‘COMPETENCY’ IN ENGINEERING’

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QPPI
The Qualification Panel for the Pipeline Industry

'Competency' in engineering

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IN THE 1960s, David McClelland (an American psychologist) showed that traditional intelligence-quotient (IQ) tests and personality assessments being used by companies to hire new staff were poor predictors of competency. He proposed that these hiring decisions are better based on 'demonstrable competencies' relating specifically to the position being filled.

'Competence' is 'the ability to do something well', in particular, the ability to undertake responsibilities, and to perform activities to a recognized standard.

Competency has long been a requirement in engineering industries. The pipeline industry is clear about the need for competency; for example, the American Society of Mechanical Engineers' pipeline standards state:

> '... the Code is not a design handbook; it does not eliminate the need for the designer or for competent engineering judgment',

and the International Standard for pipelines (ISO 13623) states:

> '... the design, construction, testing, operation, maintenance and abandonment of the pipeline system shall be carried out by suitably qualified and competent persons'.

Consequently, pipeline-regulatory bodies can justifiably ask operators to demonstrate the competency of any or all of their staff, particularly after a pipeline failure.
This paper explains what 'competency' is, and gives its key elements. It also describes competency 'standards' and 'frameworks', and also explains how to assess competencies, to allow companies to say that their staff are 'demonstrably' competent.

Introduction

The low oil price

The oil and gas industry is currently (January, 2016) experiencing a low oil price (< $30 barrel), yet has seen a global demand 'surging' to a five-year high in 2015 [1, 2]. This demand has been outpaced by 'vigorous' production, resulting in an increase in the world's oil stockpile to a record 3 billion barrels [1]. This low oil price is expected to continue: the 'futures' market is showing a < $60 barrel for the next 5 years [3].

Engineers watch oil price with interest, as it affects spending on new projects. New projects worth hundreds of billions of dollars were halted in 2015, and tens of thousands of jobs have been lost in major energy companies [3].

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An interesting, but obvious, point to note is that throughout this turmoil, the oil and gas is still being transported, in increasing amounts. Even at a low oil price ($50/barrel) a large oil pipeline (1,000,000 barrels per day), will transport $50,000,000 of oil per day, and nearly $20,000,000,000 per year. This huge revenue means the engineering infrastructure must continue to function safely, albeit at a much lower level of profitability. This is not a simple task: the infrastructure is ageing with most high-pressure oil and gas transmission pipelines over 40 years of age (see, for example, Refs 4 - 6). There are about 3,500,000 km of these pipelines around the world [5]. The replacement cost of this pipeline infrastructure (assuming a rebuild cost of $3,000,000/km) is about $10,000,000,000,000. This cost, added to the practicality of replacing the system, and the concurrent disruption in supply, means it is reasonable to assume these old pipelines will need to continue for many years.

Pipeline engineers working in operations are now presented with a difficult task: operate an ageing asset safely, with little prospect of that asset being replaced, certainly in the short term due to market pressures.

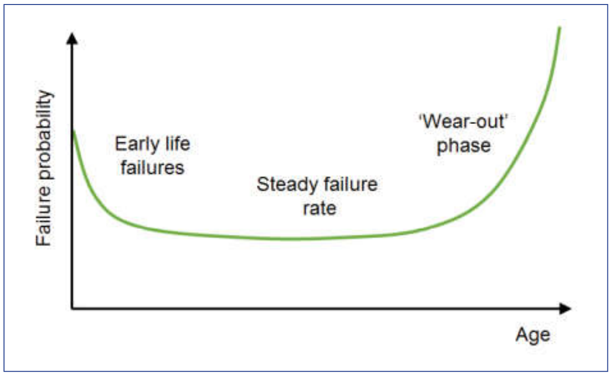

Fig.1.The 'bathtub' curve.

Ageing infrastructure

The effect of ageing on a structure is usually summarised in the 'bathtub' curve, Fig.1. This curve is reasonable as 'ageing infrastructure is a significant threat to asset integrity…' [7], and 'threats' to a structure can change and increase as the pipeline ages. The ageing process is inevitable, but the wear-out phase in the bathtub curve can be extended by good management [8, 9]: '… the safety of a well-maintained and periodically assessed pipeline is ensured regardless of age through diligent and well-planned integrity management practices' [10].

The oil and gas infrastructure is ageing: for example, about 60% of the US' natural gas pipeline system was installed before 1970 [6]. This ageing appears to be managed effectively: there is no evidence that the ageing of the pipeline system causes a greater risk of spillage as 85% of gas-pipeline incidents occur irrespective of the age of the pipeline [6]. Indeed, there is wide-ranging evidence that failure rates in pipelines are not increasing [10-13] despite the ageing process. This suggests the industry is in the 'steady failure rate' of the bathtub curve. It also suggests that decreasing this rate may be difficult.

An important point to emphasize is that simple ranking of failure rates due to single causes can overlook the potential for interaction of causes, and the root cause. This is important, as it is now widely accepted that the majority of accidents in industry are in some way attributable to human as well as technical factors, as actions by people initiate or contribute to accidents [14].

The importance of integrity management[1]

Why is the ageing process not significantly increasing failure rates? 'Ageing' is about the plant's condition, not about how old the equipment is. This means that 'old'[2] does not necessarily mean that there is significant deterioration or damage. 'Ageing' is not directly related to chronological age [15, 16]. Accordingly, 'Design life [does/may] not pertain to the life of the pipeline system because a properly maintained and protected pipeline system can provide … service indefinitely' [17, 18].

Consequently, maintenance, protection, and all other elements of integrity management are key to ensuring an ageing asset remains safe. This has resulted in many pipeline-integrity-management standards being published (for example, Refs 19-23), and the US' National Transportation Safety Board (NTSB) summarizes the situation well [24]: 'Although age alone does not indicate that a pipeline is unsafe, it does make determining the integrity of pipelines increasingly important'.

Perspective on integrity management

Integrity management is very important, and essential for ageing assets, but assessing its success purely on incidents can be misleading. A study in 2015 by the NTSB [25] found that the US' gas-pipeline integrity-management requirements had kept the rate of corrosion failures and material failures of pipe or welds low, but there was no evidence that the overall occurrence of gas transmission pipeline incidents in 'high consequence areas'[3] had declined. Again, this indicates the industry is in the 'steady failure rate' in Fig.1, and also highlights the difficulties of reducing the steady failure rate.

This is not saying that integrity management is ineffective or cannot be improved, but it is suggesting that it can be more effective in the areas that really matter: the high-consequence areas. Certainly, the general public will expect improvements, as:

- technology improves (for example, smart pigs);
- data and information increase (for example, from integrity assessments);
- regulations expand; and
- staff sizes in integrity departments increase.

The problem with these improvements is that they are all reactive, and would be expected in any industry. This approach will do little to prevent future failure types that have not yet been experienced; consequently, a more proactive approach is needed and expected [26-28].

The question now is… 'how can integrity management be improved both reactively and proactively?'.

Predicting the future

One way to improve integrity management is to take a

1 'Integrity' means a pipeline system is structurally sound, and does not leak its product. 'Integrity management' covers all the activities pipeline operators must undertake to ensure that these leaks do not occur.

2 There is no definition of 'old' pipelines, but it is generally considered that 'modern' pipelines are 1970 onwards, as this is when materials, etc., improved, and regulations started to be introduced. 'Vintage' pipelines are 1940- 1970. 'Early' pipelines are before 1940.

3 'High Consequence Areas' (HCAs), are locations along a pipeline route where a release of product could have the most adverse consequences. HCAs for natural gas transmission pipelines focus on populated areas, as environmental and ecological consequences are usually minimal.

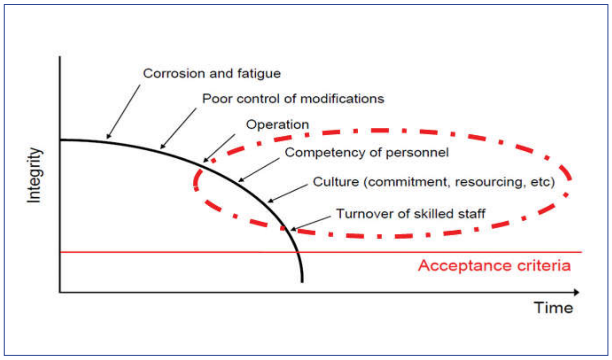

Fig.2. Causes of failure in pipelines during ageing [23].

broader view of what causes pipeline failures, and how these causes will change as the pipelines become even older. This will give a glimpse into the future.

Skills and competency

An ISO standard gives some insight into the causes of failure as pipelines age [23], Fig.2. ISO/PDTS 12747 states 'The integrity of… [a]… system will have deteriorated since installation', but it also highlights that failures from time-dependent mechanism (such as corrosion) and poor engineering control (such as faulty modifications), are early-life failure types. Later failure types are related to peoples' competency, safety culture, and staff skills.

Safety culture

Skills and competency will be covered later in this paper, but 'safety culture' is [29] 'the collective set of attitudes, values, norms and beliefs, which pipeline operator's employees share with respect to risk and safety'. These attributes must all be positive and are essential for safety. An integrity-management system cannot be effective without an appropriate safety culture.

Safety culture is the part of the overall culture of the organization affecting the attitudes and beliefs of members in terms of health and safety performance [30], and should take the form of a clearly defined set of values that is communicated and demonstrated by top management [31]. 'Safety climate' is considered the current visible features of the safety culture obtained from the employees' attitudes and perceptions [30].

Figure 2 shows the importance of 'culture' as assets age, and other industries also stress its importance. The chemical-process industry has seen its accident rate fall each decade, but the reasons for the accidents have changed, Fig.3 [32-37].

Figure 3 shows how 'eras' emerge and change. The 1950s saw technical issues/engineering causing accidents: this was a general trend, and a famous example from the aircraft industry was the first commercial jet (the de-Havilland Comet) crashing due to design/fatigue problems. In the

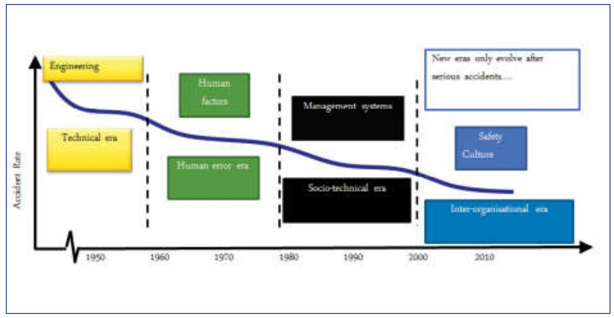

Fig.3. Changing reasons for accidents in the chemical process industry [32-37].

process industry there have been more-recent failures attributed to organizational failures; for example, the Texas City Refinery Report on the failure in March, 2005, blamed the culture of the organization on the failure, and considered poor organization was the number-one cause of the disaster: '… managers and executives… were largely focussed on personal safety – such as slips, trips, falls, and vehicle accidents – rather than on improving process safety performance, which continued to deteriorate…'. Today, the situation is even more complex as there are still organizational problems, but now there are many more inter-organizational boundaries, as work and contracts become multi-layered and work implementation more distant.

Cleary, strengthening safety culture is important now and in the future, and may be a good way to stop some future pipeline failures. Staff competency is a key part of a company's safety culture, as the culture is a product of the individual and group values, which include competency [38].

Competence is a 'hot topic' in the pipeline industry

'Competence' is now a 'hot topic' following recent pipeline failures and more emphasis in pipeline standards.

Standards

Pipeline standards have always emphasized the need for competency in staff; for example:

- 'This Standard is not a design handbook, and competent engineering judgment should be employed with its use' [39];
- '… the Code is not a design handbook; it does not eliminate the need for the designer or for competent engineering judgment' [17, 18]; and,
- '… the design, construction, testing, operation, maintenance and abandonment of the pipeline system shall be carried out by suitably qualified and competent persons' [23].

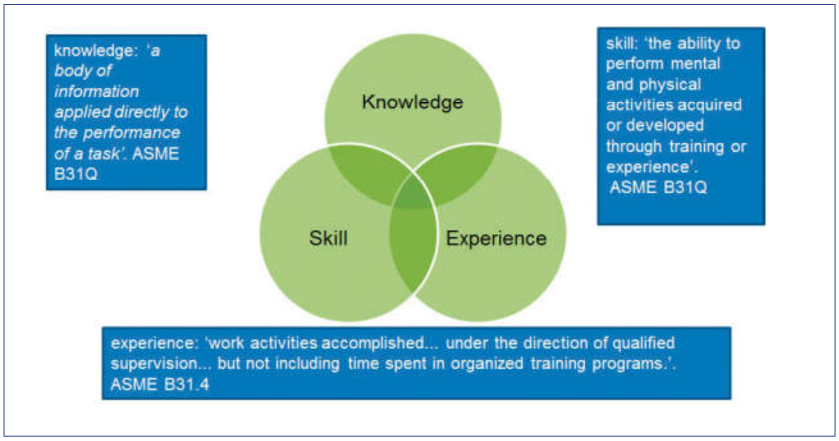

Fig.4. Components of competency.

Integrity-management standards also have similar guidance; for example [19]: '... the personnel involved in the [integrity management] program shall be competent, aware of the program and all of its activities, and be qualified to execute the activities within the program'.

Similarly, the USA Pipeline Safety Regulations Federal Register (Part 49 CFR Subpart O §192.915 (pipeline integrity management) [40]) states:

- 'Supervisory personnel. The integrity management program must provide... that any person who qualifies as a supervisor for the integrity management program has appropriate training or experience in the area for which the person is responsible.
- 'Persons who carry out assessments and evaluate assessment results. The integrity management program must provide criteria for the qualification of any person...Who conducts an integrity assessment... reviews and analyzes the results from an integrity assessment and evaluation; or... makes decisions on actions to be taken based on these assessments.
- 'The integrity management program must provide criteria for the qualification of any person... Who implements preventive and mitigative measures... or... Who directly supervises excavation work carried out in conjunction with an integrity assessment.

The conclusion is easy: standards expect staff working on pipelines to be 'competent' and 'qualified'.

Regulators

A crude oil pipeline failed in USA in 2010, with costs of over $1 billion to date. The failure report [41] from the NTSB noted: '... the management of training and competency is particularly critical for an organization...'.

Additionally, a later study by the NTSB [25] stated: 'The NTSB concludes that professional qualification criteria for pipeline operator personnel performing IM [integrity management] functions are inadequate'.

Regulators expect employers to ensure that any individual performing a task on your behalf has the competence to do so without putting the health and safety of themselves or others at significant risk.

The conclusion is again easy: Regulators expect staff working on pipelines to be competent. But the question now is: what is competence, how is it obtained, and how is it demonstrated?

Competence

The previous section emphasized the importance of 'competency' in staff, and how Standards and Regulators emphasize its importance. This section explains what competency is, and how it is gained.

Introduction

The American psychologist, David McClelland, worked on staff competency in the 1960s [43]. He demonstrated that the (then) traditional IQ tests and personality assessments used to hire new staff were poor predictors of competency. He suggested that hiring staff should be based on demonstrated competencies in relevant fields. The problems with assessing a person based on 'visible' behaviours or visible competencies are that many the competencies of many people are not visible, and are deep inside the person: the analogy is an iceberg [44] where most of its substance is below the water line, and out-of-sight. Simple tests and assessments of behaviour are not sufficient to determine true competencies.

The usefulness of managing work/staff using competencies emerged in the 1980s (for example, [45]), and was rapidly adopted to improve both company and staff performance.

There is evidence of a lack of competency in staff: a review of major accidents across hazardous industries found that a lack of competence contributed to many of those incidents [46], and most PIMS [pipeline-integrity-management systems] do not stipulate the human competencies that are required to manage the systems they support [47].

Competency

Two simple and understandable definitions of competency are [48]:

- 'competence'[4] is 'the ability to do something well';
- 'competency' is 'an important skill that is needed to do a job'.

Competency relates to the skills and behaviours needed to do a job well. This leads to confusion: for example, should we be focussing on skills or behaviours? This paper does not attempt to differentiate – it considers both skills and behaviours in its framework, as both are essential for a competent outcome to a task.

In practice, competence is the ability to undertake responsibilities, and to perform activities to a recognized standard on a regular basis [49], utilizing a combination of practical and thinking skills, experience, and knowledge [50], Fig.4 [17, 51].

The three components of competency in Fig.4 have overlap and dependency; for example, 'knowledge' is understanding gained through experience or study [52]. Additionally, competence is temporal: competence develops over time, through [53]:

- formal qualification
- training
- on-the-job learning
- instruction
- assessment.

This leads to a wider view of competency [54]:

- outputs, or competent performance (these are technical outputs, or the results of training, etc.);
- inputs, or behaviours (these are inputs, or underlying attributes, required to achieve competent performance).

Clearly, technical (functional) competencies alone are not sufficient: behaviours (attitude, physical ability, values) need to be addressed [55], and these will include staff and customer relationships, leadership, developing staff, etc., Fig.5. This leads to the definition:

competence = skills + experience + knowledge + values

4 The word 'competence' has synonyms such as 'capability', 'ability', etc. There are differences (for example, you may be capable of firing a gun, but you may not be competent enough to hit a target), but for brevity this paper will focus only on 'competence'.

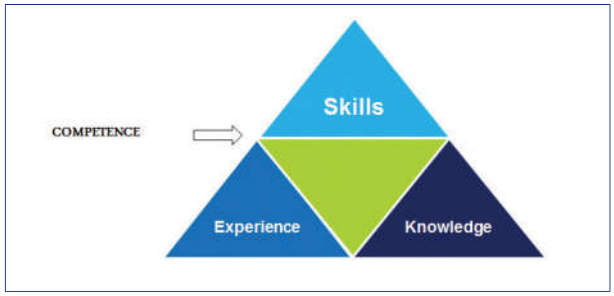

Fig.5. Adding values (behaviours) to competency.

This definition of competency is supported by the Engineering Council in the UK [56], and the UK Onshore Pipeline Operators Association (UKOPA) [57]:

> 'Professional competence integrates knowledge, understanding, skills and values. It goes beyond the ability to perform specific tasks';
>
> '[a pipeline engineer is considered competent if they have the] required theoretical and practical knowledge and sufficient experience to carry out work safely'.

Setting and assessing

How are competencies set and assessed? A specific job will require certain competencies at certain skill levels, and associated additional or complementary skills; for example, an aircraft pilot needs the skills to fly the aircraft he/she is asked to fly, but will need combat and weapons skills if asked to fly a fighter plane.

Competencies are both specified and assessed by a specialist in the area of that competence. In the pipeline business these specialists are usually referred to as a 'subject-matter expert' or a 'competent person'.

> A subject-matter expert (SME) is often quoted in the literature and regulations. The US Department of Transportation (which regulates pipelines) defines 'subject-matter expert' as 58]… 'An individual recognized as having a special skill or specialized knowledge[5] of a process in a particular field, or of a piece of equipment.' It is likely that a subject-matter expert will need at least ten years of relevant experience [60].
>
> A 'competent person' [57] '… should have such practical and theoretical knowledge and actual

5 The USA's Department of Transportation (DoT) defines skill, knowledge, and training [58, 59]:

> Skill: 'A demonstrable competency to perform a given task well, arising from talent, training or practice.'
> Knowledge: 'Understanding gained through experience or study'.
> Training: 'An educational or instructional process (e.g., classroom, computer-based, or on-the-job) by which an individual's knowledge, skills, and his/her capacity to do or act, physically and/or mentally, are improved'.

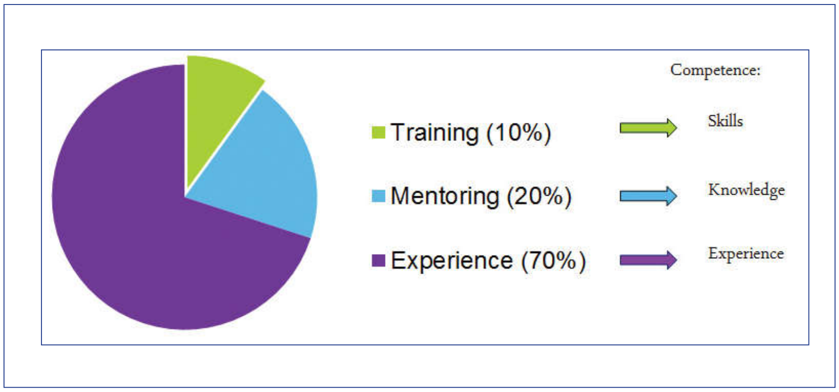

Fig.6. Developing competency.

> experience of machinery or plant which he has to examine, as will enable him to detect defects or weaknesses which it is the purpose of the examination to discover and to assess their importance in relation to the strength of the machinery or plant in relation to its function.'

Clearly, an SME or a competent person must have demonstrable:

- education
- training
- practical and theoretical knowledge; and
- experience.

Note that the US Department of Transportation defines 'demonstrate' as 'provide tangible evidence' [59]. This emphasizes the importance of:

- documenting training, etc.; and
- record-keeping.

It is also worth noting that a subject-matter expert or a competent person can be a body of people who collectively possess the necessary competencies [61].

Developing competency

Competence is temporal and develops over time [53, 62]. The process of gaining competence is obtained from a combination of training, mentoring, and experience [63]. When developing competence, experience is the most important element. Figure 6 gives the classic split of 70:20:10 to experience:mentoring:training. The values in this split can be debated, but the point to emphasize is the inclusion of mentoring in the split, and that training may be the least important element of competency. Reference 62 covers 'mentoring'.

Confidence versus *competence*

Everybody enjoys 'confidence': there is a sense of calm when a confident airline pilot announces his/her flight plans ahead of a long-haul flight. A confident tone to their voice, a relaxed approach, and clarity, help the passengers relax. The passengers would not want a pilot filled with self-doubt telling them they 'hoped' to arrive at the destination.

Unfortunately, confidence can be confused with competence: most people have experienced colleagues who are not the most able, being promoted due to their confidence, ahead of less-confident, but more-competent colleagues. What is far more worrying is that the confident, but incompetent, people create an organization that is 'largely unaware of limitations on its own capabilities' [64]. Additionally, research has shown that these over-confident people are rated highly by their peers: a study of university students found that students who were confident about their own academic abilities, were predicted by fellow students to obtain higher grades than others, regardless of their actual performance [64].

Another problem created by these confident, but incompetent, people, is that they admire and recruit similar staff: the 'mini-me'. This creates a company of incompetent people, who – as a group – think they are all correct in all decisions.

Clearly, over-confident staff need to be challenged. Their confidence must be supported by evidence-based competency, and any claim supported by facts, not bluster [64].

Confidence and leadership

Competence is not solely concerned with 'doing things well'. It is well known that the least competent people often end-up in high positions in a company because they are over-confident about their own abilities [65], and those in power do not realize this. There is little doubt that many successful companies are run by confident people, but it was not their confidence that causes success: their success gave them confidence [66]. The bias towards over-confidence also leads to mistakes in leadership; for example, when teams are asked to choose a leader [67]:

- 55% of teams choose the most expert person; but,
- 45% do not choose the most expert person.

The latter 45% choose people who are, for example, taller, louder, or more confident [67]. If a group is without a

Level	Description
Supervised Practitioner	Has sufficient knowledge and understanding of best practice, within the organization or within the relevant industry sector, to be able to work on the tasks associated with the overall function without placing an excessive burden on the Practitioner or Expert which might compromise HSEQ performance. It will be the responsibility of a Practitioner or an Expert to check the work of the Supervised Practitioner.
Practitioner	Has sufficient knowledge and understanding of best practice, and sufficient demonstrated experience, to be able to work on tasks associated with the overall function without the need for detailed supervision. A Practitioner will maintain their knowledge and be aware of the current developments in the context in which they work. The Practitioner may be required to perform detailed checks on the work carried out by a Supervised Practitioner.
Expert	Will have sufficient understanding of the basis for current working practices and sufficient demonstrated managerial skills, to be able to undertake overall responsibility for the performance of a function. An Expert will be familiar with the ways in which systems have failed in the past. An Expert will keep abreast of technologies, architectures, application solutions, standards, and regulatory requirements, particularly in rapidly evolving fields such as process safety-related systems. An Expert will have sufficient breadth of experience, knowledge, and deep understanding to be able to work in novel situations. An Expert is able to deal with multiple problems under pressure without jeopardizing Health, Safety, Environment, and Quality performance.

Table 1. Competency level (proficiency) from Ref.71.

leader, a narcissist (self-centred, over-confident about his/her talents and abilities, and lacking empathy for others) is likely to take control [68].

This mistake can easily be avoided by having demonstrable competences, rather than self- assessment and self-publicity. This is particularly important as competence is linked to successful team leadership, influence, and performance [67]:

- the best team: has a leader who knows the most about the task to be done;
- second: is the team that shares power (non-hierarchical);
- the worst team: is hierarchical, with a randomly-selected leader.

A clear conclusion is that team leaders without a deep, technical, understanding of the topic 'led the team badly astray' [67].

Specifying competencies: 'competency standards'

Competency is a combination of skills, knowledge and experience, but these competencies:

- must meet agreed standards;
- must be updated, as competencies can deteriorate, or become dated with time, leading to a drift into incompetence ('competency decay'); and,
- must be continually assessed, as evidence is needed that they are being absorbed by personnel [14] ('demonstrable competencies').

This section will now cover the first point.

Competencies of a job holder need to be assessed against a defined standard to ensure validation. Competency standards provide a common definition of a competency, with its minimum requirements [69]. It is best to keep these standard simple, measurable, and auditable.

The required competencies can be grouped into simple categories; for example:

- corporate: all staff in a company must have these competencies and reflect company values and goals (such as people skills);
- professional: the required competencies for a particular profession, detailed by a professional body (for example, ethical behaviour [56]);
- functional: all staff in a corporate function must have this competency;
- selective: job-specific competencies.

An example of a competency standard is given in Ref.69, and other are available (for example, Ref.70). This standard would specify [based on Ref.69]:

Level	Description	Supervision
Foundation	Is able to communicate on the subject clearly and when required select from a variety of options and explain the most appropriate, thus demonstrating an understanding of effects and consequences.	Is able to carry out work with supervision from someone more proficient.
Professional	Demonstrates the competence to select the most appropriate option to improve effectiveness and efficiency. Where required, links across different aspects of [the] topic thus creating integrated solutions.	Is able to carry out work without supervision from someone more proficient.
Mastery	When dealing with conflicting objectives, uses the optimum integrated option to promote long- lasting achievement. Creating innovative step performance changes which may rely on a new approach.	Is able to train and assess others.

Table 2. Competency level (proficiency) from Ref.14.

- job description (for example, welding manager)
- business function (such as construction department)
- competency number
- competency (such as supervising welded-sleeve repair)
- category ('job specific')
- competence description
- competency elements, purpose, and outcome
- prerequisites (for example, all competencies possessed by a welding inspector)
- competency elements:
  - knowledge
  - expertise
  - experience
- training/experience recommended if competency is not satisfied.

Competency levels

Differing jobs and differing tasks will need differing competencies, and differing levels of knowledge of this competency. For example, a pipeline-operations' manager will need a basic understanding of pipeline inspection, but a pipeline-inspection manager will need a more-advanced level.

Tables 1 and 2 give examples of proficiency level. The individual member of staff will know (from his/her job description) the level required (see Table 3 later), and when he/she does not meet the level (job descriptions change, as technology/business changes), then training may be required, or he/she may be a high achiever, and meet higher levels, and warrant promotion.

The competency of staff needs to be proportionate to their job and place of work; for example, the health and safety competence of staff working in an office will not be the same as that of staff working on a hazardous construction site or installation. The level of competence required will depend on the complexity of the situation; therefore, differing competency levels need to be accommodated.

Competency mapping/matrices

Any job or a task will need a number of competencies at differing levels. 'Competency mapping' can (for specific jobs) mean two things:

- identifying key competencies for a particular job; or,
- identifying and assessing the strengths and weaknesses of staff (both functional and behavioural competencies require mapping).

In practice, the 'map' needs both these meanings: the map needs to contain the competencies needed to do a job (as listed in a job description), and these can be compared to the competencies of the job holder, or prospective candidate. Any gap can be managed, then – in parallel – filled by training, etc.

This map is usually a simple staff vs competencies matrix: it starts with a job specification, and what competencies (for example, A-Z) are needed to perform the job tasks. The map or matrix can be a simple job vs competencies, specifying the required competencies and the required proficiency level (see the next section). Examples of levels are [72]: level 1 (awareness); level 2 (intermediate); level 3 (practitioner); level 4 (expert).

Job title	Required competency and level								
	A	B	C	H	K	L	N	X	Y
Apprentice	1	1	1	1	1	1	1	1	1
Assistant inspector	2	1	2	1	1	2	1	2	1
Inspector	3	1	2	2	1	3	2	3	2
Senior inspector	4	1	3	3	1	3	3	3	3
Principal inspector	4	2	3	3	1	3	4	4	4
Inspection manager (SME)	4	3	4	4	2	3	4	4	4

Table 3. Compentecy management.

Competency assessment

Staff competencies will need to be assessed against a job description, and these assessments are normally conducted during annual competency appraisals. There are various assessment methods, Fig.7 [62], but assessment will usually use a combination of methods.

The best competence assessments are 'outcome-based' or 'evidence-based', where [73]:

- the competence is stated and described
- assessment criteria for judging performance are listed, and
- the level (detail) of performance evidence required for the job is stated.

Caution should be exercised with 'self-assessment' by staff because incompetent people tend to see themselves more competent than they are, whereas competent people tend to see themselves less competent than they are [65].

Self-assessment has a role, for example, staff can self-assess, then compare their assessment with their manager/SME's assessment. Disagreements can be resolved by reviewing evidence, and a third party (for example staff mentors) can help resolve disagreements.

Competency frameworks and management systems

Frameworks

A member of staff's required competencies are directly related to his/her job description, and company role. They are defined and assessed within a 'competency framework'. Traditionally, a competency framework:

- compares the competency requirements of a job, with the competencies of the job holder; then
- any gaps between the requirements and the holder are filled by structured and assessed education, training, mentoring, or experience.

These frameworks:

- recommend the competency requirement for each task allocated to a person undertaking work in the company by listing the required competency standards and required proficiency levels;
- ensure competency assessment is carried out by reviewing and confirming evidence under these categories.

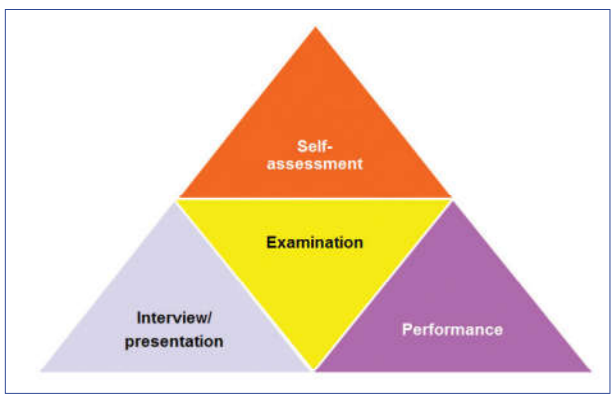

Fig.7. Assessing (demonstrating) competencies.

Implementation of frameworks

The UK's Chartered Institute of Personnel and Development notes that the implementation of a competency framework is not straightforward [55]:

- ensure employees understand what the purpose of the framework by good communication;
- identify the key themes that will support the organization's aspirations (such as business aspirations, goals, values, business plans, etc.);
- company culture, resourcing, and management structures must support the framework;
- the framework is not only focussed on knowledge, skills, and experience, as attitudes and behaviours can affect competency (Fig.4);
- keep it simple, and short and easy to use;
- ensure that everyone who uses the framework is trained in how to use it.

The 'simplicity' bullet point is important [55]: 'In designing a competency framework, care should be taken to include only measurable components… restrict the number and complexity of competencies… no more than 12…'. The simplicity also includes the degree of detail: if the framework is too detailed the whole process becomes a bureaucratic nightmare, with high costs.

Management system

In many countries, organizations have a legal duty to put in place suitable arrangements to manage for health and safety: Indeed, in the UK, the safety regulator notes that for operators of pipelines systems: 'competency management systems [need to be] in place' [74].

These systems [71,75] detail the organizational arrangements to control, assure, and develop, competent performance. The aim is to ensure:

- that individuals are clear about the performance that is expected of them;
- they have received appropriate training, development, and assessment; and,
- that they maintain, or develop, their competence over time. The system must include verification, audit, and review.

Legal perspective

A review [73] of past major engineering incidents indicated a lack of certain skills or knowledge, leading to errors that contributed to the incident: it had been assumed that an individual with a certain level of experience or training would be competent and/or that the dissemination of a procedure would be sufficient.

In the oil and gas industry there is clear evidence of a lack of competency in staff: a review of major accidents across hazardous industries found that a lack of competence contributed to many of those incidents [46]. '… human error was, by far, the most frequent cause for "loss-of-containment events"' [46]. Also, in the pipeline industry, there can be limitation in their management systems: '… most PIMS [pipeline-integrity-management systems] do not stipulate the human competencies that are required to manage the systems they support' [47].

The general public expects engineers to be competent. This competency is contained in an engineer's 'standard of care', and places a legal duty on engineers. This section covers this aspect of competency.

Standard of care

Engineers have a duty to provide their services in a manner consistent with the 'standard of care' of their professions. Two good working definitions of the standard of care (both taken from the USA legal system) of a professional are [76, 77]:

> 'that level or quality of service ordinarily provided by other normally competent practitioners of good standing in that field, contemporaneously providing similar services in the same locality and under the same circumstances'; or,
>
> 'that which is commonly possessed by members of that profession or trade on good standing. It is not that of the most highly skilled, nor is it that of the average member of the profession or trade, since those who have less than median or average skill may still be competent and qualified'

An engineer's service need not be perfect: since the engineer, when providing professional services, is using judgment gained from experience and learning, and is usually providing those services in situations where a certain amount of unknown or uncontrollable factors are common, some level of error in those services is allowed.

When you hire an engineer you 'purchase service, not insurance' [78]; therefore, you are not justified in expecting perfection or infallibility, only 'reasonable care (see later) and competence'. The fact that an engineer makes a mistake that causes injury or damage is not sufficient to lead to professional liability on the part of the engineer [77]. Professional liability is proven when the services are shown to be professionally 'negligent' (the services are shown to be beneath the standard of care of the profession). When one hires an engineer, one accepts the risk, and the liability, of that professional making a mistake similar to mistakes other normally competent engineers make, using reasonable diligence and their best judgment.

The standard of care is not what an engineer should have done in a particular instance, and it is not what others say an engineer would do, or what others say they themselves

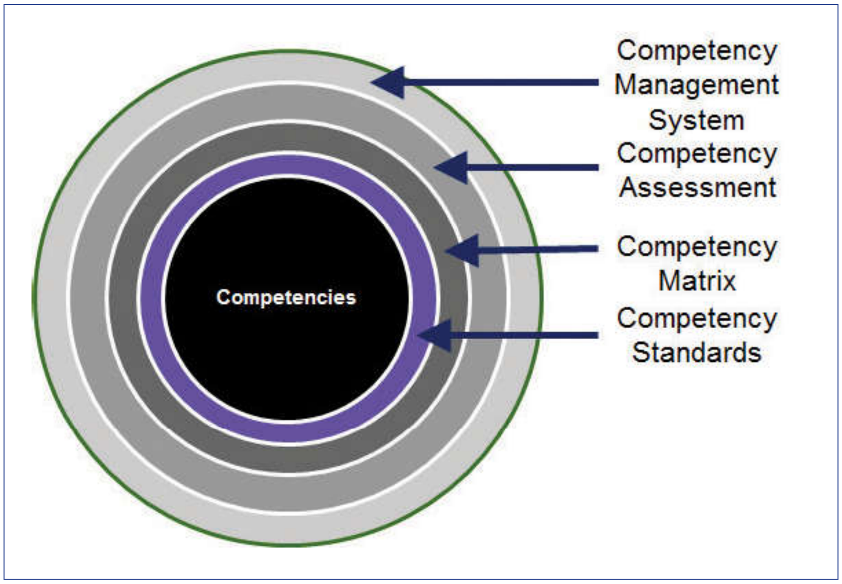

Fig.8. The competency bubble.

would have done; it is just what competent engineers actually did in similar circumstances [77].

Determining standard of care

A trier of fact (a judge or jury) has to determine what the 'standard of care' is and whether an engineer has failed to achieve that level of performance, and it does so by hearing expert testimony. People who are qualified as experts express opinions as to the standard of care and as to the defendant engineer's performance relative to that standard. The trier of fact listens to the testimony from all sides and decides in each case what the standard of care was, and whether the defendant met it.

Jury instructions have been standardized: a Bench Approved Jury Instruction in the USA reads [78]:

> 'In performing professional services for a client, a [structural engineer] has the duty to have that degree of learning and skill ordinarily possessed by reputable [structural engineers], practicing in the same or similar locality and under similar circumstances.
>
> 'It is [the structural engineer's] further duty to use the care and skill ordinarily used in like cases by reputable members of the [structural engineering] profession practicing in the same or similar locality under similar circumstances, and to use reasonable diligence and [the structural engineer's] best judgment in the exercise of professional skill and in the application of learning, in an effort to accomplish the purpose for which [the structural engineer] was employed.
>
> 'A failure to fulfil any such duty is negligence.'

'Reasonable care'

In the USA 'reasonable care' [79] is... 'the amount of care that a reasonably prudent person would use in similar circumstances', and this can easily be related to standard of care. If an engineer does not exercise this 'reasonable care' he/she may face prosecution. This standard of conduct that the law imposes can perhaps best be understood in terms of the hypothetical 'reasonable person' [80]: the law presumes that there is a standard of behaviour that a person of 'ordinary prudence, skill and care' would follow in all situations, so as to avoid creating unreasonable risks or harm to others. If a reasonable person deems that a competent engineer should have predicted the outcome, the engineer is held accountable [81].

Conclusion and the importance of records

Competence is important, and we must not assume that engineers will be insulated against legal claims. Other professions, recognized for their competence, are being subjected to extensive litigation; for example, the medical profession in the USA is paying out billions of dollars in negligence claims every year (averaging one pay-out every 43 minutes), and medical negligence is the third leading cause of death in the USA (behind heart disease and cancer) [82].

The law can become involved with an engineer if and when there is actual injury or damage to life, property, or the environment. When legal proceedings occur, the outcome depends primarily on evidence (for example to prove that an engineer has exercised due skill and care) [83]. The most cogent form of evidence recognised by the courts or any other tribunal is that provided by 'contemporaneous' (at the time of the event) written records [83]: 'Engineers need to understand the importance of establishing such contemporaneous written records'.

Discussion and conclusion

'Competency' is now a hot topic in the pipeline business, and demonstrating competency is essential in pipeline engineering. This paper has explained the meaning of competence, stressed its importance, and summarized competency frameworks and management systems.

Competence

Staff competency requirements are usually specified/ detailed in job descriptions (for example, 'essential' or 'desirable' skills), but their importance also requires them to be defined, explained, and managed using a competency framework. This framework is a structure that sets out and defines each individual competency (such as problem-solving or people management) required by individuals working in an organization or part of an organization.

Figure 8 shows how competencies are managed within the framework, and how competencies are developed. Summarizing:

- 'Competency' is the ability to undertake responsibilities, and to perform activities to a recognised standard. It is a combination of practical and thinking skills, experience, and knowledge. Developing and maintaining competencies involves education, training, mentoring, etc. It should be emphasized that acquiring the necessary technical competencies does not necessarily make an engineer competent: competence is realized in performance, and performance involves attitudes, values, etc.

- 'Competency standards' provide a common definition of a competency, with its minimum requirements, and allow the job holder to be assessed against this standard to ensure validation. These standards are produced by 'subject-matter experts' (SMEs) or 'competent persons'. Competency assessment is best conducted outside an annual performance review, as these reviews tend to be very bureaucratic, unpopular with staff, time-consuming, linked to fiscal gain, and stressful for all parties. This environment is not good for competency assessment.

- A competency 'map' needs to contain the competencies needed to do a job (such as listed in a job description). The SME decides on the required competencies and the proficiency level for that competency for that job (for example, level 1 (awareness), level 2 (intermediate), level 3 (practitioner), level 4 (expert)).

- A 'framework' compares the competency requirements of a job, with the competencies of the job holder. The required competencies are defined and assessed within the competency framework. These frameworks need to be simple and workable, otherwise staff will avoid them, and they will be viewed as too complex to use.

- A management system details the organizational arrangements to control, assure, and develop, competent performance. The system must include verification, audit, and review.

Non-technical competencies

In engineering there will be a clear and necessary bias towards technical competencies, but the 'softer' competencies (people management, etc.) must not be ignored. Most organizations need staff who are dependable, and have good judgment, honesty, and integrity, and they want staff with an ability to solve problems that have still not been defined [84]. They are also looking for staff who can understand other people's moods, behaviour, and motives, in order to improve the quality of relationships [85]. These attitudes and values must be incorporated in any competency list.

The next step

This paper has focussed on competence: its definition, importance, and management. A future paper [86] will explain how competence is gained, qualified and certified, and complements the current paper.

The paper will explain that training and learning programmes are essential for gaining and maintaining competence. These courses/trainers/organizers need to be accredited by a reputable organisation, the materials quality assured, and the necessary competence levels specified and defined, with an assessment to demonstrate understanding. This will allow a process of credible learning which is organized, regulated, with control and assessment.

Academia can help with this process, as it has a well-established, but relatively simple, system to ensure its learning process is credible. It has: courses that are assessed to a specified learning level, with clear objectives, outcomes, and qualification requirements; materials that are independently quality assured; lecturers that are qualified to teach; and an assessment, qualification, and certification process that demonstrates the student has acquired all the stated skills. This leads to credibility.

The paper ends with a 'way forward' for the pipeline industry, in its goal of demonstrating competency in its workforce.

Final words

This paper has emphasized the importance of competence in engineering. Competence of staff will become increasingly important as technology and management systems improve. These improvements will reduce failures, narrowing the reasons for the remaining failures, Fig.3. The emphasis then will naturally be on staff competency, and safety culture.

It is interesting that technology improvements are expected each year, and management system improvements are expected. It is therefore reasonable to expect staff competency to improve every year. Status quo is not sufficient.

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