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A model for the implementation of industry-wide knowledge sharing to improve risk management practice

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ABSTRACT

This article examines the process of industry-wide OHS/safety information management in the Australian coal industry. It uses as a case study the novel RISKGATE interactive database that has been created as part of collaborative efforts between multiple coal mining industry stakeholders over the last five years. The RISKGATE database operates within both the information systems and organisational learning models of knowledge management, capturing inter-organisational expert knowledge and facilitating dissemination to field practitioners through the medium of a digital web-based tool. This discussion will utilise variations of the Data–Information–Knowledge–Wisdom (DIKW) hierarchy as a means of interrogating, firstly, the process of how the various industry stakeholders codify their tacit knowledge on safety issues in the coal mining industry; and secondly, how that data is then made available through the RISKGATE database to practitioners (and others) working in the field. While Frické (2009, 131) thinks the DIKW hierarchy out-dated by reason of its 'philosophical backdrops of operationalism and inductivism' amongst other problems, we believe it still has relevance if considered a dynamic entity and not a fixed hierarchy.

1. Introduction

The juxtaposition of the two concepts: 'risk society' and 'information society', is a critical one (Hansson, 2002). Both labels are largely post World War II developments, ones that have accompanied a range of other 'post' re-configurations of the social, political, cultural, economic and technological landscape: 'post-industrial', 'post-modern', 'post-fordism', amongst them. As a concept, the 'information society' has been traced back to Fritz Machlup's 1962 book, *The Production and Distribution of Knowledge in the United States* (Crawford, 1983). From a technological trajectory, 'the invention of the transistor' is the 'crystal fire' precipitating 'the birth of the information age' (Riordan and Hoddeson, 1997). The 'risk society' concept is usually attributed to Ulrich Beck's landmark work from 1992: *Risk Society: Towards a New Modernity*. These works (and many more besides) assume and persuasively argue for a surfeit of each: we now have colossal levels of risk and monumental amounts of information, or rather, data. Furthermore, there has been much discussion, debate, and controversy over both terms. Inevitably, there are many causes (and outcomes) of this titanic excess of both risk and information in the post World War II period: intensifying globalisation, technological transformations, conflicting ideologies, the rise of mass media, political upheavals, environmental concerns, and wealth imbalances amongst them. We can, however, be certain of one thing: both a mutually compatible and a dualistically antagonistic relationship exists between risk and information.

Greater levels of information might suggest that both a decrease and an increase in the level of risk is possible, while a greater and a lesser cognisance of risk can arise from both more and less information. If this point is confusing it's meant to be, largely because confusion arises easily when human cognition is overloaded by too much risk and/or too much information (Miller, 1956). This intertwining of risk and information is especially pertinent in hyper-industrialised contexts like coal mining where an acute awareness and an enactment of both concepts underpin their safe and ongoing operation.

The communication of existing, *relevant* information related to risk/OHS management is one of the primary purposes of safety management systems (SMSs), with the objective of dispersing expert knowledge and making available tacit knowledge in an explicitly codified form (Wold and Laumann, 2015). SMSs are also designed to provide a standardised technology for regulating safety

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management procedures throughout an organisation, an assumption of linear knowledge diffusion that will be challenged within this discussion.

This article examines the process of industry-wide OHS/safety information management in the Australian coal industry. It uses as a case study the novel RISKGATE interactive database that has been created as part of collaborative efforts between multiple coal mining industry stakeholders (mining companies, suppliers, contractors, consultants, regulators, and researchers) over the last five years. While certain industries, such as the nuclear industry (Wahlström, 2011; Nesheim and Gressgård, 2014) and the geophysical industry (Threadgold, 2014), have been developing safety management systems at an inter-organisational level for some time, there is not yet any overarching industry-wide framework for the capture, retention and dissemination of safety-related information in the Australian coal mining industry.

The RISKGATE database operates within both the information systems and organisational learning models of knowledge management, capturing inter-organisational expert knowledge and facilitating dissemination to field practitioners through the medium of a digital web-based tool. This discussion will utilise the Data–Information–Knowledge–Wisdom (DIKW) hierarchy as a means of interrogating, firstly, the process of how the various industry stakeholders (referred to above) codify their tacit knowledge on safety issues in the coal mining industry; and secondly, how that data is then made available through the RISKGATE database to practitioners (and others) working in the field.

The DIKW hierarchy is used extensively, either explicitly or implicitly, in a wide variety of contexts, from libraries, museums, knowledge management, epistemology, and media communication, amongst other disciplines (Rowley, 2007). Furthermore, the DIKW hierarchy is traditionally configured diagrammatically as a vertical pyramid (see Fig. 1), with 'data' at the bottom, progressing through 'information' and 'knowledge', with 'wisdom' at the top (see Rowley, 2007; Awad and Ghaziri, 2004; Chaffey and Wood, 2005). A different variation simply inverts the hierarchy: data at the top and wisdom (or knowledge) at the bottom, as in Fig. 2 (Tuomi, 1999). Critically, as Nissen (2006, 22–24) acknowledges, information technology (or equally, digital or electronic technology), is closely interrelated to the evolution of the DIKW hierarchy, with both having emerged almost simultaneously over the last thirty years. However, given the omnidirectional and multitudinous nature of data as it is mediated via electronic technology, the term 'hierarchy' itself should be brought into question. Subsequently, and in response to the inverted model advocated

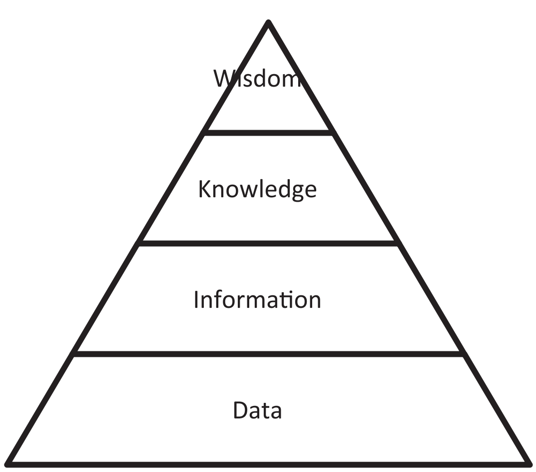

Fig. 1. Standard DIKW hierarchy.

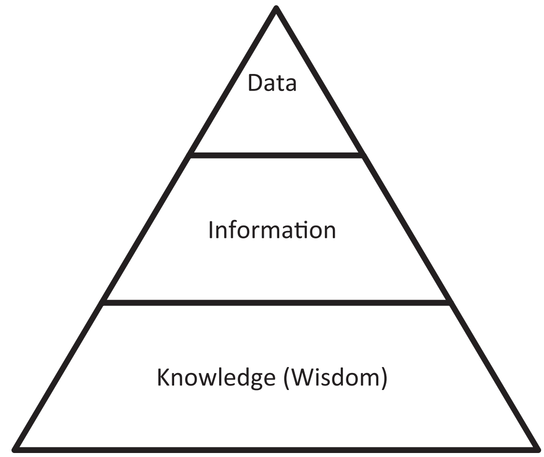

Fig. 2. Tuomi's inverted hierarchy.

by Tuomi (1999, Fig. 2), Nissen (2006, 21), proposes a DIKW model he calls 'knowledge flow directionality', where the various DIKW categories are duplicated on an horizontal axis with the 'producer/source view' of the categories on the left and the 'consumer/receiver view' on the right of the diagram (Fig. 3).

As will hopefully become even clearer during the course of this discussion, Nissen's 'knowledge flow directionality' inflected DIKW model seems more appropriate to understanding the flow of safety information through the RISKGATE database. While Frické (2009, 131) thinks the DIKW hierarchy out-dated by reason of its 'philosophical backdrops of operationalism and inductivism' amongst other problems, we believe it still has relevance if considered a dynamic entity and not a fixed hierarchy. We will have more to say on how data in the DIKW model flows through the RISKGATE database in due course.

2. The background

2.1. Australian coal mining OHS

The Australian coal mining industry has been recognised as highly progressive in its approach to Occupational Health and Safety (OHS) (Cliff, 2012a,b). This quality is best exemplified in the change, throughout the late 1990s and early 2000s, from a compliance-based safety system to a risk-based management system (Kirsch et al., 2014e; Cliff, 2012a). This altered method was first proposed in the Robens Report in the UK in 1972, but did not have a major influence on Australian mining OHS regulations until it was formally introduced following a series of three major underground mining explosions in Moura, Queensland, the first occurring in 1975 and subsequently in 1986 and 1994 (Yang, 2011; Kirsch et al., 2014e). These explosions resulted in the death of 36 workers, and prompted the Queensland government's introduction of the 1999 *Coal Mining Act*, which was followed by a similar solution in New South Wales, the 2002 *Coal Mine Health and Safety Act* (Kirsch et al., 2014e). Each of the Australian states has implemented their own legislation for mining safety, although not all have moved away completely from compliance requirements, and there is no overarching federal legislative framework in place as yet (Cliff, 2012a). Joy (2004) describes the initial years of implementation of risk management approaches in Australian mining, which was accompanied by the introduction of duty of care and workforce representation and involvement, collectively driving the significant changes to safety management.

Risk-based OHS legislation is now the primary safety system in Australian black coal mining, with a predominance of operating

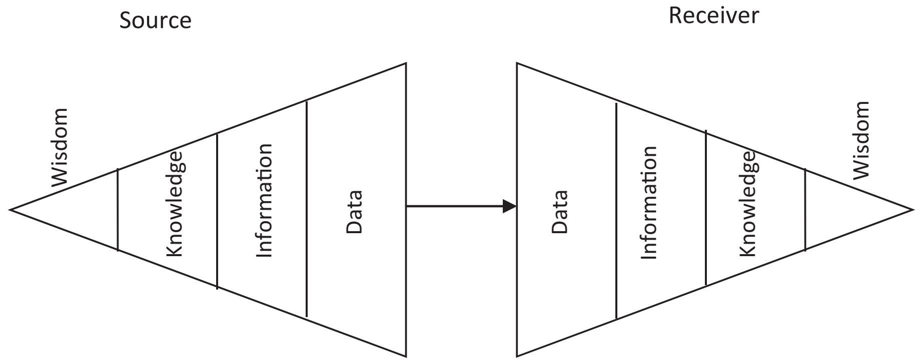

Fig. 3. Nissen's knowledge flow directionality model.

mines located in New South Wales ($n = 60$) and Queensland ($n = 47$) (Kirsch et al., 2014e). The OHS system stands as an alternative to prescriptive legislation that may 'lead to apathy on the part of both workers and management … and an encouragement of a minimum compliance mentality which militates against the development of a culture in which safety is everybody's responsibility' (Gunningham, 2006, 36). Instead, it is characterised by the 'requirement to reduce the risk to workers to as low as reasonably possible' (Cliff, 2012b, 30). As a result, risk management is now the accepted method for achieving the required level of safety, with the risk assessment model used to identify and mitigate potential hazards.

The risk assessment model of OHS requires access to a comprehensive knowledge network of practical experience and expert understanding of the potential hazards in order to identify, collate and implement appropriate controls for the prevention or mitigation of incidents. For the most part, this knowledge already exists within the industry and simply needs to be identified and transformed into a format that allows accurate transferral of information. Indeed,

> *… it is rare to find that [a] hazard was new or unknown. Far more often, the knowledge of hazards and their controls resides somewhere in the organization or the industry, but for some reason has not filtered through to the people who need it, or has not been applied at the right time.* (deMeulles, 2002, 65)

In order to achieve an effective level of risk assessment and management, there must be the technological capacity for information dissemination *and* a culture of sharing safety-centred experiential and empirically orientated information, at personal, organisational and industry levels.

2.2. Information-sharing

An information-sharing culture is a broad concept and one which is not easily achieved in any formalised manner, but is nevertheless commonly recognised as essential to the development of an organisation and for an increase in overall knowledge for both individual employees and for the subject area (O'Dell and Hubert, 2011; Handzic and Agahari, 2004). As Nonaka (1994, 15) contends, implementing a knowledge-sharing culture requires '"communities of interaction" [to] contribute to the amplification and development of new knowledge'. The success of this contribution can be evidenced in the transferral and transformational processes that occur as a result of the interpersonal communication of information, as well as the general growth of a body of information.

Originally put forward by Polanyi (1962), there are two forms of knowledge – tacit and explicit – or what we will refer to as codified, and it is through the effective transferral of both forms from the knowledge holder to recipient that expertise can be acquired and development can occur. Polanyi introduces the idea of tacit knowing by explaining that '*we can know more than we can tell*' (1966, 4), a concept further expanded by Nonaka:

> *"tacit" knowledge has a personal quality, which makes it hard to formalise and communicate. Tacit knowledge is deeply rooted in action, commitment, and involvement in a specific context. (1994, 16)*

Within Polanyi's definition, tacit is both subsidiary to codified knowledge, because it cannot be consciously known and explained, and also forms the structure that supports and results in codified knowing. Within the industry or organisation tacit knowledge is difficult to capture and transfer in a formalised manner as it is inherently difficult to isolate and record. Conversely, codified knowledge is '*focal* knowing' (Polanyi, 1962, 240), as it forms the structure as a whole, and is 'transmittable in formal, systematic language' (Nonaka, 1994, 16). According to Smith (2001), it has been widely acknowledged that tacit knowledge can make up to 90% of an organisation's overall knowledge.

To effect a knowledge-sharing culture there must therefore be a system in place to facilitate the communication of *both* forms of knowledge, necessitating techniques that enable the transfer and capturing of tacit knowledge, and converting it to explicit to enable its widespread diffusion throughout the organisation. The method for achieving this capture and conversion is presented as 'externalisation' by Nonaka, and can be to some extent actualised through the process of storytelling, reflection or analogy with relation to the previous experiences of subject matter experts in possession of tacit knowledge (Smith, 2001; Taylor, 2007; Nonaka, 1994; Swap et al., 2001), thereby enabling synthesis and presenting it in a reduced, explicit format.

In the case of the organisation, tacit knowing is both an advantage 'because it is unique, imperfectly mobile, imperfectly imitable and non-substitutable' (Emadzade et al., 2012, 781; Barney, 1991) and therefore a valuable resource (Kakabadse et al., 2001), as well as a problem because it requires time and investment to harvest and transform into codified knowledge (Gubbins et al., 2012), as the format which is best adapted for transferral between individuals. When considering knowledge-sharing within risk management this immobility of tacit knowledge can only be a disadvantage as it inhibits sharing, and it is therefore necessary to streamline the tacit to explicit conversion and diffusion through the establishment of a knowledge management system, one that structures the capture, storage and transfer of information.

2.3. Knowledge management

An increasingly vital consideration within any organisation, a knowledge management system presents a method for preventing the loss of existing organisational knowledge; a particularly important consideration in the face of changing employment habits, ‘where a disproportionate amount of the workforce has either less than 5 years or greater than 25 years in the industry’ (Kulakofsky, 2008, 1).

Mining is a major economic driver in many countries, including Australia and Canada, and attracting highly skilled people, retaining this talent at the remote location of most mine sites and keeping them motivated during times of predicted job losses is a major human resource challenge (Dickie and Dwyer, 2011; Kirsch et al., 2014b). Job losses and industry growth both create circumstances where knowledge becomes less available either as people leave an organisation, or as large numbers of greenhorns are recruited. Several studies suggest that there will not be enough skilled workers to replace retirees or meet the increasing demand for workers globally in this industry over the next decade (e.g. Mining Industry Human Resources Council, 2011; Brandon, 2012; Molloy and Tan, 2008; National Resources Sector Employment Taskforce, 2010; Skills Australia, 2011).

There is a pressing need to record and make available existing OHS information, and particularly tacit information/data, due to the ‘growing mobility of labour and broader use of random workers’ (Urbancová and Linhartová, 2011, 84). Similarly, knowledge is also being lost through organisational changes that reduce operational costs and permanent employee numbers such as outsourcing, downsizing, mergers and terminations (Smith, 2001).

de Kretser and Wilkinson (2005) suggests that there can also simply be a loss of organisational memory over time, and this can be an industry-wide problem where a lack of collaboration means that known risks accounted for in individual KM systems are frequently sourced from only a limited number of resources (Paltrinieri et al., 2011). Paltrinieri et al. refers to this as identifying only “known known” events rather than gathering “unknown known” events from incidents that have occurred on a broader spatio-temporal scale than the single organisation or from existing employees’ knowledge. “Rapidly decaying corporate memory (Minerals Industry Safety and Health Centre, 2006, 3)”, identified as a major contributor to ongoing moving equipment incidents in Australian mining was largely because “within two or three years, the rate of people leaving their positions resulted in the characteristic that it was unlikely that the principal players in the incident, still worked at the site where the incident occurred or at corporate offices (Minerals Industry Safety and Health Centre, 2006, 14)”.

Beyond preventing loss, information management systems also generally enable the sharing and organisation of information, increasing and streamlining the available knowledge base for application by individuals. There are a great many descriptions of the information management process, with no commonly accepted definition. However, Jasimuddin (2012) has compiled an overview of the frequently listed generic steps within the process, summarised here as:

- acquisition of organisational knowledge; sourcing existing knowledge from employees and systems
- creation of organisational knowledge; the creation of information through exchange amongst organisational members and between existing tacit and explicit knowledge
- storage of organisational knowledge; preservation of knowledge for reuse and creation of new knowledge
- transfer of organisational knowledge; transmission of information to an organisational member, who then absorbs it
- application of organisational knowledge; exploitation of the knowledge exploration in an organisation

When applying Jasimuddin’s (2012) generic process to risk management, his qualifying scope of ‘organisational knowledge’ can be expanded to encompass the subject matter knowledge of an entire industry. Further, risk management knowledge processes are not designed for competitive or economic advantage that accrues to an individual entity, instead, the goal is to facilitate, capture and make available the most comprehensive knowledge base for improvement of wide-scale industrial practice. In order to complete this process at the scale of the industry, there are a number of factors that must come into play, including provisions for scale, distance and time. As such, within the knowledge management process there is an overlap between interpersonal communication and the information system, with the latter included as a method of storing and making available a full body of knowledge, creating a ‘socio-technical system for knowledge transfer’ (Norheim and Fjellheim, 2006, 2). The knowledge management information system effectively augments personal transfer of knowledge by overcoming the spatio-temporal restrictions. To complete this integration of information systems into the process of knowledge transfer, the knowledge must be broken down into a manageable format for storage and transmission through retrieval.

2.4. DIK(W) model

As pointed out in the Introduction, we will be examining the RISKGATE database through the lens of the DIKW flow model advocated by Nissen (2006). Before doing so, some background to the DIKW hierarchy will help set the scene. An influential and early advocate of the DIKW hierarchy, Russell Ackoff (1989, 3), states that ‘information systems generate, store, retrieve, and process data’, reflecting what is often considered the starting point of the data–information–knowledge–wisdom (DIKW) hierarchy. The DIKW hierarchy is one of the more basic and widely used models within the knowledge management literature (Rowley, 2007). It is applicable to the overlap between the personal, interpersonal and information systems within a single knowledge management system. DIKW describes the transformation that knowledge undergoes during the KM process, as it is reconstructed by the individual seeking to acquire knowledge from the data or information provided by the KM information system.

Within the traditional DIKW hierarchy, each of the elements transforms into and is included within the element above it, through an increase in meaning and complexity, which is generally assumed to be facilitated by increased understanding on the part of the individual (Rowley, 2007) (see Fig. 1). The elements have been defined by Ackoff (1999, 1989) (omitting understanding as a separate element due to updated consensus in the field, Rowley, 2007; Bellinger et al., 2004) as follows:

- ‘Data consists of symbols that represent objects, events, and/or their properties. They are products of *observation*‘ (1999, 15).
- Information is data that has been processed into useful forms. It is ‘contained in *descriptions*, answers to questions that begin with such words as *who, what, where, when*, and *how many*’ (1989, 3).
- ‘Knowledge is contained in instructions. Knowledge consists of *know-how*, for example, knowing how a system works or how to make it work in a desired way’ (1999, 15).
- ‘Wisdom is the ability to perceive and evaluate the long-run consequences of behaviour. It is normally associated with a willingness to make short-run sacrifices for the sake of long-run gains’ (1999, 16).

There are, of course, many definitions for each of the elements, with some more succinct than others (see Rowley, 2007; Bellinger et al., 2004; Nissen, 2006; Wognin et al., 2012; Zeleny, 2005; for varying definitions). However, Ackoff is one of the earliest proponents of the hierarchy and his definitions continue to ring true. While under this definition, wisdom has limited relevance as it forms merely an abstracted extension of applied and contextualised knowledge, Zeleny (2005) is right to assert that after the cognitive consolidation of data, information and knowledge, the wisdom level is closely associated with action. This seems essential especially in a safety context.

What a number of texts on the DIKW hierarchy suggest, however, is that there is another method for considering the evolution of the hierarchy, which posits that data is the result of a stepped distillation of knowledge; '[d]ata can emerge only if a meaning structure, or semantics, is first fixed and then used to represent information' (Tuomi, 1999, 107). Tuomi puts forward a method of dealing with this structured emergence of data in the form of an inverted hierarchy (see Fig. 2), which begins with knowledge and progresses through information to arrive at data.

Therefore, we may note that there are two sides to the knowledge hierarchy, with one side being a reduction from knowledge *to* data or the *knowledge source* (as the inverted hierarchy) and the other a construction of knowledge *from* data or the *knowledge receiver* (as the standard DIKW hierarchy), with the information system (or the database) forming a link between them and in the simplest form illustrating a one way flow of information, what Nissen terms 'knowledge flow directionality' (Nissen, 2006, 21) (see Fig. 3), although in practice the production and distillation of knowledge may be asymmetrical, consisting of multiple sources and resulting in a construction of knowledge that does not match the original source. In addition, the knowledge receiver is also a knowledge producer, as a member of an independent community of practice within an existing knowledge domain, and this existing expertise may influence the knowledge transfer process.

2.5. Communities of practice

Within the context of safety management in hazardous industries, communities of practice (CoPs) are highly differentiated, particularly with regards to their level of involvement, physical or otherwise, within day-to-day operations. Within the separate sides of Nissen's knowledge flow directionality model (Fig. 3) lie (for the most part) separate CoPs, which creates some difficulties in acceptance of the knowledge flow from one side to the other, but also allows the risk management system to remain location specific with the knowledge receiver, conversant in the operations of a particular site, able to select relevant safety information from an industry-wide collection of data.

On the left hand side of the diagram, the *knowledge source* commonly takes the form of the subject matter expert and their discourse-based CoP, which is afforded an authoritative role within the organisation on the specific subject of their expertise. On the far right side of the diagram is the CoP consisting of field-based practitioners, who, as *knowledge receivers*, are expected to accept the distilled knowledge from the subject matter experts and incorporate it into their own practice. The field-based practitioners have their own existing operational expertise and as such this is not necessarily a straightforward process, with tensions between the existing knowledge of the receiver CoP and the new knowledge they are expected to learn and incorporate into their practice.

As Wold and Laumann (2015) summarises with regards to a study carried about by Antonsen (2009) investigating attitudes towards new safety procedures within a field-based CoP in the shipping industry:

> *The seamen in Antonsen's study saw the procedures as based on the theoretical knowledge of some "office worker", and not as based on the practical knowledge possessed by competent seamen ... (24)*

This 'us and them' attitude is a pervasive one (see also Gheradi and Nicolini, 2000), and can be attributed primarily to the structure of the CoP. Although highly variable, with few defining characteristics beyond their objective of facilitating knowledge transfer between members, CoPs retain a basic structure. As discussed by Wenger et al. (2002), they consist of a domain of knowledge, a community of people, and the shared practice or knowledge base that they are developing (Saputelli and Ungredda, 1999; Beatty et al., 2003).

The antagonism demonstrated towards the 'office worker' in the above example is caused by a perceived challenge to the existing domain of operational knowledge possessed by members of the field-based CoP, the seamen. This is a common problem encountered within safety management, as there are subject matter experts exist outside the field-based CoPs, and operate on the same topic but within a different discourse and practice (Gubbins et al., 2012; Gheradi and Nicolini, 2000). As Almklov et al., 2014 notes,

> *[g]eneric safety knowledge may be embedded in a discourse ... in which the local and system-specific knowledge of the practitioners is marginal, irrelevant, or even meaningless. Safety professionals may gain a model monopoly ... in their interaction with practitioners (2014, 25).*

In circumstances such as these, with tensions between existing knowledge communities and an established organisational hierarchy, it is important to construct the information system in such a way as to act as a mediating power. As the move from compliance-based to risk-based safety management can attest, knowledge on a topic may be extensive, but its application is situation-specific and, particularly in the area of safety, existing field-based knowledge is highly relevant to preventing and/or mitigating problems at a specific site. It is therefore important to recognise the asymmetry between the two sides of the knowledge flow directionality model, with the receiver hierarchy being built up using existing situational knowledge that rests within that CoP's knowledge domain. The information system must be able to respond to this by presenting a broad cross-section of relevant data in a manageable way and trusting in the ability of the field-based practitioner to apply their existing knowledge, incorporating and creating new knowledge as appropriate. RISKGATE is designed in such a way so as to work with this asymmetry between information source and information receiver, presenting a comprehensive array of safety knowledge and allowing the field practitioner to filter options as appropriate based on their existing knowledge.

3. A contextual model

3.1. A KM system for safety management in the Australian coal mining industry

This case study explores the practical development of a safety management system, RISKGATE, for application across the Australian coal mining industry. The system takes the form of an interactive database, and is intended to make industry safety knowledge widely available through the implementation of knowledge-sharing strategies and knowledge management principles that go beyond a particular organisation. The RISKGATE system has been funded by the Australian Coal Association Research Program (ACARP) to assist in the management of major coal mining hazards through the presentation of accurate and practical interactive checklists of controls. It does this in the form of a web-based tool, designed to be easily navigable according to the type of risk or unwanted event the user is interested in managing.

The system is structured to provide clear and current information through a checklist format. There are 18 specific high-priority unwanted events, referred to as topics, which are specific to Australian coal mining and are listed within the tool (Kirsch et al., 2014f).

These include:

• Fires	• Explosives open-cut	• Outburst
• Strata control	• Explosives underground	• Interface
• Ground control	• Explosions	• Inrush
• Tyres	• Manual tasks	• Tailings dam
• Isolation	• Slips, trips and falls	• Occupational hygiene
• Collisions	• Coal bumps and bursts	• Fitness for work

For a comprehensive overview of each of the topics, see Kirsch et al. (2014d) or the RISKGATE website [http://www.riskgate.org/]. The topics listed in Section 3.1 form the basic structure of the tool, and each contains a number of core 'initiating events' which were developed through discussions amongst subject matter experts in a series of participatory action-research workshops, facilitated by the Minerals Industry Safety and Health Centre (MISHC), University of Queensland for each topic.

The information gathering and development of the RISKGATE database content has been outlined in Fig. 4, and can be understood as a sequence encompassing the stepped capture of data, from the MISHC's organisation of the workshops to the process of discussion around the topic with specialised subject matter experts from the participating mining companies, and consequently the initiating event followed by the controls. The resulting data was then entered into the database after an extensive review process, and the resulting web-based tool is currently in beta mode. The structure of information capture was heavily influenced by the visual configuration of the database itself for ideal usability and presentation of data.

3.1.1. Bow-tie analysis method

The bow-tie analysis method (BTA) was used to organise the discussion within the workshops, and similarly as the presentation format within the online tool. BTA is being adopted broadly across many industrial sectors (De Dianous and Fievez, 2006; Duijim, 2009; Ferdous et al., 2011, 2012; Kirsch et al., 2014e), and, as expressed by Chevreau et al. (2006, 277), is 'based on the coupling of a fault tree and an event tree linked to a critical event that represents a threat ...' (see Fig. 5).

The 'critical event' that Chevreau et al. refers to is the initiating event within RISKGATE, and forms the centre of the bow-tie. On either side are listed the causes (fault tree) and consequences (event tree) of that event, on the left and right respectively. Each of the causes and consequences are linked to a series of controls that have the potential to either prevent the event from occurring (preventative controls) or reduce the extent of the consequences (mitigating controls) (Kirsch et al., 2014a). A primary objective of the RISKGATE system was to create a body of knowledge of current controls that are in use throughout Australian coal mining companies, consolidating and organising into one database the existing but segregated industry knowledge. The process of identifying controls was undertaken by the subject matter experts during the workshops, as representative of and knowledgeable about the risk management processes in place within individual mining companies as well as industry standards.

3.1.2. Collection and collation: explosions

An example of this workshop process was the one undertaken for the topic *Explosions*, which consisted of eight subject matter experts from five coal-mining companies (including Adani Coal, Anglo American, Caledon Coal, Centennial Coal, Peabody Energy) (Kirsch et al., 2014a). Areas of technical or management expertise possessed by participants included underground mine management, ventilation and gas management, and general mine operations. There were a total of six workshops held for the topic Explosions, amounting to 11 days. The group identified five initiating events (see Table 1) that were then used as a basis for gathering knowledge around related causes, controls and consequences. Following the workshops, the information was uploaded into the RISKGATE system in the bow-tie format.

The process that the subject matter experts went through to establish each of the events and their subsequent causes, controls and consequences involved the identification of both explicit and tacit knowledge. The discussion between workshop participants facilitated the storytelling, reflection and analogy that allowed the transfer of tacit knowing as well as codified knowing, while simultaneously highlighting gaps in individual companies' risk management experience and policies. Through this process of knowledge sharing, the group was able to capture a broad cross-section of industry knowledge, organising it in a manner that is easily accessible and relevant.

3.1.3. Field application

The completed bow-tie is then made accessible online for use by site-specific operators, principally field-based practitioners. The simplicity of the RISKGATE system is integral to its use, particularly in light of the need to integrate it into existing organisational risk management systems and bodies of knowledge. The BTA tool is presented as a checklist, with users given the ability to check or uncheck particular controls, causes or consequences as relevant within the specific situation to which it is being applied. This tailored checklist can then be downloaded by the user and applied within a real-world situation to gain a broader set of applicable controls to prevent or mitigate damage than might otherwise be considered.

The passive nature of the system allows the existing knowledge of the field-based practitioner to dictate the relevance of a particular element within the bow-tie to the real-world situation they are currently assessing. By acting as a facilitator, the system relies on the practitioner's ability to judge the situation, and creates an opportunity for knowledge growth without pushing unnecessary procedures that can create resentment.

Although development of the system is still in progress, the released topics are being used within the coal mining industry as a body of collective knowledge that acts as reference material when conducting risk assessments. An example of this is Peabody Energy Australia's use of the topics Strata Underground and Ground while conducting audits of their geological/geotechnical principal hazard management plans (Kirsch et al., 2014f). Similarly, the RISKGATE system is able to operate as a comparative database for gap analysis of corporate standards, and to inform the development of new standards. This has been demonstrated by Anglo American's use of the system to benchmark their global isolation standard (Kirsch et al., 2014f).

3.2. Discussion

The RISKGATE system, with its contents, development process and situational application, closely adheres to Nissen's knowledge flow directionality model established within the previous

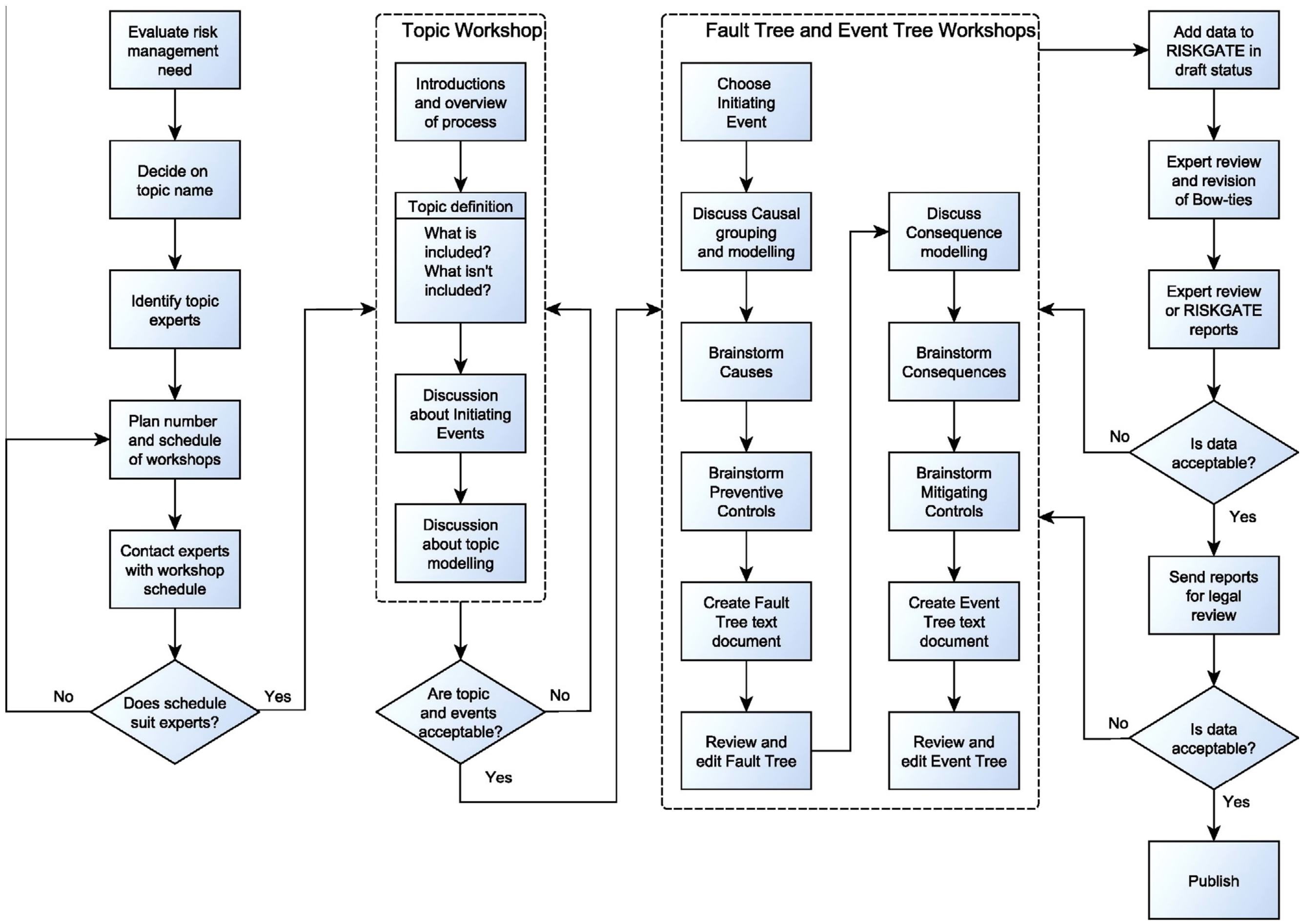

Fig. 4. Structure of the RISKGATE planning, information capture and publishing process.

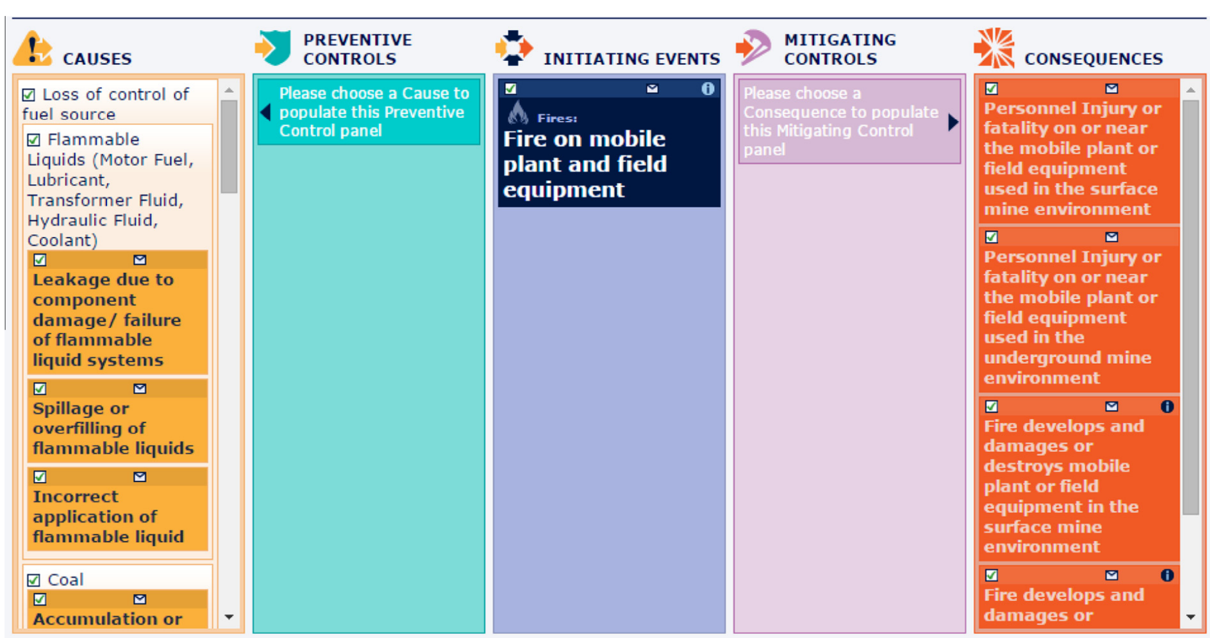

Fig. 5. Example of the RISKGATE system's use of bow-tie analysis for graphic representation.

Section 2.4. It achieves this through the introduction of a socio-technical relationship, combining the distillation of expert knowledge with an information system to allow the widest possible access to that knowledge by an unlimited number of non-experts. RISKGATE seeks to overcome the common perception that the introduction of an information system inevitably stymies

Table 1
Bow-tie elements within the Explosions initiating event.

Explosions initiating event	Causes	Preventative controls	Mitigating controls	Consequences
Extraction face (pillar and longwall)	11	54	7	1
Sealed area	4	23	7	1
Unsealed goaf	4	23	7	1
Development panel or first working	11	54	7	1
Outbye	10	48	7	1
Surface mine workings	5	17	4	1
Coal storage area	4	17	4	1

the success of a knowledge-sharing culture by reducing emphasis on interpersonal interactions; an opinion encapsulated by Dainty et al. (2005, 19) when they state, 'the overemphasis on technological solutions for managing knowledge within large organisations has contributed to the relatively high failure rate of knowledge management (KM) within many industries and organisations'. This failure is frequently contributed to by the gradual erosion of novelty within a new system, at which point usability and relevance become paramount for its ongoing use. This case study demonstrates the manner in which both kinds of knowledge management can be included within a single system, to drive knowledge-sharing on a greater scale than interpersonal communications will allow, without suffering a loss of value.

Indeed, RISKGATE corresponds not only to the knowledge flow directionality model, but also to the many principles of knowledge management outlined by Jasimuddin (2012), simultaneously progressing through Nissen's flow model as well as the stages of knowledge management, as shown visually in Fig. 6. By focussing not on the technical nature of the information system, but rather its place within the overall knowledge management process, and acknowledging its role as a tool for facilitating knowledge transformation, it is anticipated that the RISKGATE system will overcome the real-world application problems of many technical solutions.

The following sections examine this assumption by breaking down the transformational processes within the various stages of knowledge management and elaborating on the interpersonal, intrapersonal and human–computer interactions that take place at each stage.

3.2.1. Acquisition/knowledge to data

The process of acquisition involves the identification of existing sources and formats of knowledge, and the techniques used to gather them. It also represents the transformation from knowledge to data and from tacit to codified knowledge for collection. Within RISKGATE this process was achieved through action research workshops. The workshops prompted discussion around a specific topic that allowed an exchange of knowledge, both tacit and explicit, between experts acting as a cohesive community of practice as they followed the spiral format of action-research with continuous reflection and review of emergent knowledge. Initial workshops sessions focused on collecting and listing a very broad set of thoughts from all members of the specific CoP, as illustrated in Fig. 7, and this baseline of data was then filtered, categorised and further refined in the subsequent workshops. The face-to-face nature of the workshops enabled the recounting of experiences and stories, communicating tacit knowledge and allowing it to become tangible and therefore explicit. As the discussion progressed, knowledge on a topic grew as it was revised and added to by the participants in a cycle of action and reflection.

The workshops were designed to substantiate the bow-tie structure of the RISKGATE tool, established prior to the involvement of experts, and the discussion that was captured by the facilitators followed this framework. This reduced complex knowledge to accurate essentials through careful concentration on particular relationships between controls or initiating events and their causes or consequences, reflecting the transformation of knowledge to information and data, for its inclusion in a database.

3.2.2. Creation/modes of knowledge creation

The sharing of tacit and explicit knowledge was an opportunity to enact one of the more uncontrollable, but highly valuable, steps within knowledge management: creation. Creation refers to the formation of new knowledge through social interactions that prompt previously separate items of knowledge to connect and produce new knowledge, as well as the exchange of different forms of knowledge.

Nonaka (1994) explores this through establishing the 'modes of knowledge creation', one of which we have already discussed – externalisation – which describes the four types of knowledge conversion – socialisation, combination and internalization, in addition to externalisation – as it moves from tacit to explicit or vice versa. This is primarily a social activity, with three out of four of the modes dependant on sharing information between individuals.

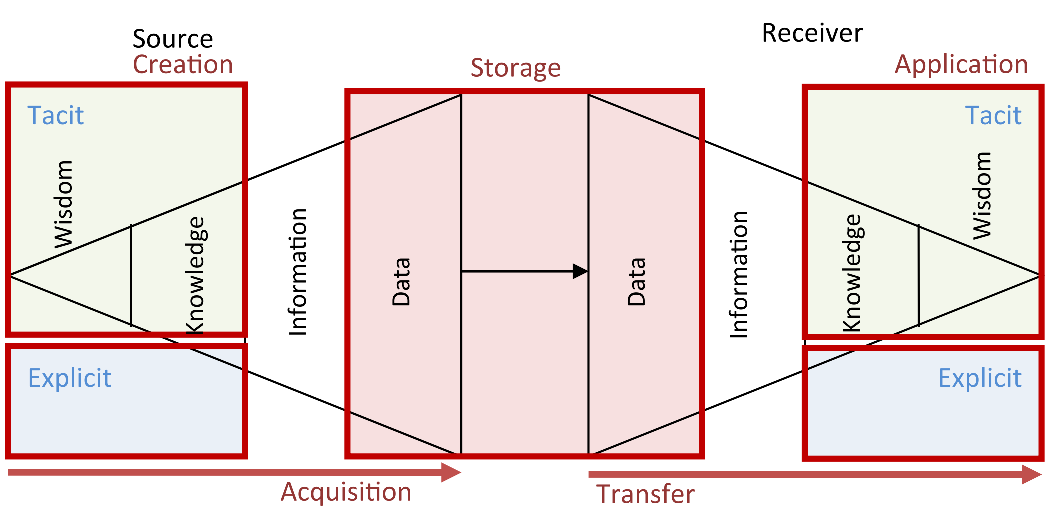

Fig. 6. Overlaying Nissen's knowledge flow directionality with Knowledge Management.

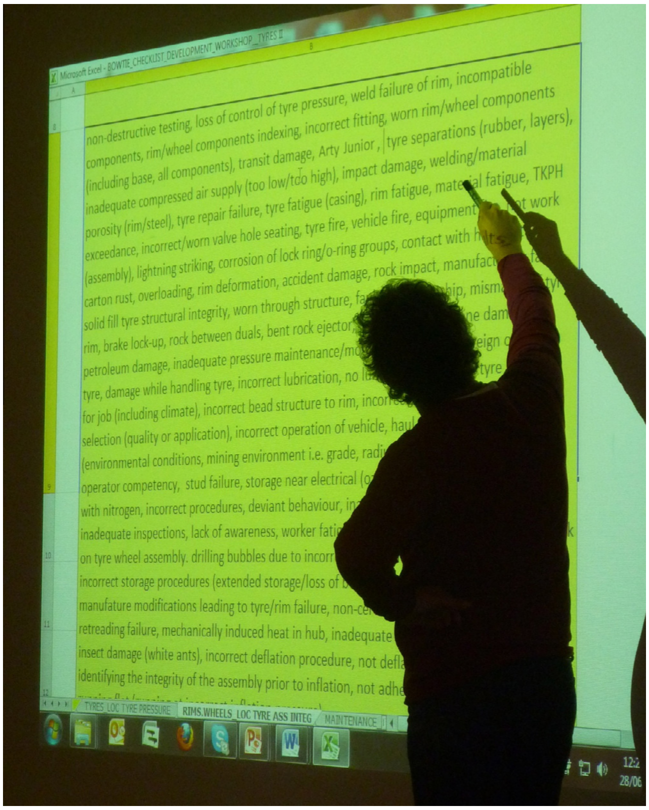

Fig. 7. RISKGATE workshop: a collection of thoughts (tacit knowledge) about tyre incidents which is being reviewed and codified through the participatory action research process.

Although this is not directly reflected within Nissen's model, it transverses it, and remains not only an important consideration but one of the key outcomes of a knowledge sharing culture. Indeed, knowledge creation does not only occur during expert workshops, but is one of the main results of the synthesis with existing knowledge that occurs alongside knowledge transfer, as discussed in Section 3.2.4.

3.2.3. Storage/database data

The reduction of knowledge to data as a result of acquisition enables storage in an information system for wide distribution, for the creation of new knowledge, and to preserve existing knowledge beyond the cognitive capacities of the individual. This latter motivation is particularly powerful in relation to the organisation that values information as an asset for competitive advantage, but is equally important to an industry such as coal mining that is threatened by swiftly changing employment habits (Minerals Industry Safety and Health Centre, 2006) and increasing pressures on safety as a component of maintaining a social license to operate (Worden et al., 2014; Kirsch et al., 2014c).

The reduction to data is necessary for inclusion within the information system, as it allows the greatest flexibility in retrieval for the user. Within the RISKGATE online tool, this data is presented in a particular context, within a staggered layout that descends from topic to initiating event and is broken down further into causes and consequences, followed by controls (see Fig. 5). While each section contains discrete sets of data, they are connected to each other through the bow-tie structure, retaining contextual meaning and therefore presented as both data and information. It is then up to the user to transform that data/information into knowledge and subsequently wisdom via its successful application within the context of an individual site. There are, of course, caveats when using such knowledge distribution structures, particularly in relation to the comprehensiveness of the knowledge being recorded; it is only possible to place existing knowledge into the system, so 'unknown unknowns', or knowledge that the knowledge source is not in possession of cannot be recorded. This means that while the bow-tie system is effective at making existing knowledge available to the user, it is not infallible and complacency should be avoided. Further, such knowledge systems need to be curated and kept current to accurately communicate changes that may take place in the ways that industry manages risks over time.

3.2.4. Transfer/data to knowledge

The database exists as a conduit through which information can be dispersed to a wider audience without the need for face-to-face interactions. RISKGATE embraces this task, as its disparate CoPs having limited opportunities for inter-community exchanges. It therefore relies on not only the collation and storage of data, but on its effective transfer and reconstruction once it has been accessed within the system. The transferral of information through RISKGATE creates codified knowledge in the form of 'know-how', as per Ackoff's (1999) original definition, as the database provides a template for its application and sets out a series of instructions that can be internalised by the user.

The field-based practitioner is the anticipated primary user of RISKGATE, with its applicability to safety procedures making it useful to all employees engaged in risk assessments on site. The practitioner's interpretive system is therefore very important for the information transfer, and the system relies on the existing knowledge of the user to reconstruct data into knowledge through the lens of situational specificity. The combination of tacit site knowledge combines with the codified knowledge made available on RISKGATE, enabling a more comprehensive and informed approach to risk management.

3.2.5. Application/existing site knowledge with new safety information

The effective application of this industry-wide safety information is essential, as the central purpose of the entire socio-technical system is to effect more informed decisions on site; in the case of RISKGATE, these decisions take the form of preventive and mitigating controls. As Jasimuddin notes, 'it is important to utilise the right knowledge in the right place at the right time, immediately after exploring [*sic*] it from the right source' (2012, 51), and indeed it is important to actively recognise the applicability of the information within specific contexts and take steps to encourage its use.

A particular case study which supports RISKGATE's ongoing relevance and applicability is Centennial Coal's integration of the system within its own risk assessment software, Stature, for site-based application (Harris et al., 2014). The company developed an interface template that allowed RISKGATE checklists to be uploaded directly into Stature, where they are used as up-to-date reflections of industry standards in risk management.

RISKGATE can be used at any stage of the Stature risk assessment process to help scope, conduct or review a risk assessment. This means that Centennial Coal's field-based practitioners can be confident in their safety analyses despite their own isolation from inter-organisational practitioners and subject matter experts, as they can access industry-wide knowledge within their own familiar system. This allows them to become aware of their own activities in relation to the wider industry and make improvements accordingly. Simultaneously, they are able to retain control of the risk analyses conducted within the site with which they are familiar, as the checklist nature of the RISKGATE system allows practitioners to eliminate irrelevant information as applicable.

4. Conclusion

Industry-wide knowledge management systems are relatively achievable within the context of safety and risk management. When creating a KMS it is important to consider the role of the employee, the information system or database and the subject matter, with the spatio-temporal dispersal of industry employees making the establishment of a technology for information and data storage essential. As such, the transformation of knowledge is of vital importance, with its distillation and reconstruction on either side of the information system's storage functionality proving to be the primary processes in effective knowledge capture and dissemination.

The RISKGATE case study has demonstrated the validity of both Tuomi's inverted hierarchy and the standard DIKW hierarchy in the two halves of the knowledge-sharing process. The introduction of Nissen's knowledge flow directionality model has combined the two hierarchies into a single process that explains the overall transfer of knowledge from subject matter expert to information system to field-based practitioner. This model can be matched up with the general principles of knowledge management when they are considered within the spatio-temporal restrictions of an industry-wide system.

The discussion has also demonstrated that through recognition of the existing knowledge held by field-based practitioners, the knowledge directionality flow model can be applied not only within compliance-based safety management systems, but also risk management systems. It allows the site specific contributions of the knowledge receivers to influence the knowledge reception, and to create new knowledge through the collision of explicit knowledge transferred through the information system and tacit knowledge existing in the mind of the receiver. This removes passivity, and allows the available knowledge base to grow while remaining sensitive to individual situations.

Information systems and databases alone cannot guarantee the sharing and communication of knowledge (de Kretser and Wilkinson (2005)), but they must form part of the process, as a facilitator of knowledge transfer and as a tool to be used discerningly by the knowledge receiver. The challenge that remains for RISKGATE is to instigate and maintain systems for updating information, particularly changing standards and regulations.

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