Competence Considerations for Systems Safety

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Abstract *People often use the word 'competence' without understanding what it means even when it is vital for safety. This paper examines common definitions of competence to identify the individual components and understand the principles underlying the specification and assessment process. Safety management must facilitate the achievement and maintenance of competence for those developing and operating safety-related systems. The paper examines the theory and principles underlying the attainment and maintenance of competence providing a framework for a discussion on competence assurance. The specification of competence criteria is an important safety management activity and these are unique for different systems. This paper describes how competence criteria can be specified and assessed for safety-related systems. Safety assurance is ultimately based upon the competence of the people involved and it is a vital requirement for the validity of any safety claim. The paper examines common safety assurance issues associated with competence and some suggestions are made on how to improve the validity of safety claims based upon competence.*

1 Introduction

Competence for any professional is a desirable attribute but it is an essential requirement for those involved with the development, maintenance and operation of safety-related systems. The international safety standard IEC 61508 (IEC 2010) now has normative requirements for demonstrating the competence of those involved in safety-related systems activities across all safety lifecycle phases; however, the standard lacks guidance on how to fulfil that requirement.

New technologies, particularly those containing software, have enabled systems to function more effectively and allowed more sophisticated ways to make them safe. Paradoxically, new technology has also brought its own challenges such as increased design complexity. The accelerated use of new technologies and the associated complexity increases the criticality of the activities undertaken by people engaged in the design, development, maintenance and use of safety-related

systems. The achievement of sufficiently low levels of risk is critically dependent on individual and team competence.

In parallel, the pace of change in industry continues to accelerate, with frequent restructuring and much movement of people between roles, between companies and even between sectors. Ever newer technology requires new skills. Even if new staff possess these skills, they may be unfamiliar with the organisational culture and more importantly the safety culture. Long term familiarity of managers with the capabilities of their staff can no longer be assumed, so increasingly organisations need to establish Competence Management Systems (CMS) in order to satisfy themselves, their customers and regulators that their staff are competent for the tasks to which they are assigned.

Competence is a vital issue for those involved in hazardous systems, not just for the system developers, operators and maintainers but also for those providing safety assurance based upon expert opinion and judgement.

2 Understanding Competence

This section examines the meaning of competence and identifies its main components in order to understand the underlying principles associated with the process of attaining and maintaining competence (section 3) and also specifying and assessing competence (section 4).

2.1 Competence Definitions

The term *competence* generally means the ability to do something successfully or efficiently and many synonyms are used including: capability; ability; proficiency; expertise and skill. It is useful here to differentiate between the closely related (and oft confused) terms *capability* and *competence* as there are important but subtle difference between the two concepts. Capability describes the ability of an organization while competence describes the ability of an person to do something (Holt and Perry 2011).

The UK Engineering Council (EC 2013) provides the following definition of competence:

> The ability to carry out a task to an effective standard. Its achievement requires the right level of knowledge, understanding and skill, as well as a professional attitude.

The definition of competence given by UK Office of Rail Regulation (ORR 2007) is similar:

> The ability to undertake responsibilities and to perform activities to a recognised standard on a regular basis. Competence is a combination of practical and thinking skills,

> experience and knowledge, and may include a willingness to undertake work activities in accordance with agreed standards, rules and procedures.

The UK Health & Safety Executive (HSE 2007a) defines competence as:

> The ability to undertake responsibilities and perform activities to a recognised standard on a regular basis.

The HSE also assert that to be competent an organisation or person must have:

- Sufficient knowledge of the tasks to be undertaken and the risks involved.
- The experience and ability to carry out duties in relation to the project, to recognise limitations and to take appropriate action to prevent harm to those carrying out or affected by work.

Competence can develop (and decay) over time and it is vital in abnormal and emergency situations. Generally, people develop competence through a progressive mix of initial training, on-the-job learning, instruction, assessment and formal qualification. In the early stages of training and gaining experience, people should be closely supervised and as competence develops, the need for direct supervision should be reduced (HSE 2007b).

2.2 Competence Components

In the sciences methodological reductionism provides explanations of concepts in terms of their individual, constituent parts and their interactions. Similarly, while general definitions of competence are helpful, a more detailed examination of its separate elements can provide a better understanding of how it may be acquired and maintained.

Many different explanations of the elements of competence exist; however, an examination of the similarities between the EC, ORR and HSE definitions reveal three main components of competence which are shown in Figure 1.

- *Knowledge* which is acquired through training, both formal and on-the-job, and is required to enable people to formulate a plan of action to undertake an activity.
- *Skills* which are the things that experienced people often do subconsciously. Skills can be thought of as the execution part of a plan of action. Skills are an observable act or behaviour (sometimes referred to as ability) exhibited while undertaking an activity.
- *Attributes* are associated with personal qualities such as determination, integrity, effective communication etc.

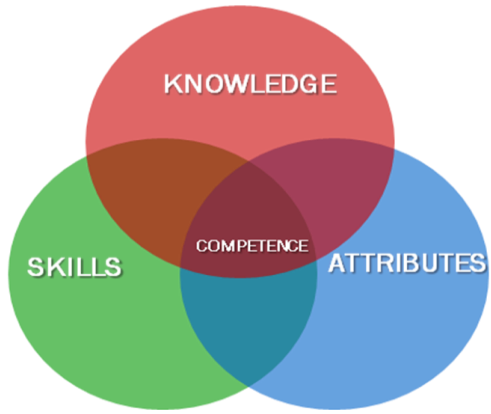

Fig. 1. Competence Components

Competence involves much more than technical training, it includes a person's attitude and behaviour as well as experience and knowledge of the application domain (HSE 2007a).

IET publications on competence (IET 2007, 2016) suggest that competence consists of: technical skills; behavioural skills; underpinning knowledge and underpinning understanding. A distinction is made between technical and behavioural skills. Technical skills can be thought of as those vocational skills learned for a specific role (e.g. an aircraft pilot's motor skills or their ability to interpret meteorology reports) while personal behavioural skills are more general (e.g. the ability to communicate effectively or problem solving ability).

Competence might be transferable from one work situation to another, but the extent to which this is possible depends very much on the *context* in which apparently similar competence is required. For example, an person considered competent to develop software for an aircraft In-Flight Entertainment system will almost certainly not be considered competent to undertake the development of the Flight Management System (FMS) for that aircraft without having the experience and detailed knowledge of FMS functionality and, importantly, how the FMS is used operationally.

3 Attaining and Maintaining Competence

This section will examine the theory and principles associated with the process of attaining and maintaining competence to provide a foundation for an examination of the specification and assessment of competence (section 4) and provide a framework for a discussion on competence assurance (section 5).

3.1 Conscious Competence Model

Much of the literature on competence comes from the teaching profession and is encapsulated in various theories of learning. One prevalent model of learning, and change management in general, is the Conscious Competence Model (CCM) (Robinson 1974) which will be examined here as it is useful to frame the discussion presented later on organizational and individual safety competence.

Notwithstanding the various claims to original authorship, many of the proponents of the CCM consistently advocate the separate stages of learning (or change) as shown in Figure 2.

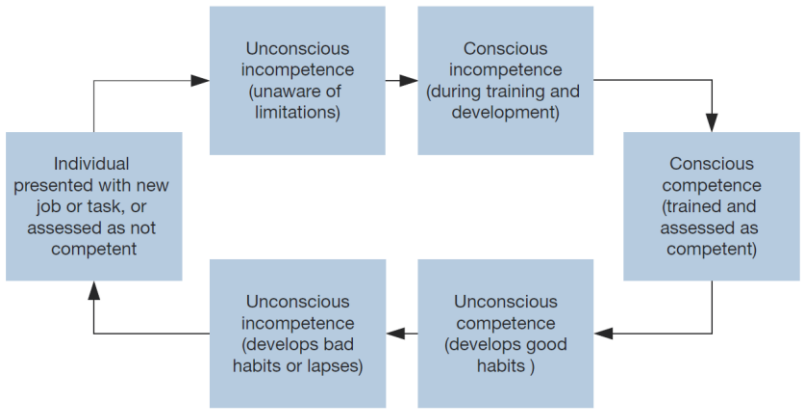

Fig. 2. Conscious Competence Model (adapted from Robinson 1974)

- *Unconscious Incompetence* is a state when a person or organization is blissfully unaware of their lack of a specific skill, knowledge or attitude required for a given task.
- *Conscious Incompetence* is a state when a person or organization becomes aware of their lack of a specific skill, knowledge or attitude required for a given task.
- *Conscious Competence* is when a person or organization has consciously attained a degree of skill, knowledge or attitude required for a given task but it requires conscious effort to complete.
- *Unconscious Competence* is when a person or organization has attained a high degree of automatic skill, knowledge and attitude required for a given task and it requires minimal or no conscious effort to complete.
- Unconscious Incompetence is when an unconsciously competent person can regress to unconscious incompetence due to changing environmental factors or the erosion of competence through the development of bad habits.

Once a state of unconscious competence is attained, proactive measures must be taken to maintain that state and avoid unconscious incompetence; for example professional or chartered engineers are required to undertake Continuing Profes-

sional Development (CPD) to maintain their knowledge, experience, skills and personal qualities. CPD encompasses both the acquisition of new skills to broaden competence and the enhancement of existing skills to keep up to date with evolving knowledge.

3.2 Unconscious Competence

The name of the CCM model may not be appropriate as the name implies that conscious competence is the aim when in fact the ultimate aim is the attainment and maintenance of *unconscious competence*.

Nonetheless, the CCM is a useful model to frame any discussion of safety competence and how it may be acquired and maintained both at the organizational and individual level. Typically, an organization can be characterized as operating at the unconscious incompetence level until some point in time when they are either awarded a contract with safety requirements to fulfil or they simply recognize that developing safety-assured systems is a good business strategy and from necessity they will transition to the conscious incompetence level.

The organization could then take action to initiate training to take individuals and teams to the conscious competence state and after time (and perhaps some on-the-job training) individuals and teams could transition to the unconscious competence state. The organization could even transition directly from the conscious incompetence to unconscious competence through judicious recruitment of competent people.

The aim for any organization dealing with safety should be to facilitate the transition of the organization and individuals from conscious incompetence to unconscious competence and to maintain that level through the formal development and implementation of a CMS (see HSE 2007a, 2007b) and the specification and assessment of suitable competence criteria for the activities they undertake (see IET 2007, 2016).

4 Specifying and Assessing Competence

The international safety standard IEC 61508 (IEC 2010) now has normative requirements for demonstrating the competence of those involved in safety-related systems activities across all safety lifecycle phases; however, the standard lacks guidance on how to fulfil that requirement. It is useful to examine the general principles of competence management and identify where the detailed specification of criteria are required for the achievement and maintenance of safety competence.

The specification of safety competence is unique for different systems and operational domains and it is an important element of safety management. The re-

quirement to demonstrate safety competence involves the identification of safety-related activities and their associated tasks each at a specified level of competence for a given system; these are referred to collectively as competence criteria. Competence criteria for safety-related systems developers are significantly different to those for developers of non-hazardous systems because different technical skills, knowledge and personal attributes are usually required. However, the specification of competence criteria must be based on a coherent model of competence to provide a common reference framework.

4.1 Competence Model

A competence model sets out the relationships between various concepts used when evaluating competence, in particular the relationships between roles, activities, tasks, attributes, competence criteria, levels of competence and activity or personal competence profiles. Discussions within this paper are based on the general competence model shown in Figure 3.

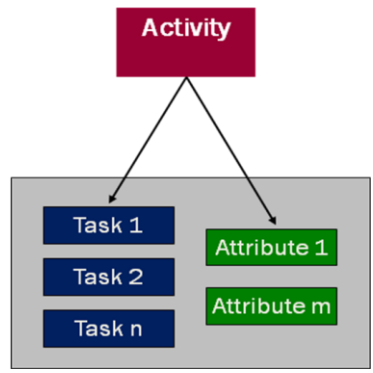

Fig. 3. Competence Model (adapted from IET 2007)

A person working either alone or in a team, performs an *activity*. Figure 3 shows that each activity is subdivided into a set of *tasks* each of which require particular technical skills and knowledge. All the tasks in an activity also require behavioural skills and underpinning knowledge and understanding which are expressed as a set of *attributes*.

The relationship between a role and an activity can be confusing and needs to be clarified. An activity may be undertaken by an person or by a team. When working in a team, each person may contribute to the completion of the activity by performing a role within the team and carrying out part of the activity. If the entire activity is fulfilled by one person then they do still perform a role equivalent

to carrying out the whole activity. A role can therefore be equivalent to an activity or it may be a part of an activity.

An activity can be thought of as the high-level things that an organization needs to do to achieve a specified goal; for example, activities arise from the activities associated with achieving the goal of providing functional safety assurance. Each activity is decomposed into a set of tasks each of which require the necessary technical skills and knowledge to be defined. In addition, each activity is decomposed into a set of attributes each of which require the necessary behavioural skills and knowledge to be defined.

An example of this hierarchy for a safety-related activity and using the competence model in Figure 3 could be the following:

- **Activity:** Independent Safety Assessment.
- **Task:** Safety Auditing.
- **Attribute:** Effective Communication.

4.2 Competence Levels

The tasks and attributes defined for a specific activity are typically specified at three different levels of competence which are summarised as follows (IET 2007, IET 2016):

- **Supervised:** has sufficient knowledge and understanding of good practice, within the organization or within the relevant industry sector, to be able to work on the tasks associated with the overall activity without placing an excessive burden on the practitioner or expert who is responsible for checking their work.
- **Practitioner:** has sufficient knowledge and understanding of good practice, and sufficient demonstrated experience, to be able to work on tasks without the need for detailed supervision.
- **Expert:** has sufficient understanding of why things are done in certain ways, and sufficient demonstrated managerial skills, to be able to undertake overall responsibility for the performance of a task or activity.

For any CMS established and operated within a safety-related domain, the validity of the competence criteria will have a critical influence on the efficiency and effectiveness of the CMS and in turn on the ability of an organization or individual to provide safety assurance for safety-related systems.

4.3 Competence Criteria

Competence criteria must be specified for the activities, tasks and attributes for which competence is required in an organization or individual. For an organization developing safety-related systems an example activity may be to provide *Functional Safety Management*; associated tasks may include: *Define Safety Management Policy*; *Allocate Safety Responsibilities* and *Promote Safety Culture*.

Typical attributes for the individual or team undertaking the activity may include: *Effective Communication*; *Professional Standing* and *Personal Integrity*.

Task or Attribute Title		
Description of the task or attribute		
Supervised Practitioner	**Practitioner**	**Expert**
Competence criteria for supervised practitioner level.	*Competence criteria for practitioner level.*	*Competence criteria for expert level.*
Competence criteria for both supervised practitioner level and practitioner level.		*Explanation for non-relevance of level to task or attribute*

Fig. 4. Generic Task/Attribute Criteria

A generic task or attribute criteria specification is shown in Figure 4. Each task or attribute has a set of criteria specified for it which state the competencies required to fulfil the task or attribute at any or all of the 3 competence levels discussed in 4.2.

For each of the competence levels that are appropriate to a given task or attribute, competence criteria will be specified. For example, for the activity *Functional Safety Management*, the Expert level competence criteria for the task *Define Safety Management Policy* could be expressed as (IET 2007, IET 2016):

> Has developed at least one Corporate safety management policy and has been involved in the development/ review of others. Can identify organization methods and procedures, which have had to be updated to meet new standards in functional safety assurance, and show how the updated methods and procedures fit within the organization's safety management system.

Similarly, the Expert level competence criteria for the attribute *Effective Communication* may be expressed as (ref. 8-9):

> Is acknowledged as proficient in communicating information orally in all situations. Has established effective liaison with the organization's management such that safety issues

are raised at the highest level. Has effective relationships with relevant external organisations, such as regulatory bodies.

Figure 5 shows how a competence profile can be specified for a specific activity.

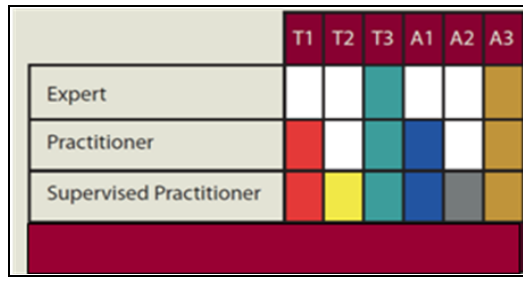

Fig. 5. Activity Competence Profile

An activity competence profile is specified in terms of an appropriate competence level for each task and attribute. The competence profile is specified for each task and attribute in terms of the three competence levels resulting in a profile for all tasks and attributes comprising a given activity. This gives a minimum activity competence profile with differing levels of expertise required for the different tasks and attributes.

4.4 Competence Criteria Process

An explicit requirement of the HSE competence management principles (HSE 2007a, 2007b) is for the specification of competence criteria and an assessment process to give confidence that all people undertaking safety-related roles are competent to perform specific work activities. There is need for a process for the specification of competence criteria and the assessment of individual or team competence against those criteria. Table 1 (adapted from IET 2016) outlines a four step competence achievement process.

Table 1. Competence Criteria Process

Competence Criteria Process	Step
Define (Activities, Tasks, Attributes, Criteria)	1
Specify (Activity Competence Profile)	2
Assess (Individual Competence)	3
Compare (Activity Competence Profile v Individual Competence)	4

Each step of the competence achievement process is briefly summarised here.

- **Step 1: Definition.** Addresses the definition of the relevant activities and associated tasks and attributes applicable to an organisation implementing a competence management scheme. In addition, for each task and attribute the associated competence criteria need to be defined at each competence level.
- **Step 2: Specification.** Addresses the specification of the minimum competence profile required for a given activity or role (but not for an individual).
- **Step 3: Assessment.** Addresses the assessing of the current competence of an individual or individuals against predefined criteria for all activities, tasks and attributes relevant to a specific assignment. The result is recorded as the individual's assessed competence profile, together with the validity period for the assessment.
- **Step 4: Comparison.** Addresses the comparison of an individual's competence profile against the competence profile required for a specified activity or activities to determine the suitability of the individual for that activity or activities.

A detailed explanation of the competence criteria specification and assessment process along with guidance and example competence criteria for safety-related activities can be fond in the IET Code of Practice: Specifying and Assessing Competence for Safety-Related Practitioners (IET 2016).

5 Competent Safety Assurance

The discussion so far has focused on the theoretical aspects of competence: what competence is; how it may be attained, defined and assessed. The remainder of the paper will examine some common issues related to organisations and individuals for whom competence is a crucial element for the provision of safety assurance.

5.1 Organisational Safety Issues

If an organization does not have competent people working on the development, operation or maintenance of safety-related systems then the organization is unlikely to produce tolerably safe systems. Organizations that are new to developing safety-related systems don't usually have safety competent staff and often the approach to competence will be reactive and programme dependent rather than the implementation and operation of a defined corporate-level CMS. In the absence of a CMS, typical organizational competence deficiencies can be categorised as: Distributed Competence; Limited Competence or False Competence which can be summarised with reference to the CCM in section 3.

- **Distributed Competence.** When an organization predominantly (or exclusively) outsources the responsibility for the safety engineering process to specialist

safety consultants while their own staff provide the system and domain knowledge. When distributed competence is the norm an organization can at best be operating at the *unconscious competence* level and will remain so unless staff with competence in general safety processes are trained or recruited.

- **Limited Competence.** When an organization that does not have core safety competence is awarded a contract to develop, operate or maintain a safety-related system. Typically, they select existing employee(s) to undertake the safety roles with minimal training. These organisations have limited competence and the responsible person undertaking the safety role will quickly reach the conscious incompetence stage while the organization itself can blissfully remain at the *unconscious competence* level.
- **False Competence.** When an organization has a false view of its safety competence; this can occur when safety staff are out of date with changes in safety knowledge or have inadequate skills. An organization such as this may consider itself to be operating at the unconscious competence level when it may in fact have regressed to a level of *unconscious incompetence*.

An organization could exhibit one or more of the above competence limitations discussed above and these are generalizations of many existing organisations, even including some that possess mature safety management systems. Organizations that exhibit characteristics of Distributed Competence; Limited Competence or False Competence can often have serious problems providing adequate safety assurance as they will be operating at either the unconscious competence or unconscious incompetence states and will be unaware of the safety-related skills, knowledge and attitudes necessary to competently undertake safety-related activities.

In addition to addressing safety competence deficiencies at the organizational level, a CMS must also consider potential deficiencies related to the competence of individuals involved in the provision of safety assurance.

5.2 Individual Safety Issues

Safety assurance is ultimately based upon the competence of the people involved in the safety assurance process and individual competence is a vital requirement for assessing the validity of any safety claims. Individual competence can have a significant influence on the safety engineering process; particularly where professional judgement is applied and there is an critical relationship between safety competence and the application of sound professional judgement for safety-related systems developers.

Professional judgement (or expert opinion or engineering judgement) can be defined as the ability of a person or group to draw conclusions, give opinions and make interpretations based on a combination of evidence from diverse sources such as experiments, measurements, observations, knowledge and experience (McKenna and Mitchell 2006). Professional judgement is frequently used by sys-

tems developers of all disciplines and it relies upon a combination of impartial and biased facts and opinions and, for anything but simple scenarios, subjectivity can be hard to discriminate from objectivity. The problems of objectivity and perception when applying professional judgement to decisions on risk have been well documented (Adams 1995).

Professional judgement is often used when an expert doesn't have any accurate or statistically significant data and the order of magnitude required for the solution to be acceptable is estimated by applying judgement gained through a combination of: academic training; experience and professional development - in other words competence. Professional judgement can be considered poor if highly subjective evidence is accepted as fact without consideration of where or how the evidence is derived and without an appreciation of when it is overstated or simply invalid. Safety assurance claims are always founded to some extent upon professional judgement and unless the person (or group) making those judgements are competent to do so conclusions, opinions or interpretations may be derived from incomplete or inadequate evidence (Sandom 2011).

Safety assurance is ultimately a matter of professional judgement and professional judgment is based inexorably upon competence. Safety-related practitioners have a responsibility to show where professional judgement has been applied and, for safety assurance claims, how that judgement is defensible. The application of professional judgement is a necessity for any systems development; however, it remains problematic; particularly for safety-related systems development. Safety assurance evidence can be deficient due to safety competence limitations and also safety claims may be over-reliant on professional judgement.

5.3 Competence Evidence

At both organizational and individual levels it has been argued here that competence is a critical element for all safety assurance claims. Regardless of the specific method used for demonstrating safety assurance, it is also asserted that an essential goal for safety assurance must be to demonstrate competence validity at both organizational and individual levels. A claim of competence validity must be supported by comprehensive and compelling competence evidence which should be routinely sought to support an overall safety assurance claim.

All safety evidence must be both comprehensive and compelling and to demonstrate that both direct evidence and meta-evidence (i.e. evidence about evidence) should routinely be sought (Sandom 2011) to underpin safety assurance arguments. If it is accepted that the validity of a safety claim is critically dependent upon both organizational and individual competence then compelling evidence and associated meta-evidence related to competence must also be provided. Competence evidence must be presented to support both organizational level claims of competence and meta-evidence must be presented to support individual level competence-based claims.

- **Claims of Competence.** An explicit claim must be made based upon the presentation by an organization of compelling evidence of the existence of a proportional CMS with adequately defined safety competence criteria that together enable an organization to effectively specify and assess the competence of the individuals involved in the safety assurance process. If safety competence cannot be managed then no claim can be made about the validity of either claims to fulfil explicit safety competence criteria like those of IEC 61508 (IEC 2010) or the implicit requirement for competence where professional judgement is applied to other safety assurance activities.
- **Competence-Based Claims**. These claims are made to provide assurance that other safety claims, arguments and evidence are based upon sound professional judgements made by competent people. For example, a claim could be made that a safety-related system can achieve a certain failure rate and evidence would be presented to support the failure rate claim; perhaps from a Human Error Analysis (HEA) of the system. At some level the claimed system failure rate will be underpinned by the application of professional judgement (e.g. human failure rates in the HEA); therefore, some meta-evidence is required relating to the identification of where the judgement was applied and for each instance the competence of the individuals providing that judgement. The original claim is related to a failure rate and failure rate assessment is based upon professional judgement therefore the original claim is a competence-based claim and meta-evidence is required.

6 Conclusions

Competence has been defined as the ability to carry out a task to an effective standard; its achievement requires appropriate technical knowledge, skills and personal attributes. The aim of safety-related organisations and individuals should be to transition from unconscious incompetence to unconscious competence and to maintain that state through effective competence achievement processes and through the specification and assessment of suitable competence criteria.

Organizations with significant competence deficiencies cannot provide adequate safety assurance as they are simply unaware that a problem even exists let alone have any awareness of the detailed competence criteria necessary to undertake safety assurance activities.

Professional judgment is applied by safety engineers during the safety assurance process and the validity of that judgement is critically dependent upon individual competence. Safety assurance therefore relies fundamentally upon the competence of all those contributing to the development, operation and maintenance of safe systems.

The validity of any safety claim is critically dependent upon organizational and individual safety competence therefore compelling evidence and associated meta-evidence must be provided to support both *claims of competence* whereby safety competence can be assessed and managed and *competence-based claims* when competent judgements are made.

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