5 levels were identified (Table 4) but the underlying principle of the five levels was 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 learning*" (Argyris and Schön[22]) to discriminate between capability levels. Single loop learning occurs when errors are detected and corrected thus

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

Level	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	Processes deliberately criminal.

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 DCMM, double loop learning is consistent with the highest 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 are needed or they may have limited or inappropriate tools for safety assessment. The lowest level organisations (Level 1) are regarded as learner organisations. They lack consistency in safety management and when safety is addressed the approach appears ad hoc.

Development of CMM scoring system

CMM models have been developed with the 5 levels of capability, although there is a view to increase this to six levels by including a level 0 (see below). In the models developed at Cranfield, each process is examined, a level of maturity 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 available. One approach is to average the individual scores for each process. While this will 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 others. 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 credit for higher levels of capability in some processes as all the processes have to achieve the same level.

Thus, it is always better to look at the overall scores say in the form of a spider diagram such as that shown in Figure 4. The diagram by providing a comparable shape clearly indicates where the strengths and weaknesses in the organisation's key processes lie.

Concerning the introduction of a 0th order maturity, 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 of organisations, it may not of course always be the case, particularly for wilfully uninformed new entrants to a business area or more specifically 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. Others using the maturity modelling approach have designated this as a "criminal level".

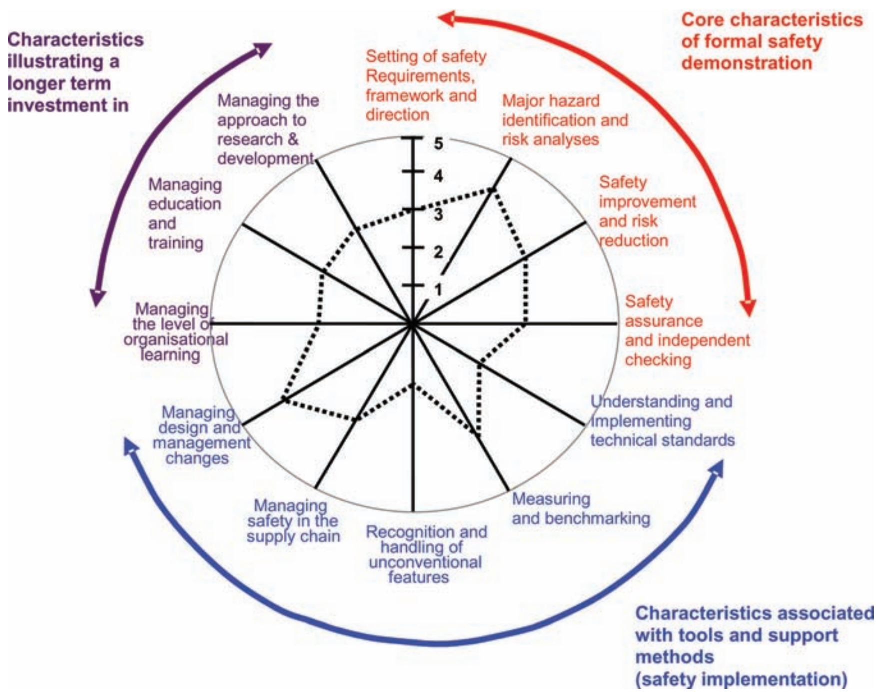

Figure 4. CMM spider diagram

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 additional information showing how organisations can progress up the maturity ladder for each process. The development of the improvement steps proved to be very useful additional interrogation points for inspectors and internal auditors.

Testing the model

Testing is an important stage in the development of a CMM and serves a number of important functions; 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 2 oil companies assessing respectively their proposed and appointed engineering contractor. Feed back 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.

From testing, there have been some adverse comments about the use of numerical scores, particularly where the scores are used in a commercial environment. It is worth pointing out that a scoring system is not necessary for CMM to be applied. The main value of a CMM audit is to identify weaknesses in the management processes. It thus creates an explicit and motivational driver for management to change the maturity level of their team, project or organisation. During the CMM assessment process, those being assessed are exposed to the characteristics of 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 motivation and improvement steps within the CMM process providing a positive influence to change that is usually absent from other assessment and feedback models and consequently often ignored.

The testing has continued, the HSE is committed to the CMM approach and we have been informed of several examples where the inspectors have worked with the duty holders to build a "self-assessment" approach within the duty holders' organisations. Further, one of the authors has developed inspection notes that are drafted in the format of the DCMM style. The team also continue to get feedback from other regulators on their application of CMM, so far this feedback has contributed to developing increased intellectual rigour in developing definitions and greatly increased care in applied language and terms.

Application of CMM

The CMM model can be applied to the different organisations and teams associated with a development and applied in different ways. Sometimes, the duty holder's organisation may score highly, but the project organisation might score poorly because of constraints set by the project. The Cranfield team provided guidance in their report to the HSE on how different stakeholders may wish to measure their DCMM characteristics; the report also provides guidance on expectations for the three main stakeholders, considered to be:

- 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 and can provide a systematic framework in which people inside and outside a design organisation can make judgements about its capability. DCMM helps direct attention to important issues, raises problems that need further investigation and provides some structure for working out how to improve the organisation. The model when applied to a range of similar organisations also enables a set of benchmarks to be established. The model 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 the spider diagram in Figure 4 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. 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 would have a demonstrable advantage.

DISCUSSION

CMM IN CONTEXT

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 quantum leap in design safety management may be achieved. 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.

Although the CMM approach provides a key to assessing one form of leading indication, it should not be misused as a though it were a specific predictive approach. The "gap" referenced above, bridges the vague view that "things are done well" to where the CMM application provides some substance to the organisational assessment by providing a relative ranking of how well they do what they are supposed to do.

The CMM approaches will not take the place of models and tools that are specific and predictive, i.e. those that predict the outcome of a specific failure mode or combined set of circumstances, (e.g. HAZOP, FMEA, FTA, HTA, HRA). The organisation will have a capability, which describes how well it is suited to carrying out various processes and in turn, how well the organisation could make use of such specific tools. However, all safety professionals will be aware that although individuals, groups or consultants can carry out the analyses to a very high degree of competency they will all have experience of the results being completely misused by the organisation the work is being carried out for.

The high level capability organisation will be able to initiate the appropriate study (having a highly competent view of what it intends to use the study to achieve) and will then have the appropriate processes to assimilate the results in a meaningful manner. The lower level capability organisation may well over-analyse as well as under-analyse, in either case, their efforts will be inappropriate and usually wasted.

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 such a 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 in the installation duty holders is necessary.

In the design safety CMM model, 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.

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 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&D and invest in R&D activities which lead to safety improvements.

The most significant characteristics of the Level 3 organisations are their better knowledge and ability to assess risk than at Level 2. Their risk assessment methods 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 a regulatory authority's 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[23]). These are:

- the precautionary principle;
- the enforcement principle;
- the communication and participatory principle; and
- the monitoring and education principle.

These regulatory principles hold true 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 Figure 5, adapted from the paper by Leinster[24]. Although these principles were developed from an environmental regulation view point, there some important analogies in health and safety regulation.

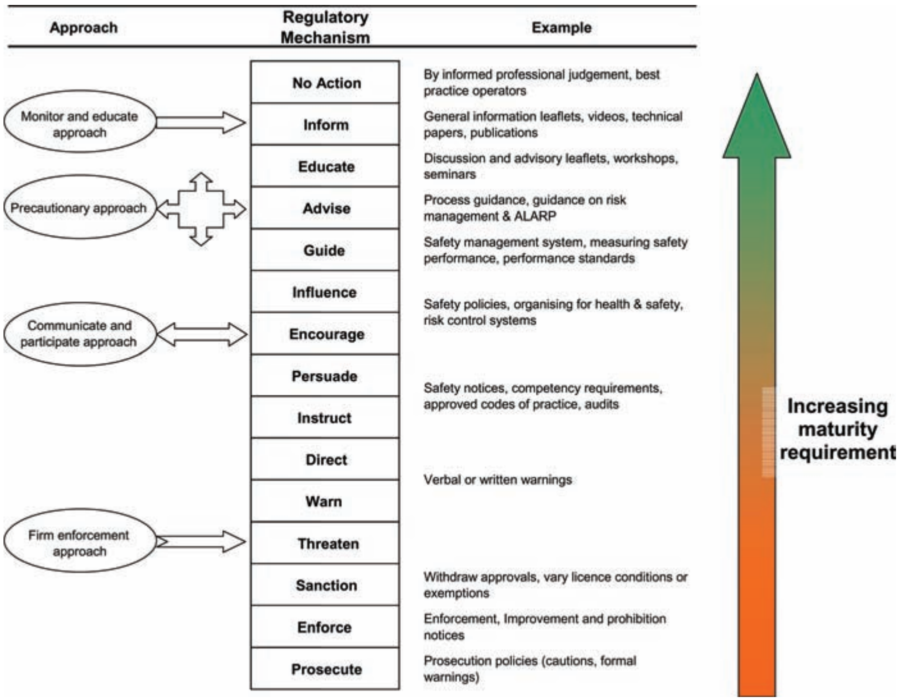

Figure 5. Regulatory ladder (adapted from Leinster, 2001)

ACKNOWLEDGEMENTS

We gratefully acknowledge the support of the UK Health and Safety Executive in supporting this project and in particular Rob Miles for contributing as part of the team rather than as a client. We also acknowledge the debt to the Professor Simon Pollard of Cranfield University for the opportunity to publish an article on CMM applications for a special edition on Risk of the journal "Environment International", (currently undergoing peer review) on which this paper is largely based.

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