Creativity Support to Improve Health-and-Safety in Manufacturing Plants: Demonstrating Everyday Creativity

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ABSTRACT

This paper reports the development and deployment of digital support for human creativity in a domain outside of the creative industries – health-and-safety management in manufacturing plants. It reports applied research to extend a risk detection and resolution process at a world-class manufacturing plant that produces tractors with creativity techniques and new digital support for the plant employees to use these techniques effectively as part of the risk detection and resolution process. The development of the digital support was constrained by the plant's processes, resources and manufacturing culture, and the new digital support reported in this paper was designed for quick use across the plant with minimum training or management overhead. The paper reports the development, implementation and early evaluation of the creativity techniques and digital support in the plant as a demonstrator for the wider application of creativity techniques and digital support tools.

Author Keywords

Creativity; health-and-safety; risk management; mobile

ACM Classification Keywords

D.5.2 [User Interfaces]: User-centered design, voice I/O

General Terms

Design, human factors

INTRODUCTION

The last decade has seen considerable advances in the use of digital support for human creative activities in arts and design – disciplines already recognized as creative such as music, and film and television. However, this focus on the creative industries has sometimes acted as a barrier to creativity research to explore and develop support for human creativity in disciplines not generally perceived as creative. For example, there is little explicit teaching or uptake of creativity techniques and methods in engineering, although few would disagree that engineering practice necessitates creative problem solving. Other disciplines, however, are not even perceived to have a role for creative thinking, even though the work undertaken in them seeks to produce outcomes that are novel, useful and surprising [23]. Examples include nursing and transport planning, and most of these disciplines provide no explicit support for human creativity, in spite of the potential benefits that could accrue from more creative thinking by their professionals. In this paper, we argue for and develop support to deliver human creativity in one important activity not treated as creative – health-and-safety management in manufacturing plants – as a demonstrator for the wider application of creativity methods, techniques and digital support tools.

Increasing the health and the safety of citizens continues to be an important aim for organisations and governments. In the United States, for example, there were 4,500 workplace deaths in 2010, 250,000+ work-related injuries and illnesses in 2011 [20], and in the European Union almost 2.5 million workplace incidents resulting in at least 3 person-days off work occurred in 2012 [9]. New legislation and management systems have resulted in improved worker health and safety through the introduction of systematic processes, however notable numbers of deaths and injuries continue to occur. Now, to reduce these numbers further, some organizations are exploring different approaches to complement systematic processes. One of these organizations is CNH Industrial, a global leader in the capital goods sector, and the new approach is creative thinking.

CNH Industrial's current systems for occupational health-and-safety management and lean manufacturing involve all of its employees in the detection, reporting and resolution of health-and-safety risks. To support employees to think more creatively in this risk detection, reporting and resolution process, the EU-funded COLLAGE project has extended it with support for creative thinking about risk resolutions and, more significantly, developed new digital support for this creative thinking. This paper reports the development and piloting of digital creativity support for employees in one CNH Industrial manufacturing plant outside of London that produces tractors. In particular, it describes how advanced natural language parsing and information retrieval techniques were combined to design new digital support for human creative thinking in an environment with little digital expertise and resources.

The next sections of the paper report related work and the current risk resolution process in use in the CNH Industrial plant. Subsequent sections describe the creative risk resolution process that was developed for use by plant employees, the digital solution implemented to support employees to undertake the process, and early results from pilot use in the plant of the process and digital support. The paper ends with first lessons for the uptake of creativity techniques and digital support tools outside of the creative industries.

RELATED WORK

Most research to develop digital support for human creativity has been undertaken in industries in which people receive creative skills and training. Examples of industries for which research was undertaken in the last ACM Creativity and Cognition conference include the performing arts, music, and film and television. However, beyond the creative industries, creativity support research has been limited. The science and engineering domains have been a focus of limited digital support, for example with new tabletop visualizations to support biological discoveries [26], social media to support collaborative creativity in education [3] and integrations of creativity techniques into complex engineering processes [8]. Moreover, although business activities have been a common target for creativity and innovation research, most has sought to support human creativity through new problem solving methods (e.g. [12]), techniques (e.g. [17]) and creative collaboration spaces (e.g. 7]).

Healthcare is one domain that has been the target of creativity research. Creativity is often treated as an important precondition for technology innovation, for example to develop new medical devices [6] and assist stroke patients [5]. Some researchers have also made the case to treat healthcare as creative work, for example to encourage creative problem solving by nursing administrators who set the tone in a work unit, and how others undertake creative work [2]. Houts et al. [11] proposed a prescriptive creative problem-solving model to help family carers deliver care to people with chronic diseases discharged from hospital. The model was tailored to the healthcare domain from the Osborn-Parnes creative problem-solving model [19], and distinguished situations in which creative problem solving could be used from situations in which advice needed to be sought from experts. More recently, care for older people with dementia has been framed as creative work, and new creativity support technologies have been developed for use by carers, and shown to be effective in care settings [15]. Digital support tools have also been produced to support medical volunteers to think creatively to resolve non-routine medical work during emergencies.

However, in general, little research to develop digital support for human creativity outside of the creative industries has taken place, and we are unaware of applications of creativity research to improve health-and-safety work.

RISK RESOLUTION IN MANUFACTURING

CNH Industrial employs more than 71,000 people in 62 manufacturing plants worldwide. Each of CNH Industrial's brands focuses on one industrial sector, for example *Iveco* on commercial vehicles, H*euliez Bus* on buses, and the focus of this paper, *Case IH*, *New Holland Agriculture* and *Steyr* on tractors. The CNH Industrial plant east of London covers 40 hectares, employs 1,000 people and produces 133 different models of 20,000 tractors per year in the 110-270 horsepower range with 10,000 possible machine configurations at a rate of 1 every 4 minutes. Given the nature of this manufacturing process and its products, the plant treats the health and safety of all of its employees with the utmost importance – it is OHSAS 18001-certified, recorded zero non-conformities in the 2014 audit, and leads safety culture change using world-class manufacturing techniques.

The plant's existing risk detection and resolution processes are primarily paper-based and driven by levels of perceived risk. Whenever an employee encounters a serious incident or near-miss, s/he reports it verbally to an occupational health representative who uses the information to complete a *Safety Emergency Work Order* form that structures information about the incident or risk with 6 headings – *what*, *when*, *where*, *who*, *which* and *how* – and a human body chart. An example of this form is shown on the left of Figure 1. The representative emails the completed form to the relevant team leader who completes it using a predefined classification of root causes for the incident, suggests the implementation of corrective actions, and submits it to the plant and health-and-safety managers for approval. If serious injuries occur, these are reported to the enforcing Health and Safety Executive via the UK's National Incident Centre, and a member of the plant's health-and-safety team then initiates an investigation to discover root causes for the incident, analyze resolutions that can prevent reoccurrence and review procedures related to the occurrence of the incident. Each implemented resolution to the risk is then documented on the action part of the *Safety Emergency Work Order* form, copies of which are printed and posted on health-and-safety noticeboards. In contrast, whenever an unsafe act or condition is encountered, the employee who discovers it completes the *Unsafe Act and Condition* paper form and places it in one of the return boxes placed around the plant. An example of this form is shown on the right of Figure 1. A member of the health-and-safety team then collects all completed forms from the boxes, reviews them and transfers the form content using a desktop computer to a *Sharepoint* database used to assign individual incidents to managers or team leaders, and on a *MS-Excel* spreadsheet that is used for further data collection and trends analysis.

This current risk detection and resolution process implements systematic processes that place a strong emphasis on root cause analytic and structured techniques to discover the immediate, underlying and root causes of a risk. These analytic techniques, although fit for purpose, provide little scope or support for creative thinking. Furthermore, the current process offers little support for sharing effective risk resolution practices between CNH Industrial plants. Most risk resolution information is shared within a plant by printing and placing it on health-and-safety notice boards such as the one in Figure 2.

Figure 1. Two forms from the current health-and-safety procedures in the plant – the Safety Emergency Work Order form (left) and Unsafe Act and Condition form (right)

Figure 2. A typical noticeboard for sharing risk resolution information amongst plant employees

In contrast, the plant management anticipated that new digital technologies could not only increase employee engagement in the risk resolution process, but also increase cross-plant communication and creative collaboration and provide more effective management oversight of the process. Therefore, new research was undertaken to enhance the plant's process with creativity support for risk detection and resolution, and to design and implement a new form of digital support for human creativity as part of the process. The next sections describe the enhanced process and the digital support that was implemented.

CREATIVITY SUPPORT FOR RISK RESOLUTION

The plant's manufacturing process imposed significant constraints on our extension to the risk detection and resolution process with creativity support. It involved employees who work on the production lines in shifts and cannot stop their work on demand to undertake creative tasks. Moreover, due to shift rotations, even pre-planned time to participate in the process was limited to a maximum of 30 minutes per risk. In addition, most employees had little or no experience of using creativity techniques, the nature of most manufacturing work was repetitive and did not foster creative thinking, and the focus on the continuous manufacture of tractors generated a culture that was solution-oriented. This context, very different to most creative industries, provided several challenging constraints on our development of effective new creativity support for risk resolution. The digital support needed to be simple to learn and to use, not consume too much worker time, and deliver one or more candidate resolutions that could be implemented by the end of the process.

In response to these constraints a simple *diverge-converge* creative process to risk detection and resolution was developed and provided as input to a user-centred design process that was undertaken by a small design team with stakeholders including the plant manager, health-and-safety captains and health-and-safety supervisor. At the start of the process the designers observed the plant's risk detection and recording process and analyzed its paper-based and digital information artefacts, an analysis which led to the identification of a set of bottlenecks and potential barriers to creative thinking in the process. The designers, health-and-safety supervisor and some captains then collaborated in a simple co-design process to determine possible different digital interventions during risk detection and resolution processes that would be made using mobile devices available on the plant floor and desktop computers in offices. They redesigned the process to remove duplicate information about risks, replace paper-based information flows with email document exchanges, and generate a new online risk repository to store these digital documents. Once these architecture decisions had been made, a series of increasingly sophisticated prototypes of a new software application were developed and made available for formative evaluation by stakeholders. First versions of the prototype were demonstrated to the stakeholders for feedback in controlled settings, then later versions were made available to stakeholders for trial use in the plant over a period of week, to enable thorough testing and refinement through report-back sessions with the designers. The outcome of this user-centred design process was a functioning, usable and robust software application to provide support for creative thinking during risk detection and resolution processes.

The input to each instance of the new *diverge-converge* process using the application was a detected and documented risk, and the anticipated outputs were one or more resolutions to the risk that one or more members of a team composed to resolve the risk would consider novel and useful [23]. Each instance of the process was planned to last for no more than 20 minutes. To *diverge* from an input risk to generate new ideas with which to resolve it, a team uses 2 creativity techniques. The first is the S*uperhero* technique [17], with which the team selects one well-known superhero at a time, then applies the superpowers of that hero to generate new ideas about how the risk can be resolved. Each team is guided through this process with a predefined set of well-known superheroes and their special powers. The second technique is the *Seen-it-before* creativity technique. The team is encouraged to review similar previous risks that have been resolved, and to generate new ideas about how to resolve the current risk from resolutions to the previous risks. Then, to *converge* from the set of new ideas about how to resolve the risk to one resolution to implement, each team uses a third creativity technique that is a variation on the *TRIZ* method [1] adapted to the manufacturing plant environment. The technique, called *Creative Clues*, defines a set of desirable characteristics and qualities of novel risk resolutions to risks. The team selects one clue at a time and seeks to generate and evolve new ideas into risk resolutions with the stated characteristic or quality. The resulting risk resolution is documented in the existing plant forms as part of the wider health-and-safety management procedures. The overall process, and its fit within this health-and-safety management process, is depicted graphically in Figure 3.

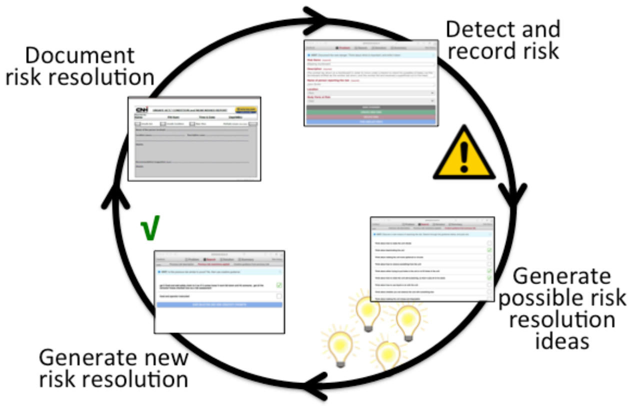

Figure 3. The new diverge-converge creative process for risk detection and resolution that was implemented in the plant

As part of the user-centred design process, a paper-based version of this creative risk resolution process was piloted in 2 one-hour training sessions at the CNH Industrial plant attended by a total of 18 team leaders and health-and-safety captains. During each session, researchers introduced the process and examples of creative problem solving in practice, then presented a previous serious incident in which a worker received a superficial cut to the head when a duckboard, which he sat on in order to view the underside of a tractor to check for oil leaks, moved unexpectedly. The team leaders and health-and-safety captains were divided into teams of 3 and asked to generate new resolutions to the risk using the new process. In the *diverge* phase each team spent 15 minutes generating new ideas using the *Superheroes* technique supported by visual images of 12 superheroes. In the converge phase each team spent a further 10 minutes evolving the new ideas into a resolution to the risk using a small number of *Creative Clue* cards such as *place one object inside of another*.

The plant management deemed the training sessions a success – all team leaders and health-and-safety captains were able to use the techniques with limited training in a short period of time. Most of the teams identified the potential benefits of the use of these techniques to resolve risks, and most of the teams generated risk resolutions that were noticeably different to the original resolution that was applied. For example, the use of the *Superhero* technique generated ideas such as *raising the tractor in the air to avoid the need to lie down* (superhuman strength), *sensor devices beneath the tractor to automate the current manual check* (x-ray vision), and *coloring the oil so that it can be seen without going under the tractor* (radioactive man). Likewise, use of the *Creative Clues* technique guided the teams to generate resolutions to the risk such as *having workers wear hats during inspections* (from the desirable characteristic of having one object inside another) and *mixing oil with other liquids to make it more visible* (from the desirable characteristic of mixing elements with liquid or air).

DIGITAL SUPPORT FOR CREATIVE RISK RESOLUTION

The user-centred design process sought to address 2 overarching challenges to develop effective digital support for risk resolution. The first was to determine an effective means with which to deliver digital technologies to replace and enhance the paper-based risk recording on the production line. Desktop computers in fixed locations throughout the plant were rejected in favor of more mobile tablet computing devices that workers could take to the incident site and complete an online risk description form, equivalent to the previous *Safety Emergency Work Order* and *Unsafe Act and Condition* forms. The second was to determine how to implement effective digital support for each creativity technique in an environment with limited digital expertise and no additional resource for knowledge management. To overcome this challenge we decided that each component of the digital support would need to be either a predefined software component that will not require plant resources to be managed or a software component that can automatically process the language of employee communication in the risk detection and resolution process – written natural language English.

Therefore, to implement the digital support for the *Superheroes* technique, the user-centred design process extended an existing web application called *Bright Sparks* [14]. The *Bright Sparks* application is a digital implementation of the *Hall of Fame* creativity technique [17] that retrieves information about well-known personas from the Internet and presents it to users to stimulate creative thinking about a problem. To extend it to support CNH Industrial's creative risk resolution process, the researchers implemented a version that did not require management by the plant and presents information about superheroes and guides users to generate new ideas based on the superpowers of each. An example of use of *Bright Sparks* is shown in Figure 4.

To implement the digital support for the *Seen-it-before* creativity technique, the user-centred design process resulted in a new web application called *Risk Hunting* to exploit the one digital resource already available in the plant – the natural language data that had been digitally recorded about 5000+ detected and resolved risks in CNH Industrial's existing *Sharepoint* database. The application was implemented with a set of computational mechanisms developed to make sense of, match and generate new creative content from the unmanaged natural language resource to present to employees to encourage creative thinking about resolutions to a current risk. And to implement the digital support for the *Creative Clues* technique, researchers codified the set of desirable characteristics and qualities of novel resolutions to risks so that employees using the *Risk Hunting* application receive automatically generated creative ideas that are both possible resolutions to the risk and guidance to discover the risk resolution.

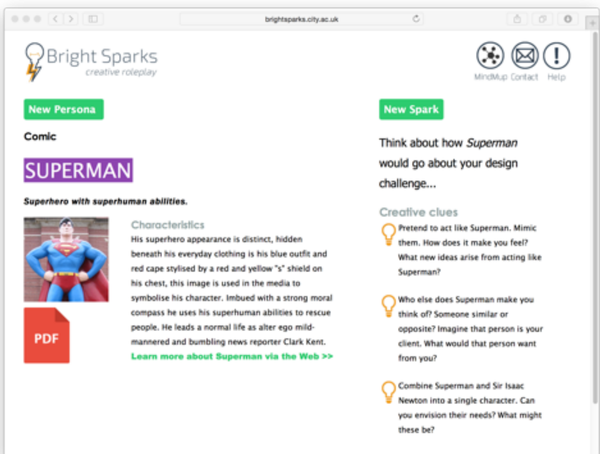

Figure 4. Digital support for the Superheroes technique with the Bright Sparks application

The *Risk Hunting* Application

The *Risk Hunting* application was developed for use by health-and-safety teams in creative sessions lasting a maximum of 20 minutes. It was implemented with the 4 software components: (1) a front-end web application that employees interact with to describe a risk, receive creative guidance to resolve the risk and document new resolution ideas; (2) a digital repository of descriptions of previous risk-resolution cases; (3) a computational software service that automates the *Seen-it-before* technique to discover and retrieve creatively similar risks and their resolutions; and (4) a computational software service that automates the *Creative clues* technique to generate clues automatically from descriptions of detected risks and retrieved risk resolutions. One further component implements the *Bright Sparks* application as part of the *Risk Hunting* application, but it is not reported further in this paper.

The application was developed to support human-centred creative cognition [13], an activity in which idea generation takes place concurrently with information finding. The application supports members of a health-and-safety team to search for and generate ideas in the 3 search spaces depicted graphically in Figure 5. The first search space is formed by the 8000+ previous risk-resolution cases described in the digital repository, and the creative search service searches this space of cases automatically to discover similar risk-resolution cases as part of the implementation of the *Seen-it-before* technique. The second space is the search space of possible new risk resolutions to be generated from each retrieved resolution. The application guides members of the health-and-safety team to undertake exploratory creativity to generate new ideas through information finding in this space. The third space is the search space of new risk resolutions that result from the combination of previous risk resolutions and the desirable qualities and characteristics of resolutions to risks in manufacturing plants codified in the *Creative Clues* technique. The creative clue generation service searches this space automatically in order to generate possible risk resolutions that the application presents to the team members to guide their idea generation process. As such, members of the health-and-safety team are directed to undertake a guided creative cognition activity through the search of 3 different search spaces in order to find relevant information and discover and generate new risk resolution ideas from it.

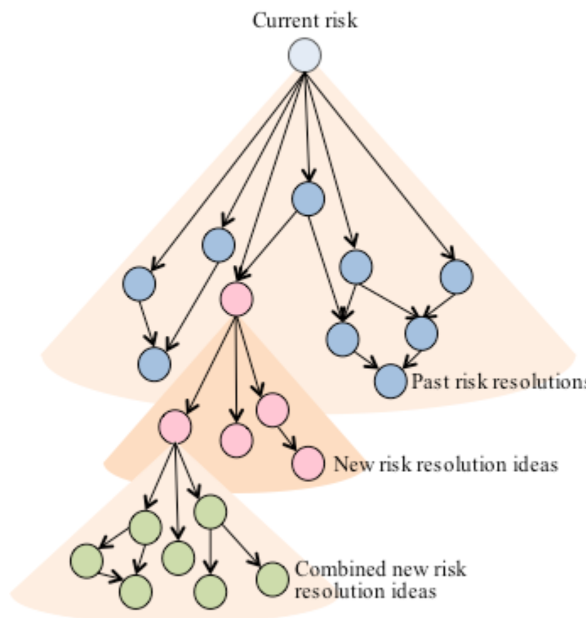

Figure 5. The spaces of previous risk-resolutions and resolution ideas that creative search strategies support navigation of

The front-end web application supports this human-centred creative cognition by accepting unrestricted natural language input and tick-box selections from plant employees. More visual interactions were rejected in order to ensure the application use by the widest range of employees. At the start of a new risk resolution session, one or more team members enter key information about the detected risk – a risk description, location and risk to different human parts – into the application that is extracted from the *Safe Emergency Work Order* or *Unsafe Act and Condition* forms. Each risk is described using unstructured natural language – it does not require explicit tagging with predefined terms – constraints that might inhibit the required creative flow during the session. Use of the application to document information about the moving duckboard risk, reported earlier in the paper is shown in Figure 6. As well saving or editing this new risk description, the team members can request the application to find similar risks.

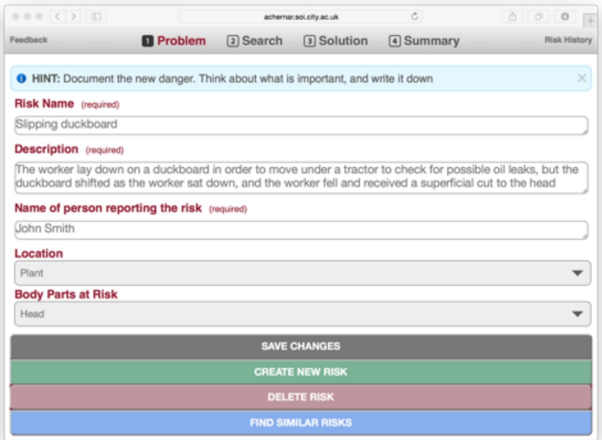

Figure 6. Entering a natural language new risk description into the *Risk Hunting* application.

The team members then browse simple descriptions of previous recorded risks that are retrieved by the application as similar to the detected risk and select one or more to review further. For each retrieved risk, the team members can review the original resolution(s) that were applied successfully to resolve the risk and request creative clues that the application generates automatically from retrieved information about risk resolutions. Examples of retrieved previously-resolved risks shown on the left of Figure 7 include an *oil leak from a tractor unit*, *an extractor fan that fell from its mounting*, and *an extruding object such as a bar axle*. Some creative clues to resolve the current risk based on the previous risk resolution related to an *extractor unit* shown on the right of Figure 6 include *think about deactivating the unit*, *think about either trying to put holes in the unit or to fill holes in the unit*, and *think about how to make the unit self-sustaining, so that it uses all of its waste*. The team members can also request the application to generate creative clues from information that the team members enter directly about the detected risk. Examples of the creative clues that the application generates for the current risk example in the bottom right of Figure 7 include *think about if it is possible to regenerate the leaks*, *think about whether you can balance the worker with something else*, and *think about doing the opposite of what is expected with the leaks*.

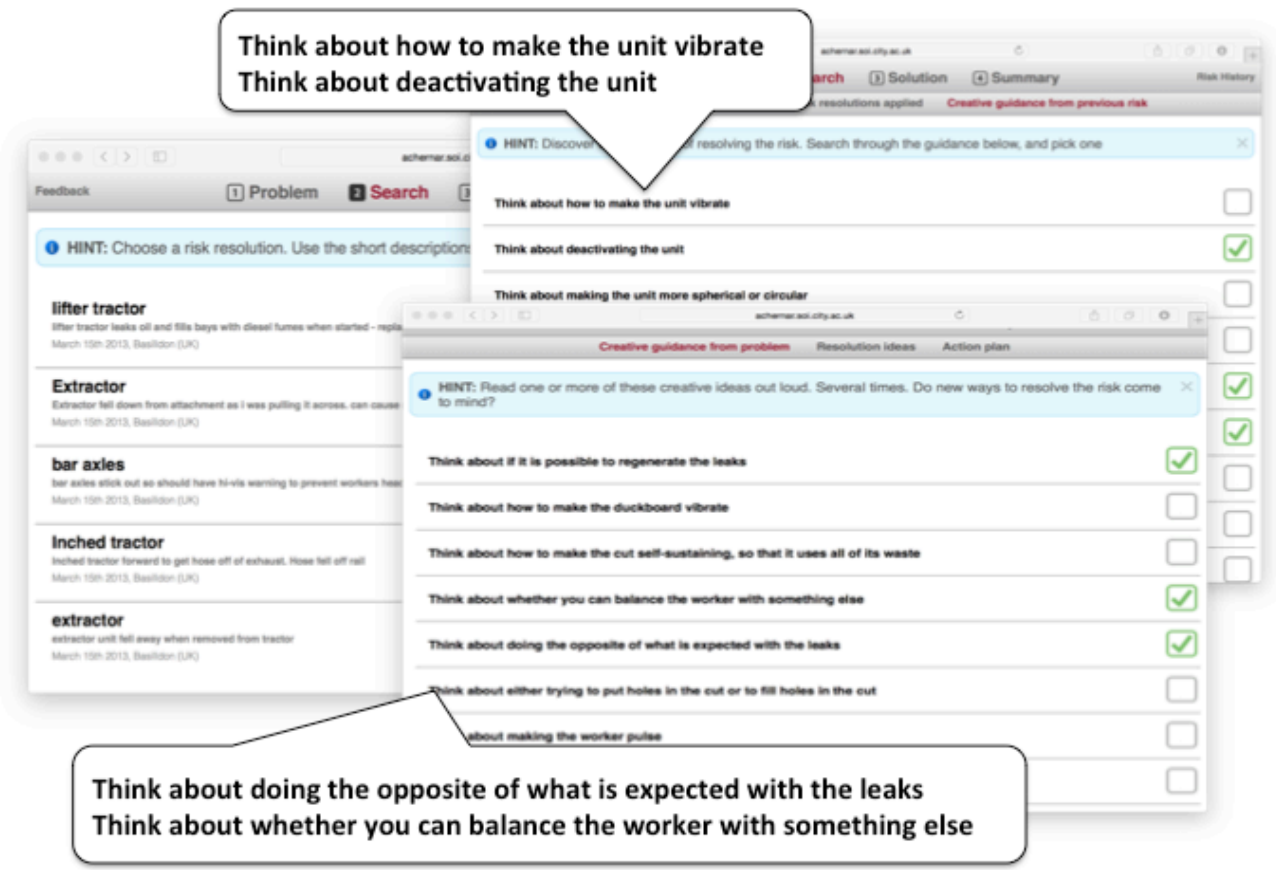

Figure 7. Creative guidance for resolving a risk based on computationally generated creative clues from selected previous risk cases and the current risk information

The team members might use these clues to generate ideas such as seeking to replicate and discover oil leaks with specialist equipment in order to detect risks, develop a mechanism that takes the worker's weight and support them to spot oil leaks in relative safety, and in response to doing the opposite of what is expected, postpone the detection of oil leaks until a later, more effective stage in the production process.

The Digital Repository of Risk Resolutions

The digital repository is implemented using eXist, an open source native XML database featuring index-based XQuery processing that the creative search service queries using XQuery, a query language designed for processing XML data. It stores natural language descriptions of previous risks and their resolutions in XML based on the structure of CNH Industrial's *Sharepoint* database of risks. The current version of the digital repository implemented in the plant maintains a record of more than 8000 detected risks and their resolutions. Each risk-resolution case and its attributes are specified in 3 parts. The first part describes the detected risk and specifies attributes such as a natural language description of the risk situation, employee body parts that were at risk, and details of the location of the risk. The second part describes the resolutions that were applied successfully to resolve the risk, and specifies attributes such as corrective actions and future recommendations. The third part describes all other information about the risk-resolution and specifies a larger number of attributes that include the incident short code and persons involved in the incident. As reported earlier, no ontology or tags are specified to provide semantic information about each case.

The Creative Search Service

The service was implemented to discover and retrieve risks and their resolutions that are similar to the current risk. To do this it implements 3 different creative search strategies to generate new content about: (1) objects or actions described in the new risk description, for example new resolutions associated to objects such as the *duckboard* or actions such as *slipping*; (2) the wider classes of object or action described in the risk description, for example all classes of action in which someone or something falls over, and; (3) objects and actions that are indirectly associated with the original risk description, for example about *accidents*, an event that is indirectly related to the action *slipping*. The creative search service was developed to use natural language parsing and information retrieval techniques. It automatically disambiguates each term in an entered risk description with its most probable meaning, then extends queries generated from the risk description with additional terms based on the disambiguated meanings that implement each of the above creative strategies to match to terms in previous risk-resolution cases [27]. These creative search service capabilities are implemented in 4 software components shown in Figure 8.

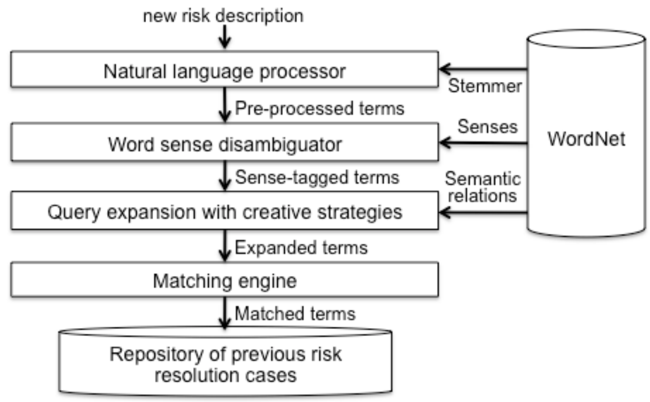

Figure 8. The algorithm of the Creative Search Service

In the first component the detected risk description is divided into sentences then tokenized, part-of-speech tagged and modified to include each term's morphological root (e.g. *shifted* to *shift*, *leaks* to *leak*) using the Brill Tagger [4]. In the second component the service applies increasingly sophisticated procedures to disambiguate each term by discovering its correct sense and tagging each term with that sense using context knowledge from other terms in the query (e.g. defining a *leak* to be *an accidental hole that allows something (fluid or light etc.) to enter or escape* rather than *unauthorized (especially deliberate) disclosure of confidential information*). In the third the service implements the creative search strategies by expanding each term with other terms that have similar meaning according to the tagged sense to discover previous risk-resolution cases with different forms of similarity to the input risk description (e.g. the term *leak* is synonymous with the terms *opening, gap and space* which are then also included in the query based on the creative strategy). In the fourth the service matches all expanded and sense-tagged query terms to a similar set of terms that describe each case in the repository in 2 steps: (1) XQuery text-searching functions to discover an initial set of case problem descriptions that satisfy global search constraints, and; (2) traditional vector-space model information retrieval, enhanced with *WordNet*, to refine and assess the quality of the candidate risk-resolution case set. WordNet is an on-line lexical database based on psycholinguistic theories of human lexical memory [22] that divides the lexicon into nouns, verbs, adjectives and adverbs. The meanings of words, called senses, for each are organized into synonym sets, or synsets for short, which represent concepts, and each synset is followed by its definition or gloss that contains a defining phrase, an optional comment and one or more examples. Senses are also structured using semantic relations between them to link concepts.

As such, the creative search service uses *WordNet* word sense and definition data to generate and direct creative searches. Expansion of a query with new terms that are semantically different to the original terms will enlarge the search space of risk-resolution cases compared with expansion of the query with new terms that are semantically more similar. Each strategy was designed to generate new content about an object or action described in the new risk description, the wider class of object or action that is described in the risk description, or about objects and actions indirectly associated with the original risk description. To implement these directions, the service uses different types of ontological information from *WordNet* to discover semantically related terms to each term:

1. *Synset expansion*: each original term is replaced with its synset, for example the term *shift* is replaced with its synset for sense #2 [*shift, dislodge, reposition*]. As such, the strategy expands the query to retrieve then generate new content about each object or action described in the new risk description using synsets;
2. *Hypernym expansion*: each original term is augmented by its WordNet direct hypernym, for example the hypernym of *leak* is *hole* so the revised query includes both terms. This strategy expands the query to retrieve then generate new content related to the classes of each object or action described in the new risk description using hypernyms;
3. *Gloss words expansion*: each term is augmented with all of the terms in its gloss *specified in WordNet*. For example the sense#1 definition of the term *leak* is *an accidental hole that allows something (fluid or light etc) to enter or escape.* Hence the terms *hole, fluid, light, enter* and *escape* are extracted and included in the extended query. This strategy expands the query to retrieve then generate new content related to each object or action using the gloss definitions from *WordNet*.

The resulting query of expanded terms is transformed into a XQuery that is fired at the equivalent risks resolved previously described in the digital repository. At the end of each invocation, the service returns an ordered set of the descriptions of the five highest-scoring cases that are presented to the employees, as shown on the left of Figure 7.

The Creative Clue Generation Service

The creative clues technique is implemented as also shown in Figure 7 using a second computational service that automatically generates instances of creative clues based on the TRIZ method [1] with names of objects extracted from descriptions of detected risks and retrieved risk resolutions. The set of classes of creative clues was selected from a wider set of qualities and characteristics associated with creative outcomes developed as part of the TRIZ [1] creative method. A total of 85 different classes were selected according to the relevance and feasibility of its quality and characteristic in the pilot CNH Industrial plant, then ranked by the paper's authors for its perceived usefulness to creative thinking about risk resolutions, and based on this ranking, a multiplier was attributed to that class to increase its presence in the creative clues that are generated by the service at run-time. A subset of the creative clue classes and their multipliers are listed in Table 1 to demonstrate the range and different forms of the classes. Some of the classes are specified to generate creative clue instances about mechanical objects named in risk and resolution descriptions, others about the actions and behaviours named in these risk and resolution descriptions. The service will, on average, generate an instance creative clue to think about dividing a mechanical object up 9 times more frequently than it will generate one about putting the mechanical object in a vacuum.

To generate each creative clue presented by the Risk *Hunting* application, the service also parses the natural language descriptions of the risk and resolution descriptions to extract (1) *objects* in the forms of nouns and proper place names; and (2) *activities* in the form of verb phrases determining the active verbs and all text through to the next punctuation/conjunction word. To do this, the service's algorithm splits the text into sentences and applies a part-of-speech tagging process to mark up words in each sentence as belonging to each lexical, part-of-speech category using information about both its definition and its context in the text. The algorithm then applies a natural language processing technique called *shallow parsing* that was developed to generate machine understanding of the structure of a sentence without parsing it fully into a parsed tree form. The output of this shallow-parsing process is a division of the text's sentences into a series of words that, together, constitute a grammatical unit. Finally, to select candidate objects and actions from these grammatical units, the algorithm applies lexical extraction heuristics on a syntax structure rule-tagged sentence to extract content words relevant for the generation of one or more objects. Returning to our example, the service returns the following objects: *worker; walkway; leak; engine,* and one activity: *slip on a walkway due to a small oil leak from an engine.* The service uses these identified objects and activity to automatically generate creative clues.

Creative clue class	Multiplier
Think about dividing the [mechanical-object] up	9
Think about how to make the [mechanical-object] move and adjust	8
Think about how to introduce feedback to the [action] action	7
Think about whether it is possible to make the [mechanical-object] an irregular shape	5
Think about how to continue to [action], rather than stopping the action	4
Think about putting the [mechanical-object] in a vacuum	1

Table 1. Example creative clue classes and their attributed multipliers for creative clue generation

DEPLOYMENT AND EARLY EVALUATION OF *THE RISK HUNTING* APPLICATION

The described version of the *Risk Hunting* application was deployed for 4 months in the tractor plant to enable its formative and summative evaluations by the health-and-safety team, primarily using mobile tablet devices as depicted in Figure 9. Early summative evaluation results have revealed both successful application use and some barriers to its widespread uptake in the plant. Both are reported here.

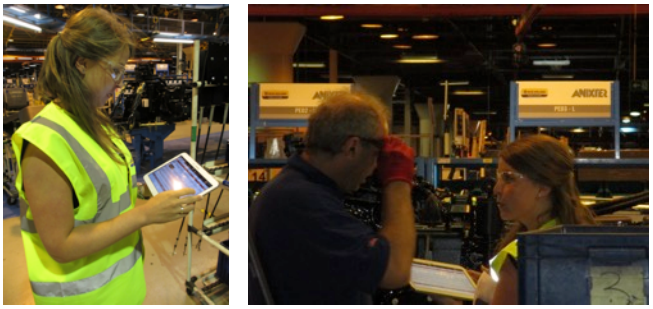

Figure 9. Use of the *Risk Hunting* application on mobile tablet devices in the tractor plant

Analysis of the data collected about application use over the first 21 working days of the summative evaluation reported in Table 2 revealed that team members using the application documented, on average, more than 2 new risks per day. Moreover, on average for each new risk, the team used the application to retrieve and select 4 different previous risks, selected 5 creative clues and document just over 2 new ideas with which to resolve each risk. The 6 health-and-safety captains and 2 supervisors documented most of these risks, while some production line supervisors accounted for the remaining documented risks.

Total numbers of …				
new risks described	retrieved risks browsed	creative clues viewed	superheroes explored	resolution ideas generated
46	180	210	67	98

Table 2. Totals of use of different Risk Hunting application features over first 21 working days of summative evaluation

Some of the 46 resolved risks documented in the application revealed evidence of possible creative thinking. Two examples are presented in Table 3. The first reported the danger from boxes that might fall due a forklift truck driver placing them in the wrong place, and the documented resolution revealed some evidence of transformational creativity – rather than just have the boxes stocked correctly, use of the selected creative clues led to a resolution that proposed to rethink the space in which the boxes are stored.

Risk	Risk description	Risk resolution
1	Boxes from prop shaft kitting area have been stocked by the flt driver outside of the designated lines, so therefore overhang into agv buggy route location e8.	Make the boxes move and adjust-area needs to be moved around to insure all boxes are situated within the lines.
2	Risk of being struck by falling object.	Clear driveline of any excess parts prior transit to pedline.

Table 3. Two examples risks and their resolutions documented in the *Risk Hunting* application

However, other risks were given simple resolutions that revealed little or no evidence of creative thinking. For example the second risk in Table 3 reports a simple risk and resolution to avoid the risk of being struck by falling objects. One reason given for such simple risk resolutions was that not all risks required creative thinking to resolve them – some risks had effective and known resolutions.

Furthermore, focus groups with members of the health-and-safety team revealed several barriers to use of the application as intended. As well as a small number of application usability problems to be overcome with small software redesigns and additional user training, these focus groups revealed that the teams considered that 20 minutes was too much time to find to think creatively and collaboratively about discovered risks. Therefore, to overcome this barrier, we redesigned the plant's roles and workflow to encourage active involvement of new creativity champions who users will be able to approach to encourage creative thinking with the application during the resolution of a new risk. A second change will be the running of 1-hour creative risk resolution sessions, once a fortnight to review risks documented and resolved in that fortnight, that can be resolved more effectively – the team of health-and-safety captains will work collaboratively to re-resolve these risks as needed, to improve the risk resolutions, all using the application.

CONCLUSIONS AND FUTURE WORK

In this paper we argue for and report new digital support for human creative cognition in the management of health-and-safety in a world-class manufacturing plant as a demonstrator for the use of creativity techniques and digital support tools outside of the creative industries. A simple *diverge-converge* creative process that invokes the use of 3 different creativity techniques was developed and piloted in sessions with plant employees. Based on the success of the pilot sessions, new digital support for these creativity techniques was implemented to operate within the constraints of the complex, time-limited manufacturing environment. The *Risk Hunting* application was developed to support human-centred creative cognition through the navigation of 3 different risk resolution search spaces. It provides deliberately simple forms of creativity support based on the outcomes of computational manipulation of untagged natural language descriptions of current and previous risks and their resolutions. The deployment and formative evaluation of the application in the plant has been successful – the employees are able to use the application, although the evaluation has revealed some socio-technical barriers that we are currently addressing through further training development and evolution of the software. A second web application called *Bright Sparks* has been developed to support the use of the superheroes creativity technique in the plant.

Our next stage in this project is to complete the summative evaluation of both applications once lessons from the formative evaluation have been implemented. This evaluation will take place over a minimum of 3 months through the spring and summer of 2015, and involve the rigorous analysis and comparison of the novelty and value of risk resolutions generated in the plant with the existing risk detection and resolution process and the new creative risk resolution process with its digital support. We look forward to reporting this further work in a future publication. In this more technical research paper, we hope that it offers encouragement and guidance to researchers to develop new digital support for human creative thinking in the many disciplines outside of the creative industries that have the potential to benefit from increased creative competences.

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