EVALUATING AN INFORMATION SYSTEM TO PROVIDE CREATIVE GUIDANCE ABOUT HEALTH-AND-SAFETY IN MANUFACTURING

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ABSTRACT

Creativity's importance to organizations and businesses is now recognized to be a precondition for both design and innovation. One strategy is to introduce new forms of information system that support human creative thinking by their employees. Most successful uses have been in professional disciplines in the creative industries such as design and theatre. This paper reports the design and evaluation of a new information system that was researched and developed to support human creativity in a non-creative industry – health-and-safety in a manufacturing plant. An established risk detection and resolution process in one plant was extended with the new system to support plant employees to think creatively about resolutions to health-and-safety risks. The new system was used in a manufacturing plant for over 3 months. Results revealed that a subset of the risk resolutions generated with the new system were more creative and more complete than risk resolutions generated without the system in a corresponding period. However, the employees needed more time than was available to generate more complete risk resolutions. The evaluation results led to coordinated changes to both the information system and work practices associated with it.

1. INTRODUCTION

Creativity is the ability to produce work that is novel and appropriate to the task (Sternberg 1999). Its importance to organizations and businesses has grown in the last 25 years, and is now recognized to be a precondition for the design and innovation of information systems (Cougar et al. 1993, Cooper 2000). Exploiting the creative skills of employees has become critical to the long-term success of creative industries and advanced economies (e.g. Cox 2005). In response, organisations now implement diverse strategies to encourage creative thinking by their employees, from the establishment of innovation labs (e.g. Magadley & Birdi 2009) to uses of design thinking processes (e.g. Dorst 2011).

One alternative strategy suited to the digital era, but not explored by many organizations, has been to introduce new forms of information system that support human creative thinking (e.g. Massetti 1996, Wierenga & van Bruggen 1998, Greene 2002, Fischer et al. 2005, Magallanesa et al. 2018). The more successful of these systems have been characterized by their support for human creative activities such as data and information exploration, idea association, and engagement with content for active learning (Greene 2002). One typical early example was *combinFormation,* a mixed-initiative information system that integrated capabilities for searching, browsing, and exploring information to support creative discovery and learning about problems of the user's choosing (Kerne et al 2008).

However, whilst a small number of successful uses of this new form of information system have been reported, most have been in professional disciplines recognized as creative, such as music, and film and television (Alaoui et al. 2015, Honauer & Hornecker 2015). Examples include *StoryCrate*, a collaborative editing tool developed to drive creative workflow within a location-based television production environment (Bartindale et al. 2013), *Trigger Shift*, which appropriated commercial information technologies into performance art in theatre (Schofield et al. 2013), and *Crowdboard*, which allowed online crowds to provide real-time creative input during early-stage design activities such as brainstorming and concept mapping (Andolina et al. 2017). Information systems have also been developed to support collaborative creative tasks during early design activities (Schnädelbach et al. 2016, Andolina et al. 2017, Chan et al. 2017, Huang & Quinn 2017) and problem solving in research (McNeil et al. 2017). Research has also investigated how existing technologies such as social media platforms afforded collaborative creativity in creative domains (Díez et al. 2014, Lee et al. 2014). By contrast, few information systems support human creativity in non-creative sectors, even though work undertaken in them often seeks to produce results that are novel, useful and surprising (Sternberg 1999, Maher & Fisher 2011). One such sector is health-and-safety management.

Increasing the health and safety of people is an aim of organisations and governments. In the United States, for example, there were 4,500 workplace deaths in 2010, over 250,000 work-related injuries and illnesses in 2011 (OSHA 2014), and in the European Union 2.5 million workplace incidents led to at least 3 person-days off work per capita in 2012 (Eurostat 2014). New legislation and more systematic management systems have improved health and safety, but deaths and injuries continue.

Some organizations have explored creative thinking to complement health-and-safety management. One of these organizations was a global leader in commercial vehicle manufacture. The process for managing health-and-safety in this organization involved all of its employees in the systematic detecting, reporting and resolving of health-and-safety risks. The process was paper-based, and relied on the skills, knowledge and experience of employees to detect, report and, most importantly, contribute to the resolution of risks. To support the organization's employees to think more creatively to resolve risks, the process was extended with a new information system in one of the organization's manufacturing plants.

The remainder of this paper is in 5 sections. Section 2 reviews different definitions of creativity, information systems developed to support creative thinking beyond the creative industries, and risk management techniques and systems. Sections 3 and 4 describe the previous plant's risk resolution process and new *Risk Hunting* system developed to support employee creative thinking about risk resolutions integrated into process. Section 5 reports the method, research questions and results from an evaluation of use of the new system in the plant. The paper ends by drawing conclusions and outlining implications for information systems to support human creativity outside of the creative industries.

2. RELATED WORK

Creativity research has produced many definitions of creativity and creative outcomes. According to Maher & Fisher (2011, p46), most definitions of creativity include novelty as a criterion in creativity assessment, often expressed as a new description, or a new value of a creative product. Kaufman & Beghetto (2009) refine these definitions with 4 different forms of novelty that distinguish between, for example, Big-C creativity that delivers eminent contributions to society, and little-c creativity that is the everyday activities of non-experts that produce novel outcomes that are not often perceived to be creative in society. The new information system evaluated in this paper was designed to support plant employees to generate risk resolutions that were novel and useful in the plant's health-and-safety process, i.e. to deliver little-c creative outcomes in the form of risk resolutions that were novel and valuable to the members of the organization's health-and-safety team, but not necessarily to others.

2.1 Information systems that supported creative thinking beyond the creative industries

Few information systems that support creative thinking beyond the creative industries have been reported. Some systems were developed to support creative thinking in science and engineering, for example in the forms of new tabletop visualizations to support biological discoveries (Wu et al. 2011) and social media to support collaborative creativity in education (Aragon et al. 2009). Businesses often seek to support the creativity of their employees, but most of this support is delivered as methods (e.g. Isaksen et al. 2011), techniques (e.g. (Michalko 2006) and collaboration spaces (e.g. (Doorley & Witthoft 2012) rather than as information systems. The limited creativity support in healthcare also relies on techniques to encourage creative problem solving by nursing administrators (Arbesman & Puccio 2001) and family carers of people with chronic diseases (Houts et al. 2011), with systems limited to the management of distressing behaviours of older people with dementia (Maiden et al. 2013). The manufacturing sector is no different. In manufacturing plants, most creative thinking by employees is supported by more traditional and non-digital techniques such as brainstorming, for example in BMW to improve health awareness on production lines (Loch et al. 2010) and Toyota to engage employees to improve their work environments (Yasuda 1991).

2.2 Human-centred creative cognition

To design the new information system, we adopted Kerne & Smith's (2004) definition of creativity as a process of human-centred creative cognition to frame the research and development of the new *Risk Hunting* system. Human-centred creative cognition is an information discovery process that emphasized idea generation over information finding (Kerne and Smith 2004). It exploits digital search capabilities to discover information and support idea generation. This information discovery process is deliberately iterative – changes in a user's understanding, in response to information that had been discovered, can lead to cognitive representation shifts often associated with insight and ideation (Kerne et al. 2008). In turn, these representation shifts direct the discovery of new information, sometimes in different spaces. It is an information-processing model that describes creativity as the structured and deliberate search for information then ideas to generate (Plsek 1997) – a framing that underpins many of the established and successful creative problem solving processes such as Synectics (Gordon 1960) and Creative Problem Solving (Isaksen et al. 2011).

Many of the reported information-processing models describe creativity as iterations of divergent thinking to generate creative ideas by exploring many possible solutions, and convergent thinking to generate fewer, more complete answers to a problem. Within this framing, Boden distinguishes between exploratory and transformational creativity (Boden 1990). Exploratory creativity assumes a defined space of partial and complete possibilities to explore – a space that also implies the existence of rules that define the space. Changes to these rules produce what might be thought of as a paradigm shift, called transformational creativity. Ideas that are novel and useful are reached in the space by a set of generative rules for divergent thinking and convergent thinking. Boden also identified one specific form of exploratory creativity, called combinational creativity, which is the process of making unfamiliar connections between familiar items in the pre-defined search space (Boden 1990) using a different set of generative rules.

2.3 Information systems that implemented creative search

Some existing information systems for creative thinking searched information in ways that operationalize generative rules and directed humans to discover novel and useful ideas in a space. *Dynamic HomeFinder* was a prototype that used dynamic queries that allow real-estate agents to adjust the cost, number of bedrooms, and locations to explore available house locations on a map more creatively than with traditional queries (Williamson & Shneiderman 1992). *CombinFormation* integrated searching and exploring information to support exploratory and combinational creativity with information retrieved by Internet search engines (Kerne et al. 2008). *TweetBubble* was a browser extension to Twitter that supported exploratory browsing on top of metadata type system with new presentation semantics (Jain et al. 2015). *Carer* was a mobile app that implemented exploratory creative search strategies to retrieve information about good practices for caring for older people with dementia (Maiden et al. 2013). And the *IdeaMâché* system implements freeform web searches to stimulate creative engagement during ideation work using exploratory strategies such as collect, shift perspective and write (Kerne et al. 2017).

Moreover, some information systems for case-based reasoning that retrieve past solutions to solve new but similar problems (Kolodner 1993) also have the potential to support exploratory creative search, and some of these systems were applied successfully to different business challenges. For example, the *PwC Connection Machine* managed and supported experience exchange in a professional services firm (Goker et al. 2006), although no evidence of creative outcomes was reported. Analogies from biological system have been applied to engineering design (Goel et al. 2011). The AntiQUE system, which searched service designs from non-automotive domains, supported creative thinking in automotive engineering (Zachos & Maiden 2008). Although short evaluations revealed the potential of these systems to support the creative thinking of professionals, no longer continuous evaluation of these systems have been reported.

2.4 Risk management techniques and systems

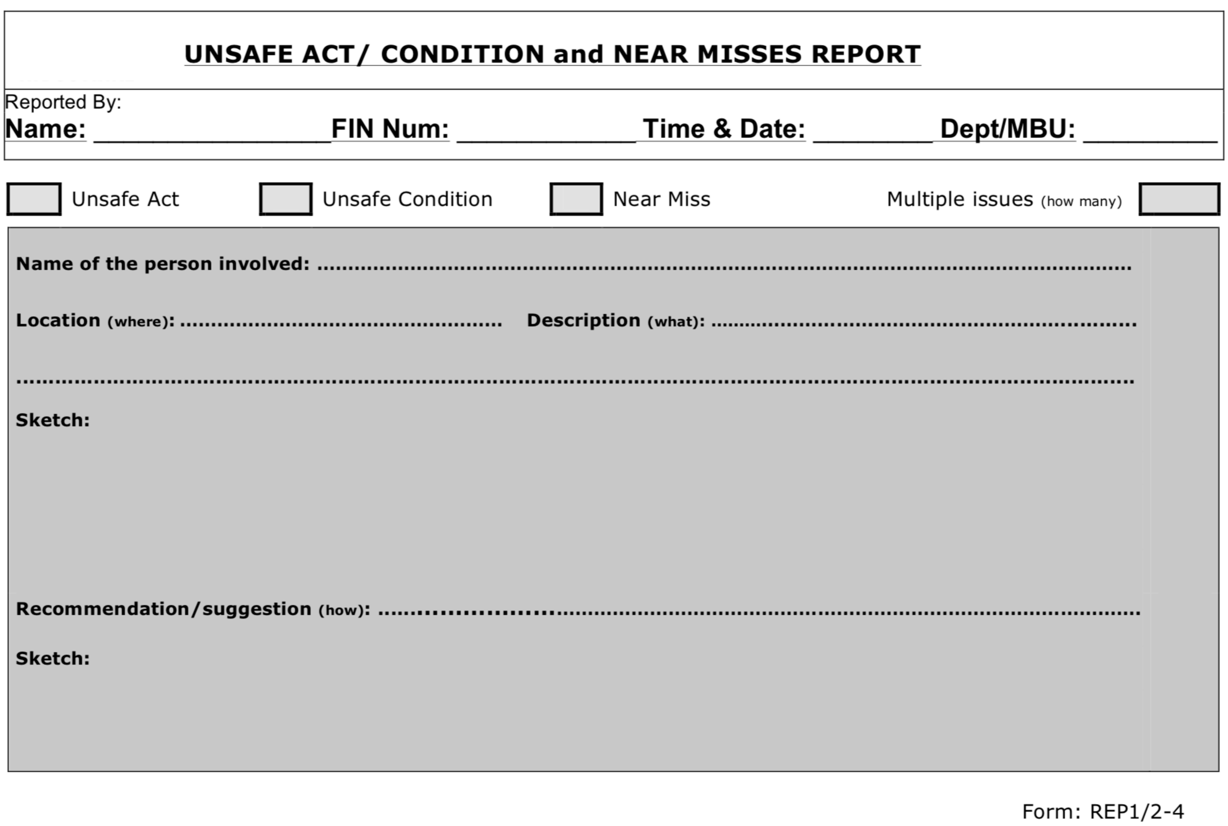
Most reported health-and-safety management techniques support systematic analyses to guide people to discover the immediate and underlying root causes of a risk. Diagramming techniques such as the Ishikawa or fishbone diagram have been used to discover underlying causes (e.g. Ishikawa 1976), for example through analysis of different types of cause such as environment, personnel and machines. However, although fit for purpose, these techniques do not provide explicit support for creative thinking. Likewise, few information systems provide intelligent support for health-and-safety, and most were limited to information management support for risk identification, analysis and assessment. For example, the *cr360* system, which logged health-and-safety incidents for reviews, was used successfully to migrate 5 years of Nestlé's health-and-safety data and made available at 1,400 facilities in 100 countries as part of the organization's commitment to health-and-safety management systems (Nestle 2018). However, no health-and-safety management systems that provide explicit creativity support to employees to resolve encountered risks have been reported.

3. RESOLVING RISKS AT A COMMERCIAL VEHICLE MANUFACTURER

The related work revealed few information systems outside of creative industries that supported human creative thinking. Therefore, when a research opportunity with the global manufacturer of commercial vehicles arose, it enabled the authors to design, develop and evaluate a new system of this form to support risk management in health-and-safety as a research intervention in a non-creative sector. The remainder of the paper describes the new information system, how it was adopted in the work environment, and the effect of its use on risk management in the plant over a 3-month period.

The organization employed over 70,000 people worldwide in their manufacturing plants. Its plant in the United Kingdom covered 40 hectares, employed 1,000 people and produced 20,000 agricultural vehicles each year on multiple different production lines at a rate of 1 every 4 minutes.

Prior to the research intervention, the plant's established risk detecting, reporting and resolving process was paper-based. Whenever an unsafe act or condition was encountered, the employee who discovered it completed the A6 paper form shown in Figure 1, which employees often kept blank copies of on their persons during shifts to facilitate risk recording. The employee was required to use the form to write the risk location and description, sketch the risk, then to write the risk resolution in the space underneath. The form size – just 105x148mm – offered limited space to describe each risk and possible resolution to it.


UNSAFE ACT/ CONDITION and NEAR MISSES REPORT

Reported By:
Name: ________________ **FIN Num:** ____________ **Time & Date:** ________ **Dept/MBU:** _________

☐ Unsafe Act ☐ Unsafe Condition ☐ Near Miss Multiple issues (how many) ☐

Name of the person involved: ....

Location (where): .... **Description** (what): ....

....

Sketch:

Recommendation/suggestion (how): ....

Sketch:

Form: REP1/2-4

Figure 1. The plant's existing unsafe act/condition A6-size form, used to document unsafe acts and conditions in the plant's health-and-safety procedures prior to the research intervention

Periodically, a member of the health-and-safety team collected all completed forms from different locations around the plant, then used a desktop computer to transfer information from the forms to a *Sharepoint* database, and assigned each incident to a manager or team leader to develop and apply a resolution. Once the manager or team leader had investigated and resolved the risk, the form was updated with the applied resolution. If serious injuries were possible or occurred, additional forms were completed and communicated to both the UK's Health and Safety Executive and to the plant's health-and-safety team, to initiate an investigation to discover the risk's root causes and to analyze resolutions.

Communication of the applied risk resolutions to employees was simple – after the successful resolution of a risk or incident, the health-and-safety team updated each form, generated A4 photocopies of it, and placed the photocopies on physical noticeboards situated across the plant.

However, the plant's management team identified that this current process was slow and often resulted in the same types of resolution being recommended for different types of risk, most of the time in the form of short and incomplete descriptions. Typical types of resolution included only asking someone else to investigate, for example:

```
ask maintenance to inspect
```

in response to the risk:

```
wear strips falling from monorail
```

and recommending only to do the opposite of the risk, for example:

```
no parts to be left on driveline
```

in response to the risk:

```
metal bar left on driveline from medical line - fell off when about to do my
job.
```

Neither type of resolution was judged sufficient by the plant's health-and-safety management team to resolve sufficient numbers of risks effectively and in good time. The team suspected different reasons for this. These reasons included a lack of sufficient engagement by plant employees with the risk resolution process, too much focus on exploring the causes of the risk, and insufficient support for recording more complete risk resolutions. Therefore, the team sought to empower the employees to participate more in creative thinking about risk resolutions. It requested a new information system to support employees to report and resolve risk resolutions with creative thinking.

4. *RISK HUNTING*: A NEW INFORMATION SYSTEM TO SUPPORT RISK RESOLUTION

A user-centred design process with plant employees, which was reported in (Zachos et al. 2015), generated the new information system, called the *Risk Hunting* system, for individual employees to use to resolve risks prior to the involvement of managers and team leaders. The system supported concurrent information finding and idea generation (Kerne et al. 2008) with 3 different types of creative guidance. It had interactive features with which to explore information to discover new ideas to resolve a risk, compose ideas into a resolution, and share the resolution with plant employees. The interactive digital forms were designed to be as simple or simpler to use than the paper forms that the system replaced. The system was designed be used in-situ on the production lines with mobile tablet devices that employees could take to the risk site.

Furthermore, the plant aso required that employees used the *Risk Hunting* system to record and resolve a risk within a time constraint – just 5 minutes – due to the speed of progress of the production lines and not to stop any production line unnecessarily. This constraint on the use of the *Risk Hunting* system – to support creative thinking within a very short timeframe – was a new challenge not reported for other information systems that supported creative thinking.

The *Risk Hunting* system was optimized to run on the Samsung Galaxy Tab 3 GT-P5200 tablets available in the plant. When a new risk was detected, an employee entered his/her name and identifier, a freeform text description of the encountered risk, and pull-down menu selections to describe the incident category, the incident location, the parts of the body at risk, the injury type and the date. Figure 2 demonstrates this use of the system to describe a new risk: *Neil was driving a forklift in the garage, but his speed was too high, and he drove off the path. As a consequence, the forklift knocked over a box of exhaust pipes*.

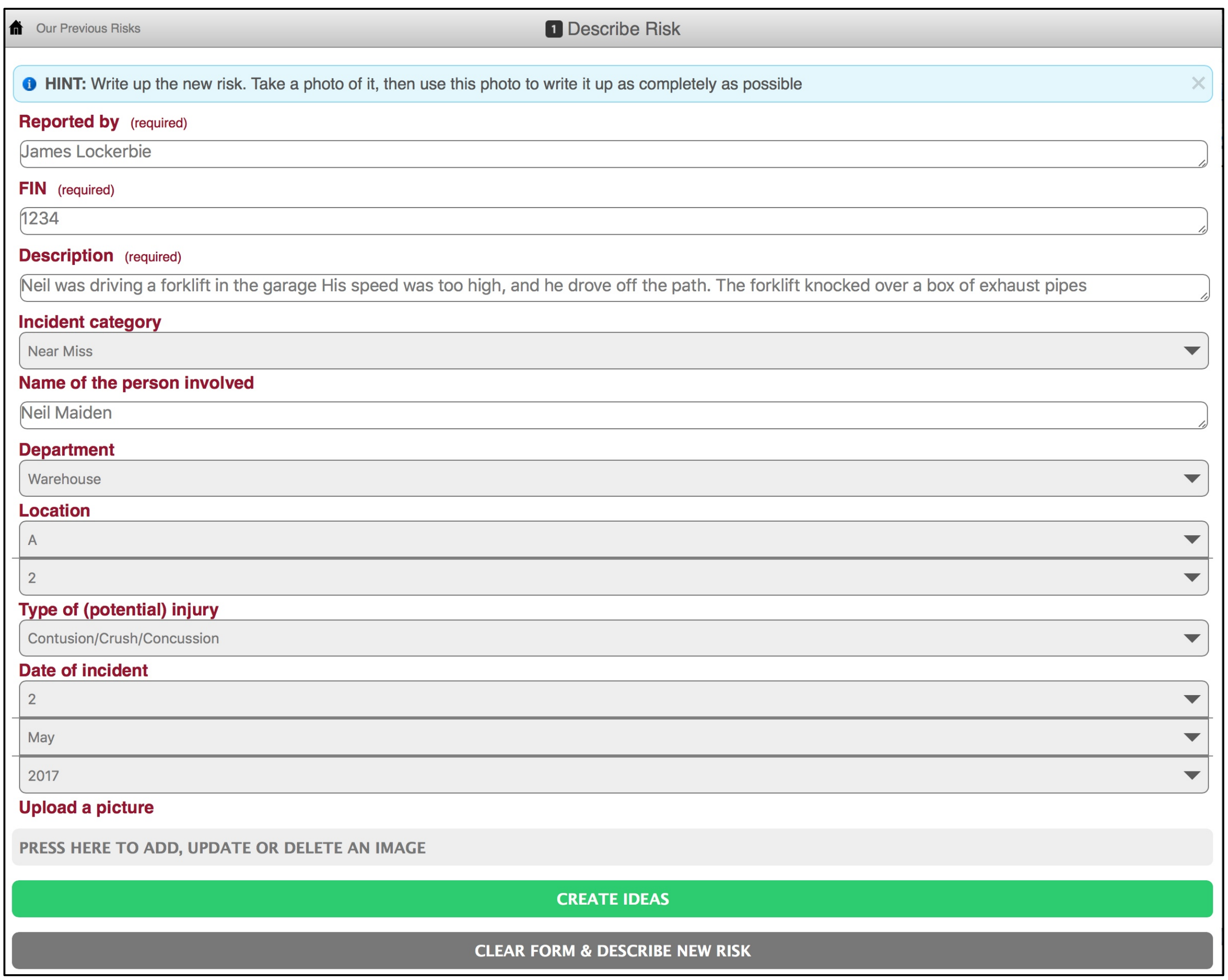


Figure 2. A new risk documented with the *Risk Hunting* system, with a freeform description of the encountered risk and employee name and identifier, and pull-down menu selections to describe the incident category, the location, the parts of the body at risk, the injury type and the date that the risk was identified

When the employee using the system clicked the CREATE IDEAS button at the bottom of the form, the *Risk Hunting* system offered 3 types of creative guidance, based on generative rule types with which to discover and document new ideas to resolve the entered risk. The system presents the 3 types of creative guidance as a simple list, as shown in Figure 3. Apart from the left-to-right ordering, the system does not direct the employee to any of the guidance types.

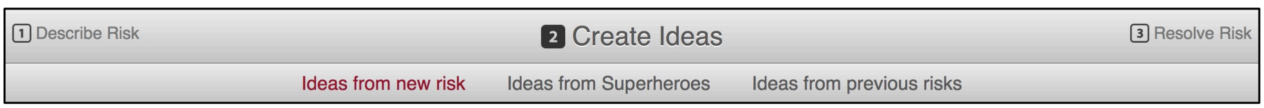


Figure 3. The *Risk Hunting* system's presentation of the 3 types of creative guidance that employees select between to use

The *Risk Hunting* system's 3 types of creative guidance had been designed with stakeholders in the plant (Zachos et al. 2015) to support different forms of creativity. Each type of guidance was based on different types of generative rule. The corresponding 3 types of generative rule were:

1. *Creative clues*: generative rules based on recurring patterns of creative manufacturing outcomes, which the system retrieved automatically from a library using a randomized search algorithm and instantiated with information about the new risk entered by the employee. An example of one such creative clue generated with one generative rule using the *speeding forklift* risk was: *Think about if you can replace something mechanical in the forklift with something that is sensory*. Use of these creative clues was intended to support exploratory creativity (Boden 1990);

2. *Superheroes and Sparks*: generative rules in the form of descriptions of superheroes and their superpowers. An example of one such superhero was *Spiderman*, who was described using his characteristics and superpowers, for example *protecting the innocent* and *predicting the presence of danger*. Use of these superheroes was also intended to support exploratory creativity (Boden 1990);
3. *Previous risks*: generative rules in the form of past successful risk resolutions similar to the entered risk. An example previous risk similar to the *speeding forklift* risk is *FLT driving over external speed limit*, and its risk resolution was *re-issue warnings to respect 5mph speed limits*. Use of previous risks information was intended to support both transformational and exploratory creativity (Boden 1990).

The *Risk Hunting* system's architecture is shown in Figure 4. Each time that an employee invoked the creativity support, the system instantiated the type of generative rules selected by the employee with either information extracted from the description of the current risk and/or information extracted from previous risk descriptions, and presented the resulting creative guidance to the employee.

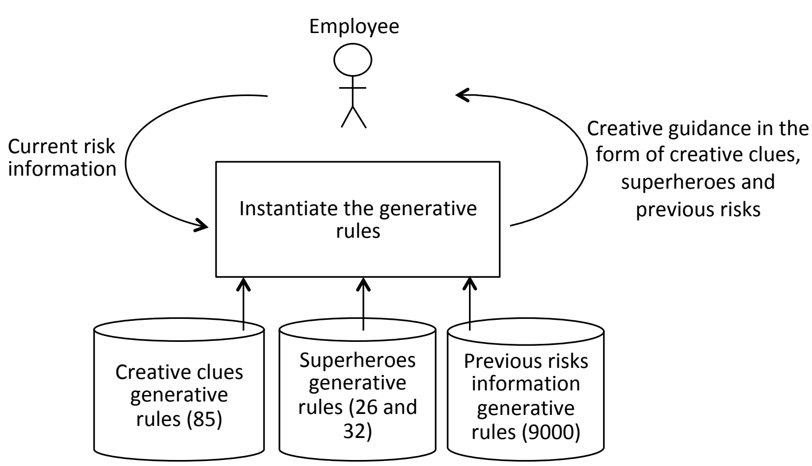


Figure 4. The *Risk Hunting* system's architecture, showing use of different types of generative rule and their number (in parentheses) implemented to produce creative guidance for employees

The design of the generative rules and how the *Risk Hunting* system generated its creativity support using these rules are described in more detail.

4.1 The *creative clue* generative rules

These rules were developed to guide employees to explore a solution space of ideas with which to resolve a risk. The rules generated creative guidance about the objects and actions described in the current risk. Candidate ideas were presented as an incomplete sentence – the stem – that the employee could then complete. The employee was responsible for developing the more complete idea.

4.1.1 Underlying principle

The creative-clue generative rules were derived from the TRIZ creative problem solving method that is reported by Altshuller (1999). TRIZ is an established problem solving method that draws on the past knowledge to accelerate a project team's ability to solve problems creatively. Part of the method provided libraries of repeatable creative solutions to similar problems. From these libraries, the researchers developed 85 different creative generative rules, based on judgments that each rule had the potential to support the generation of novel and useful risk resolution ideas in manufacturing.

4.1.2 Generative rule examples

Nine examples of the 85 generative rules are listed in Table 1. Each rule was instantiated with concrete information about either an object or an action extracted from the current risk description. Each rule was also allocated a multiplier to indicate its relative utility and cost in the plant, so that the system retrieved rules judged to be more useful and cost-effective more frequently. For example, the generative rule to divide up an object was instantiated 9 times more frequently than the rule to put the object in a vacuum.

Example generative rules	Multiplier
Think about dividing the [object] up	9
Think about how you provide a shell or cover for the [object]	8
Think about how to introduce feedback to the [action] action	7
Think about if it is possible to regenerate the [object]	6
Think about it you can replace something mechanical in the [object] with something that is sensory	5
Think about how to continue to [action], rather than stopping the action	4
Think about doing the opposite of what is expected with the [object]	3
Think about how to make the [action] action self-sustaining, so that it recycles all of its waste	2
Think about putting the [object] in a vacuum	1

Table 1. Examples of the *Risk Hunting* system's generative rules and different attributed multipliers

4.1.3 Generative rule algorithm

The software implementation of the generative rules was simple. The 85 rules were stored persistently in a software library. At run-time, a subset of these rules was retrieved from the library using a randomized search algorithm. Each retrieved rule was then instantiated with partial information about the new risk, which was retrieved using a second randomized search algorithm. Some of the 85 rules in the software library generated creative clues about mechanical and human objects, others about physical actions. To extract and select the objects and actions that were the focus of each rule from the risk description entered by the employee, the system deployed bespoke parsing algorithms. These algorithms structured a sentence into a series of words that constitute a grammatical unit, then to extract the required objects and actions from these units, one applied automated lexical extraction heuristics on each rule-tagged sentence to extract content words relevant for the generation of one or more objects and actions. So, for our example *speeding forklift* risk description, the algorithm returned the following object set: *forklift; garage; speed; path; box; exhaust pipes,* and the following action set: *driving a forklift in* *the garage; drove off the path; knocked over a box of exhaust pipes.* It then applied a randomized selection algorithm to the sets of the extracted objects and extracted actions to instantiate each retrieved rule with one of the objects or actions.

4.1.4 Interaction with creative clues

Each time that the employee requested creative clues by pressing the CREATE IDEAS button, the system listed 8 clues which were produced with 8 different generative rules, as shown in the top part of Figure 5. Example clues produced from the description of the *speeding forklift* risk included to *think about putting holes in the path, or to fill in holes in the path*, and *think about evening out the environmental forces that affect the garage*. To document new ideas generated from any of the listed clues, the employee could click on the clue at any time, and the system opened a window with the textbox such as the one shown in the bottom of Figure 5, prefilled with idea stem text from the original creative clue that the employee could extend, edit or overwrite. In Figure 5, the idea stem text was to *put holes in the path or fill holes in the path*, which was then extended with an idea generated by the employee to *introduce small speed humps, which will make driving at speed uncomfortable, and slow forklift drivers down at corners*. As such, an employee could document a new idea with the system using a creative clue in as little as 2 interactions.

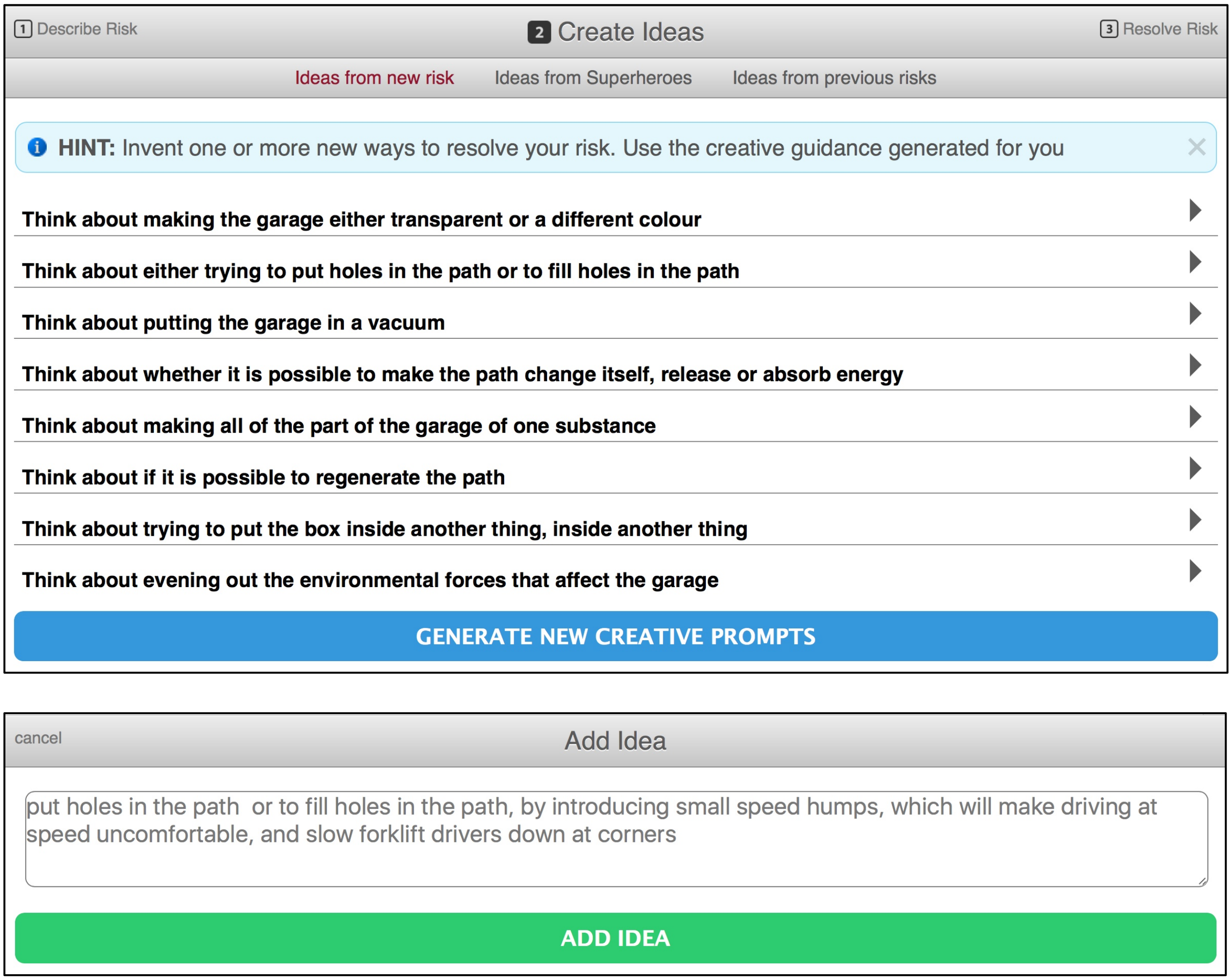


Figure 5. Creative clues presented by the *Risk Hunting* system [top], and using the system to record a risk resolution idea from idea stem text automatically generated from one selected creative clue [bottom]

4.2 The superheroes generative rules

These generative rules were also developed to guide employees to explore a solution space of ideas with which to resolve a risk. The rules generated creative guidance about the capabilities and qualities of superheroes. Unlike with the previous rules, the system did not present idea stem text to the employee.

4.2.1 Underlying principle

The generative rules were derived from an established creativity technique called *Superheroes* (Michalko 2006) that supports exploratory creativity, and which plant employees had used successfully in paper form in an earlier training session (Zachos et al. 2015).

4.2.2 Generative rule examples

Two sets of generative rules were implemented into the *Risk Hunting* system. The first was based on 26 pre-selected and familiar superheroes, to encourage divergent thinking. These superheroes included *Spiderman*, *Superman*, *Captain Marvel*, *Wonder Woman* and *Professor X*. The second set was composed of 32 rules developed by the research team to support employee use of *Superheroes* descriptions, and examples are listed in Table 2. These 2 sets of generative rules had been developed previously as part of another standalone information system. After the plant's employees had expressed positive feedback on the manual *Superheroes* technique during the earlier training session (Zachos et al. 2015), the existing generative sets of rules were integrated directly, without adaptation, into the *Risk Hunting* system.

Example generative rules
What is the most unappealing characteristic of [superhero]? Imagine you have that characteristic. What needs would you have?
What weaknesses does [superhero] have? Think of new ideas that could exploit these weaknesses in someone or something.
List the 5 most important attributes of [superhero]. Take each one in turn. Can it be modified to be an attribute of your new product or service?
Pretend to act like [superhero]. Mimic them. How does it make you feel? What new ideas arise from acting like [superhero]?
What if [superhero] joins your project team? What new ideas and concepts will [superhero] come up with?
In what environments would you encounter [superhero]? What new ideas might being in that environment trigger?

Table 2. Examples of the *Risk Hunting* system's generative rules that support the use of superheroes' capabilities and qualities

4.2.3 Generative rule algorithm

The software implementation of the generative rules was simple, and applied a randomized selection algorithm, twice. The first application retrieved one generative rule about one superhero automatically from a software library of the 26 pre-selected superheroes. The second application retrieved one generative rule automatically from a second library of the 32 pre-defined rules, and instantiated the rule with the name of the retrieved superhero.

4.2.4 Interaction with superheroes

The *Risk Hunting* system presented the superhero information to support creative thinking as shown in the top part of Figure 6. In this example, the system presented an image of *Spiderman*, a description of his superpowers and 3 creative sparks to think about the environment in which *Spiderman* is found and the values that he holds. At any time, the employee could request a new rule, in the form of a spark, related to the current superhero by pressing the NEW SPARK button, and a new rule in the form of a new superhero description by pressing the GENERATE NEW SUPERHERO button at the bottom of the screen. To document new ideas generated with superhero and sparks descriptions, the employee could click on the ADD NEW IDEA button at any time, and the system would open a new window with an empty textbox as shown in the middle of Figure 6. Unlike with creative clues, the textbox was not prefilled with text that the employee could extend, edit or overwrite, because the creative guidance offered by the technique was not directed sufficiently towards manufacturing. For example, to exploit the *spider-sense that warns of danger,* an employee might generate the idea to produce an alert for the driver if the forklift's speed approaches the speed limit, and document this idea as shown at the bottom of Figure 6. An employee could document a new idea in the system using superheroes and sparks in as little as 3 interactions.

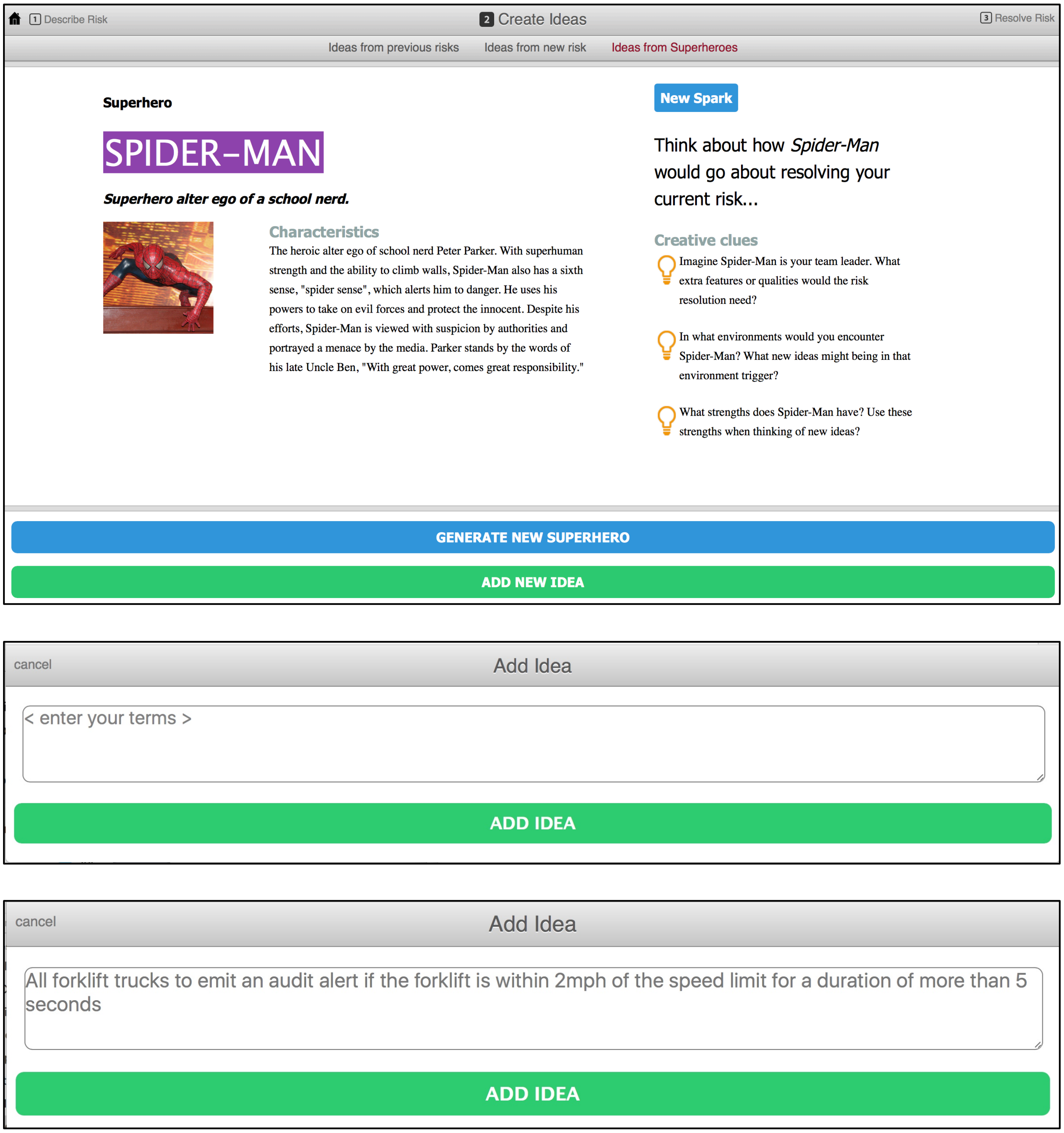


Figure 6. The description of one superhero and 3 creative sparks presented in the *Risk Hunting* system [top], the blank form to enter new risk resolution ideas [middle] and employee use of it to record a risk resolution idea [bottom]

4.3 The previous risks generative rules

The generative rules for previous risks were developed to guide employees to discover new solution spaces and search these spaces of possible ideas to resolve a risk. The rules generated creative guidance about the objects and actions related to the previous risks that had similarities to the current risk. This guidance was again presented as an incomplete sentence – the stem – that the employee could then complete. However, unlike with creative clues, the employee was required to map ideas used to solve the previous risk to solve the current risk.

4.3.1 Underlying principle

The generative rules were based on the principle of case-based reasoning (Kolodner 1993). The plant had developed a *Sharepoint* database of over 9,000 applied resolutions to previous health-and-safety risks. Not only did the plant want to reuse these resolutions more regularly, but also it wanted to exploit each resolution as a unique generative rule with which to discover new ideas with which to resolve new but similar risks. Therefore, the generative rules were developed from the database of over 9000 applied risk resolutions without modification.

4.3.2 Generative rule examples

Each previously resolved risk resolution provided a new generative rule to guide creative thinking about new risks. Examples selected from the 9,000 resolutions are listed in Table 3.

Generative rules
Accident: Operator cut his hand whilst assembling steering box wrong gloves worn. Fingerless
Parts slid: Parts slid partially off pallet. Had to get man-up truck to move parts back into place by hand
Unsafe condition: Large box placed on shop floor walkway, resulting on the need to walk onto the walkway. This runs the risk of a person coming into a moving vehicle.
Lighting: Lighting under chassis needs to be improved
Roof leaks: Roof leaks when raining, over all control panels. Electric hazard
Near miss: At BB6 water is pouring from the roof onto the slat line floor making it very slippery

Table 3. Examples of previous risk resolutions used as new generative rules in the *Risk Hunting* system

4.3.3 Generative rule algorithms

The *Risk Hunting* system automatically retrieved similar risks and their resolutions using an information retrieval algorithm that implemented creative search strategies. The implementation searched the 9000+ resolved risks in eXist, a native XML database with XQuery processing. Each record in the repository – i.e. generative rule – was a natural language description of a previous risk and its successful resolution, with no additional semantic information such as tags.

The algorithm was implemented to retrieve previous risks in 3 steps. The first automatically divided the entered risk description into sentences that were 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 (Brill 1992). The second applied increasingly sophisticated automatic procedures to disambiguate each term by discovering its correct sense and tagging it with that sense using context knowledge from other terms in the query (e.g. defining a *path* to be *an established line of travel or access* rather than *a course of conduct*) (McCarthy et al. 2004, Stevenson & Wilks 2001). The third implemented different creative search algorithms that expanded each term with other terms that had similar meanings to the tagged sense to retrieve previous risk resolutions (e.g. the term *path* is synonymous with the terms *route* and *itinerary* which are then also included in the query based on the creative strategy). These term senses were inferred automatically from WordNet, an on-line lexicon (Simpson 2005) that assigned senses to terms categorized as nouns, verbs, adjectives and adverbs. Each sense defined the meanings of a term, and WordNet organized these senses into synonym sets that describe concepts with definitions or glosses, each of which contained a definition phrase composed of terms. For each disambiguated term, the algorithm: (1) replaced it with its synonym set, for example the noun *path* was replaced with the synonym set for the disambiguated sense #3 [*route, itinerary*], so that for our *speeding forklift* example, the algorithm might have retrieved descriptions of resolutions to risks about vehicles deviating from *routes*; (2) augmented it with all terms in its definition specified in WordNet, so that for our *speeding forklift* example, the system might have retrieved a description of resolutions to a risk arising from *containers being turned over*, because the term *box* was defined as *a usually rectangular container; may have a lid*; (3) augmented it with its direct hypernyms, for example, the hypernyms of the disambiguated term *driver* were *operator* and *manipulator,* so in our example, the system might have retrieved descriptions of resolutions to risks about *operators of different forms losing control*.

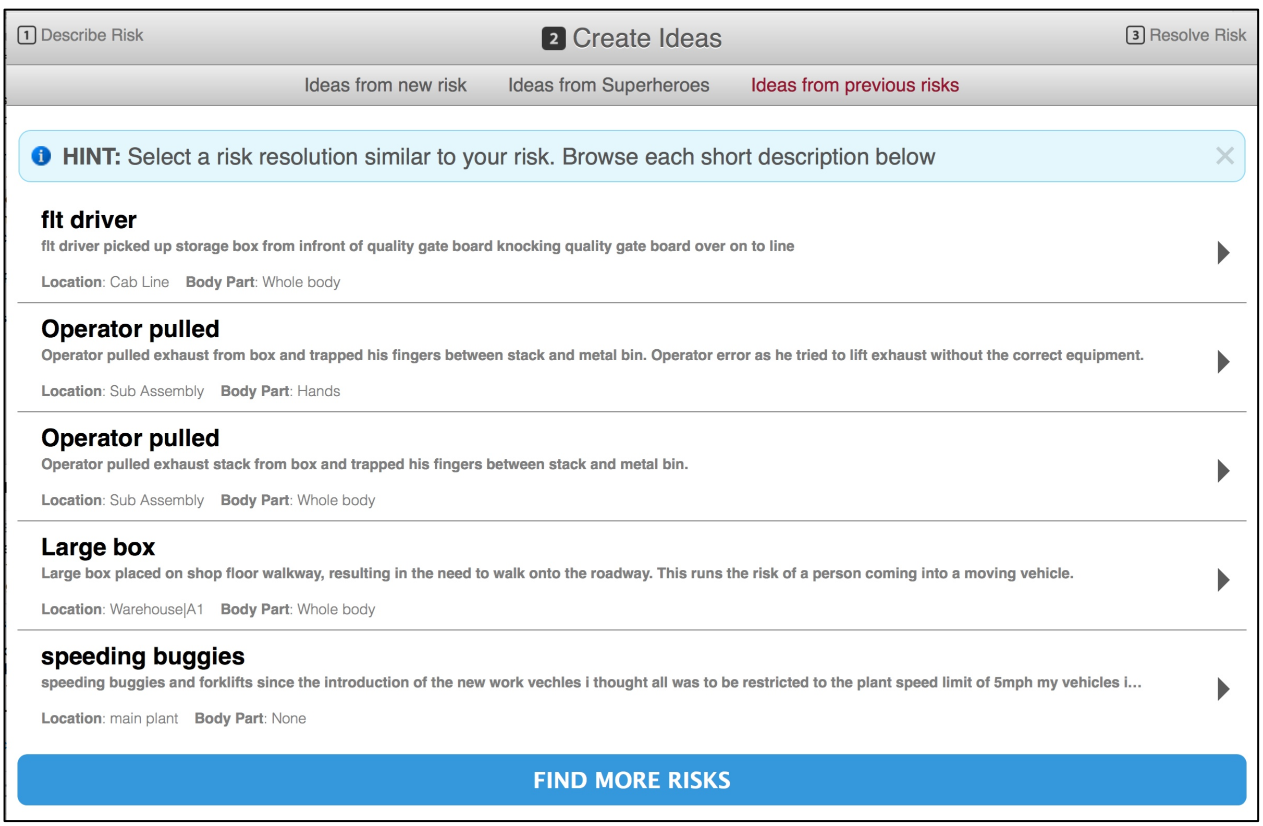
The implemented algorithm returned an ordered set of the 5 highest-scoring risk resolutions as new generative rules.

4.3.4 Interaction with previous risks

The *Risk Hunting* system presented the 5 highest-scoring risk resolutions – the 5 generative rules – to the employee as shown at the top of Figure 7. One previous risk retrieved for the example *speeding forklift* risk was *speeding buggies: speeding buggies and forklifts since the introduction of the new vehicles*..,. Although not the same as the forklift accident risk, the content of the applied resolution to this risk, which included *enforcing speed limits* and *limiting the speed of the vehicles*, could have guided creative thinking to avoid speeding forklifts in the plant, see the *previous risk resolutions applied* in the middle of Figure 7.

In addition, the *Risk Hunting* system also presented up to 8 creative clues generated for the objects and actions described in the risk resolution based on the generative rules reported in Section 4.1, see the *creative guidance from previous risk* also shown in the middle of Figure 7. Examples of these creative clues included *think about how to make the park more flexible*, *think about how to make the limit move and adjust*, and *think about how about how to introduce feedback into the limit*. Returning to the *speeding forklift* risk, the employee could generate new ideas from information about both the applied resolution such as *enforcing speed limits* and creative clues such as *think about introducing feedback to the vehicles*.

To document and store new ideas, the employee could again click on the previous resolution and/or a presented clue at any time, and in response the system would open a window with a textbox as shown at the bottom of Figure 7. As with creative clues, the textbox was prefilled with previous resolution or generated idea stem text from the clue that the employee could extend, edit or overwrite. In Figure 7, the idea stem text was to *remove something from the vehicles,* which was then extended with an idea to *impose a regulator on the maximum speed that the buggies and forklifts can travel at*. To document a new idea in the system using previous risks, the employee required a minimum of 5 interactions.



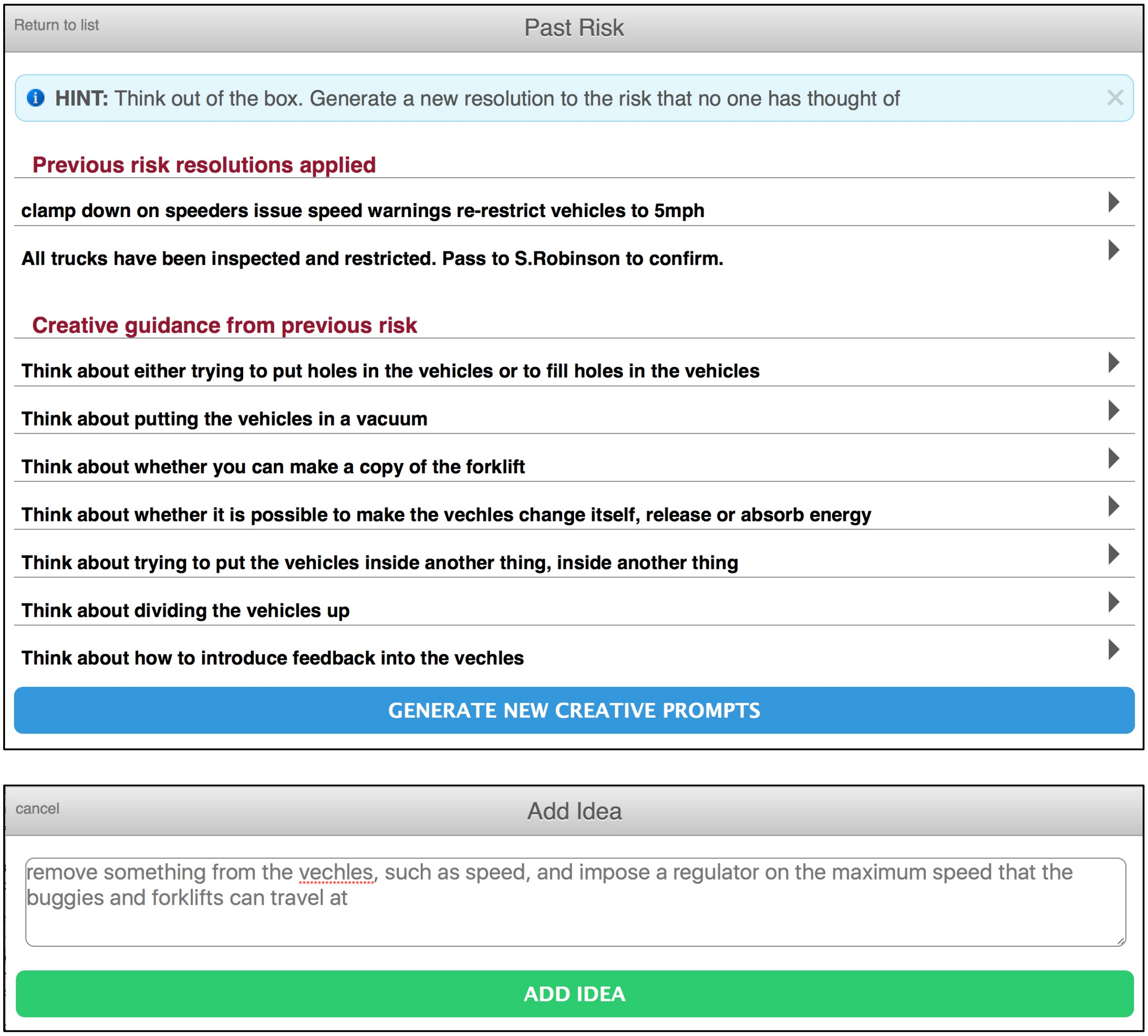


Figure 7. Previous risk resolutions – generative rules – that the *Risk Hunting* system presents using each risk's given name, description, location and employee body parts put at risk [top], previous risk resolutions and creative clues generated for one selected previous risk [middle], and system use to document and store a risk resolution idea from idea stem text [bottom]

4.4 Completing the risk resolution

The employee could save the set of ideas that s/he had generated with or without one or more of the generative rules, add comments to these ideas, generate the new risk resolution, and share the resolution with colleagues to view and exploit, as shown in Figure 8. This immediate digital sharing replaced the previous and slower means of communicating the risk resolutions, which was to place A4 photocopies of the resolution on physical noticeboards across the plant.

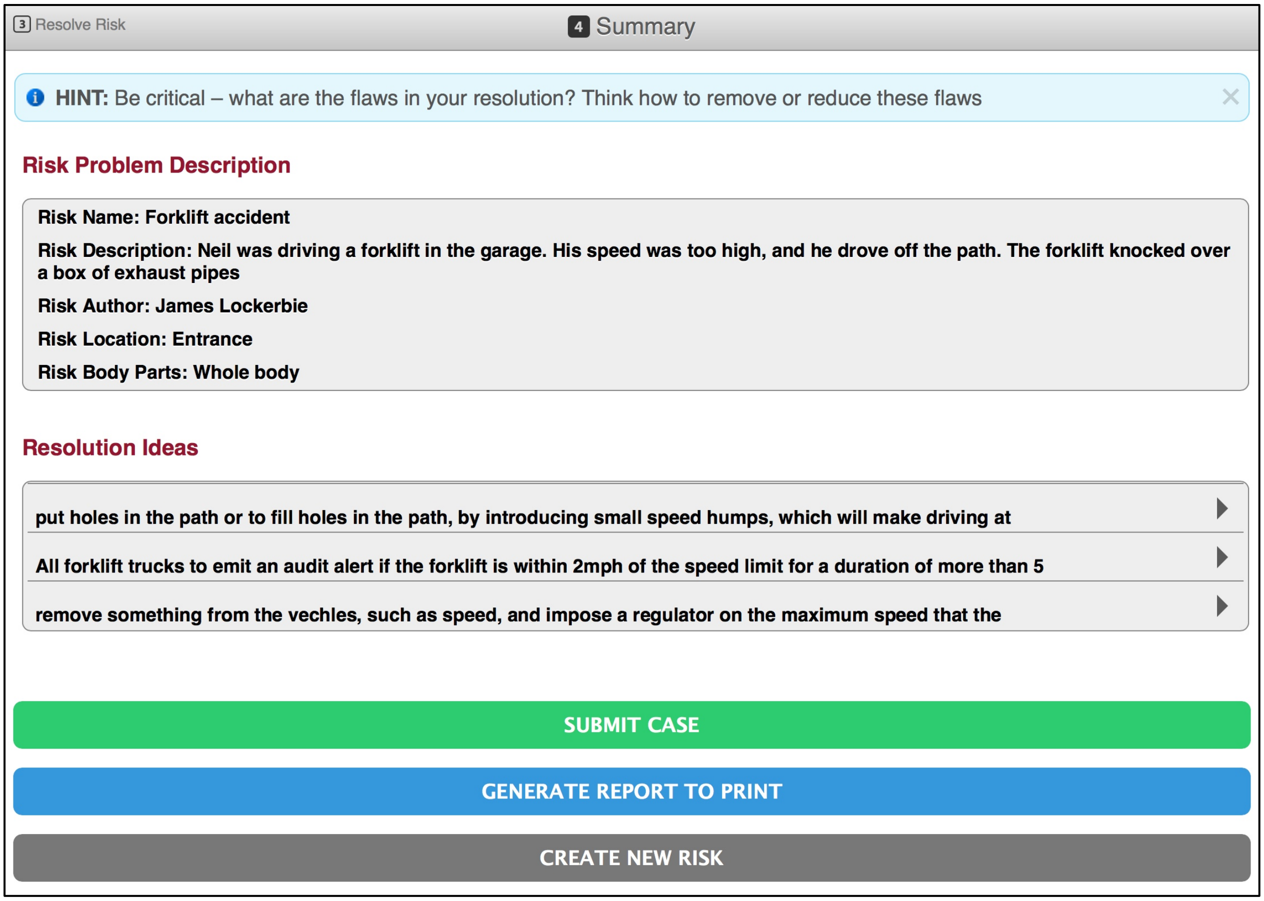


Figure 8. Completion of a risk resolution with the *Risk Hunting* system – the employee was able to edit or delete existing ideas and still add new ones, as well as submit the risk case to the plant's health-and-safety team, as well as generate a PDF form of the risk and its resolution in a form similar to the original unsafe act/condition form shown in Figure 1

The basic sequence of activities that an employee could undertake with the *Risk Hunting* system is shown in the flow diagram in Figure 9. The system was designed to encourage employees to use it in a sequence. However, at any activity, the employee could repeat the activity, and/or return to earlier activities.

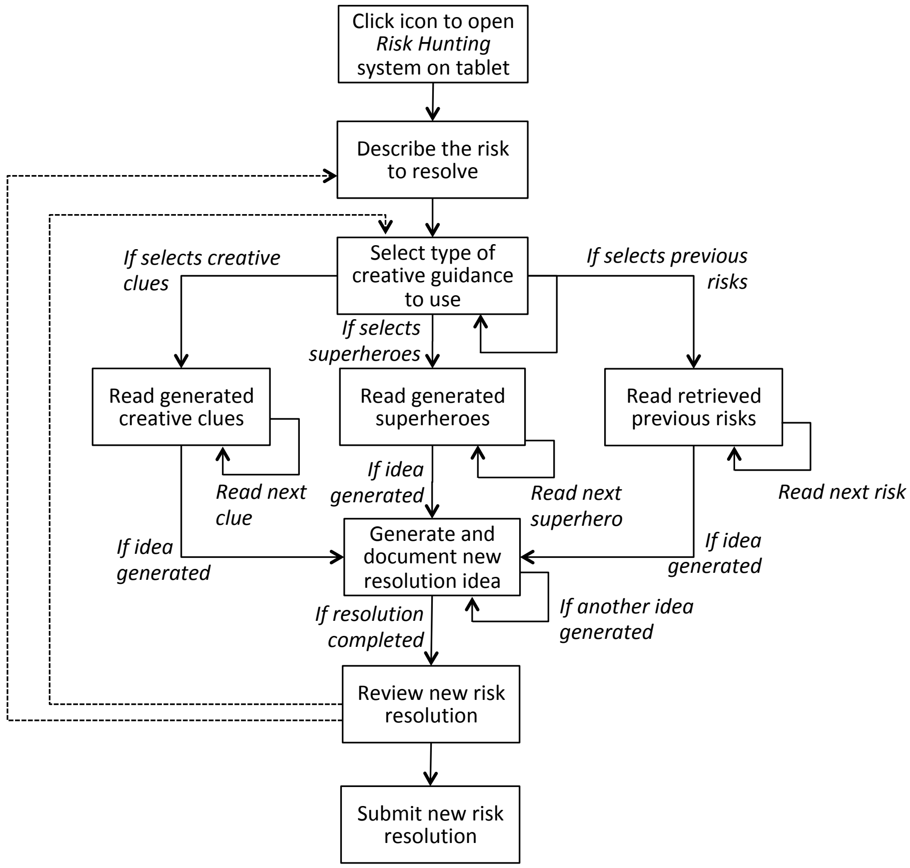


Figure 9. The basic sequence of activities during *Risk Hunting* system use. At any time during system use, an employee can return to re-describe the risk to resolve, select a different type of creative guidance to use, and read different pieces of information generated by one type of creative guidance

5. AN EVALUATION OF *THE RISK HUNTING* SYSTEM

A continuous and longer evaluation of the effectiveness of the *Risk Hunting* system's creativity support for employees at the plant was undertaken. Four research questions about employee use of the system, based on the expressed requirements of the plant's health-and-safety management, were investigated:

RQ1: Were risk resolutions generated by employees with the *Risk Hunting* system rated to be more novel and useful than risk resolutions generated with the paper forms?

RQ2: Were risk resolutions generated by employees with the *Risk Hunting* system completed within 5 minutes?

RQ3: Were risk resolutions generated by employees with the *Risk Hunting* system more complete, in terms of the number of words used to describe the risks, than risk resolutions generated by employees with the paper forms?

RQ4: Did the employees select to use one type of the *Risk Hunting* system's creative guidance more than the other two types?

Research question RQ1 was formulated using Sternberg's (1999) definition of creativity – the production of work that was novel and useful for the health-and-safety task. Novelty and usefulness are oft-used measures to evaluate creative ideas and products (Maher & Fisher 2011, Siangliulue et al. 2015), and human expert judgment is an effective source of these novelty and usefulness measures (Hollis & Maiden 2003). Research question RQ2 explored whether the creative information system might be used effectively within time constraints imposed by the time at which vehicle remained at each work station on the production line. Although typing speeds on tablets can be low and error-prone, halting the production line to generate risk resolutions was expensive to the plant, so the challenging requirement was to generate and document risk resolutions within 5 minutes. Research question RQ3 explored whether, independent of creative thinking, employee use of the system was associated with more complete risk resolutions with the time constraints for creative thinking that were imposed by the production line, using word counts as a proxy measure for resolution completeness. And research question RQ4 explored employee preferences for the *Risk Hunting* system's implementation of the different types of creative guidance.

After a period of user training and formative evaluation with the system, the described version of the *Risk Hunting* system was made available for use in the plant from 16th March to 30th June 2015 – 66 consecutive workdays. The plant operated at full capacity for 4.5 workdays each week

– from Monday morning to Friday lunchtime – to achieve its monthly production targets, although during the period, the plant was closed for several national holidays.

5.1 Evaluation method

A potential user of the *Risk Hunting* system was any plant employee who detected a new health-and-safety risk. Before the start of the usage period, the researchers trained 7 health-and-safety captains who were responsible for health-and-safety on the plant's 7 production lines, and 2 health-and-safety advisors to use the system and the plant's Samsung Galaxy Tab 3 GT-P5200 tablets that the system ran on. These captains and advisors then provided the same training to employees in different roles on their production lines – mainly group leaders, assembly operators, garage repair operators, maintenance electricians and different technical coordinator roles. Although incentivized to use the system to record and to resolve risks, all of the employees were free also to use the paper forms. Incentives to use the system included access to a new information system for resolving risks, faster sharing of employees' risk resolutions, and opportunities to inform the future development of the system for use within the plant. All employees had email and telephone access to the research team for help and support throughout the usage period. However, a limited plant budget at the plant meant that only 3 tablets were made available by the plant for system training and use, so some employees also used the system on workplace desktop computers.

At the end of the period, the researchers collected and analyzed: (a) descriptions of all risks and resolutions documented in the plant with the *Risk Hunting* system in the evaluation period, with the name of the employee who documented the risk and resolution; (b) descriptions of all risks and resolutions documented in the plant on paper forms in the period, again with the name of the employee who documented the risk and resolution, and; (c) descriptions of all risks and resolutions documented in the plant with paper forms in an equivalent period in 2014, again with the name of the employee who documented the risk and resolution. During the evaluation period, employees were free to document each risk and resolution using the *Risk Hunting* system or a paper form, so the risk resolution sets (a) and (b) were not independent, and could only be compared to provide evidence of levels of system use. Instead, the evaluation compared the risk resolutions documented with the *Risk Hunting* system (a) with the equivalent set of risk resolutions (c) documented using the paper forms by the same employees in the equivalent period 12 months earlier. This comparison was chosen because of similar weather conditions and production targets to the evaluation period. The use of these 3 data sets is depicted graphically in Figure 10.

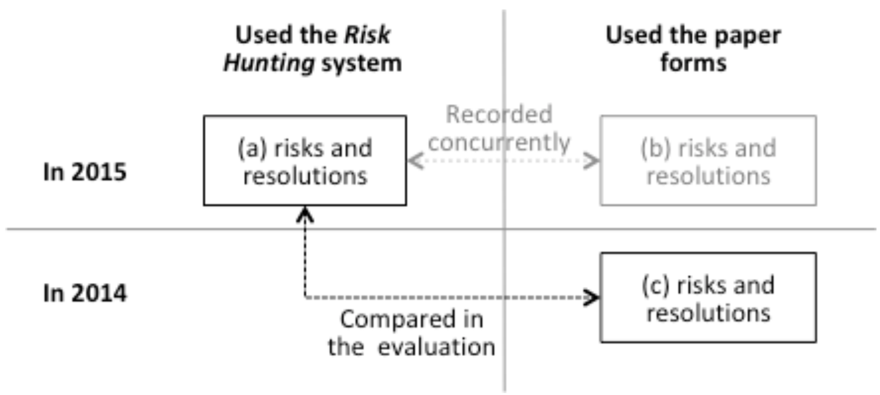


Figure 10. The 3 sets of documented risks and resolutions investigated in the evaluation

At the end of the period, the researchers also collected and analyzed: (d) the list of perceived and actual software errors reported to the researchers by employees during the period; (e) transcripts of the qualitative comments made by employees during the 2 site visits and final focus group, and; (f) log data from feature usage using all *Risk Hunting* information system use over the period.

After the end of the period, 4 risk analysts from the plant's parent group, with between 4 and 15 years of professional experience in health-and-safety work, independently rated selected risk resolutions that employees had generated using the system and the paper forms in the same period 12 months earlier. Each risk analyst was made available to the evaluation for 3 hours – sufficient time to rate up to 40 different risk resolutions.

Therefore, a random number generator algorithm at *random.org* was used to select 20 risks resolved with the system and 20 risks resolved with the paper forms 12 months earlier, of which 10 were from the first half of the period and 10 from the second half. Furthermore, to reduce bias caused by potential individual differences between employee behaviour with the system, these sets included 5 resolutions in the first half and 2 in the second half generated by the same employees – 2 health-and-safety captains. The resulting 40 risks and their resolutions were then randomly ordered in a questionnaire using another algorithm at *random.org*. To measure the creativity, i.e. the usefulness (Sternberg 1999) and the novelty (Maher & Fisher 2011) of each risk resolution, each risk and its resolution was presented on a separate page above two 1-7 Likert scales to capture the perceived novelty and the usefulness of the resolution to each risk, see Figure 11. This form of outcome questionnaire with novelty and usefulness Likert scales had been used to rate expert judgment of creative outcomes in design domains from automotive design (Zachos & Maiden 2008) to television listing websites (Hollis & Maiden 2013) and idea generation systems (Siangliulue et al. 2015).

Risk number 5

Risk encountered

Glass in the cab door shattered when closing the door in the cab drop area

Resolution applied

avoid stress in the door , and/or the situation, before it happens - was the door closed using excessive force?; unfortunately certain conditions cause glass to break ,to notify [person] to notify croix in possibility of adding grease to hinges; RESOLUTION

Rate this applied resolution to the risk using an integer between 1 and 7 in the box provided

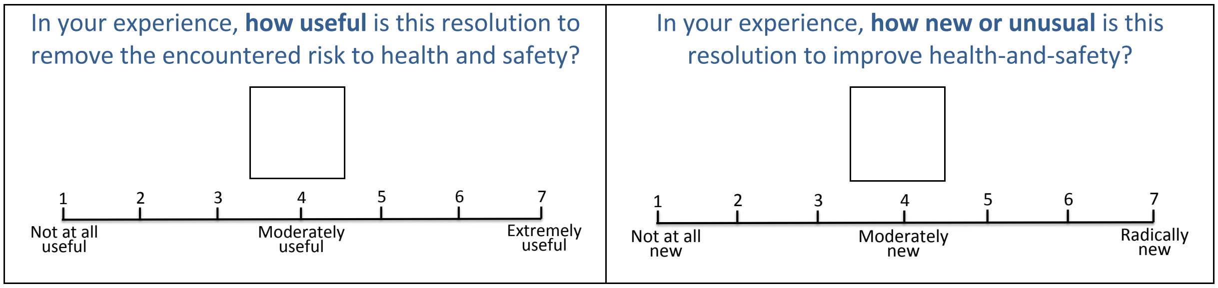


Figure 11. One sample risk, the documented resolution to the risk, and the 2 rating questions answered by the risk analysts

Each of the 4 risk analysts completed the questionnaire and returned to the researchers. All data from sources (a) to (f) were analyzed to answer the 4 research questions.

5.2 Evaluation results

During the evaluation period, the plant employees used the *Risk Hunting* system and the paper forms to document risks and resolutions to risks. A total of 33 different employees used the *Risk Hunting* system to document at least one risk and resolution, and 21 of these employees also used the paper forms to document at least one other risk and resolution. Totals of the risk resolutions generated by the 33 employees by plant role, with the system and with the paper forms, are reported in Table 4. The 33 plant employees used the *Risk Hunting* system to document 115 risks and their resolutions. For completeness, in the same period, another 118 plant employees also only used the paper forms to document another 439 risks during the period, but were not investigated further as such analyses were considered outside of the scope of the research. No employee documented an individual risk with both the *Risk Hunting* system and paper form.

Totals of plant employee, by roles, who used the *Risk Hunting* system	Total number of risks and resolutions generated in the *Risk Hunting* system (a)	Total number of risks and resolutions generated on the paper forms (b)
Health-and-safety captains working on the plant's production lines (8 users)	66	37
Health-and-safety advisors based in the administrative offices (2 users)	3	10
Assembly operators working on the plant's production lines (14 users)	34	49
Group leaders working on the plant's production lines (3 users)	3	6
Other diverse plant employees in different locations: garage repair operators, maintenance electricians, technical coordinators, maintenance technical coordinators (6 users)	9	9
Totals (33 users)	**115**	**111**

Table 4: Totals of risks generated with the *Risk Hunting* system and the paper forms by plant employee role, for employees who used the system in the evaluation period

Employees in different roles used the system to different degrees – 8 of the health-and-safety captains generated 66 of the 115 risk resolutions. Of the remaining 47 risk resolutions, 14 assembly operators generated 34, although 1 operator who was in training to become a health-and-safety captain generated 16 of these resolutions. In contrast, a total of 18 employees in different roles documented and generated just 1 risk resolution each, and the captains reported one major reason for this – the limited access that other employees had to 2 tablet devices (the 3rd device was lost at the start of the evaluation period) compared with the near limitless paper forms carried by them to complete immediately: "*I would think that this is down to availability of the tablets, only two on site*". The tablets were at some times in secure storage to avoid theft, at other times unusable due to a lack of available chargers. The other employees also received less training and therefore had less practice with the system, whereas the health-and-safety captains had time "*to be able to play with the app*".

In addition to the 115 risks documented with the system, 21 of the 33 employees who used the *Risk Hunting* system documented another 111 risks on paper forms in the same period. Six of the captains recorded risks with both the system and the paper forms, and 13 other employees only recorded risks on paper forms, again down to the absence of sufficient numbers of charged tablets in the plant that could be accessed quickly without interrupting a production line. In the interviews, one captain reported that other employees just "…*need to be able to pick it up and use it*".

Nonetheless, these 33 employees selected to use the *Risk Hunting* system over the paper forms to record over half of the encountered health-and-safety risks in the evaluation period.

5.2.1 Risk resolutions generated with the *Risk Hunting* system rated as more creative?

To answer research question RQ1, the research team investigated the expert novelty and usefulness ratings of the 20 selected resolutions to risks documented with the *Risk Hunting* system and the 20 selected resolutions documented with the paper forms. A Mann-Whitney test revealed that the usefulness ratings were greater for the risk resolutions documented with the system (Mdn=5) than with the paper forms (Mdn=3.5), $U=2371$, $p<0.0001$. This indicated that the analysts rated the risk resolutions documented with the system to be more useful. A Mann-Whitney test also revealed that the novelty ratings were greater for the risk resolutions documented with the system (Mdn=4) than with the paper forms (Mdn=2.5), $U=1975$, $p<0.0001$, indicating that the analysts also rated the risk resolutions documented with the system to be more novel. Based on the specialized little-c creativity definition adopted in this research, the selected risk resolutions that were generated with the system were more creative.

5.2.2 Risk resolutions generated with the *Risk Hunting* system within 5 minutes?

To answer research question RQ2, an analysis of the *Risk Hunting* system usage log data was undertaken. The analysis revealed that the average total time between the start of the recording of a risk to the saving of the resolution to that risk was 4m46s for all 115 risk resolutions, i.e. within the 5-minute time constraint imposed by the plant's production lines. Employees reported in the post-period focus group that risks were documented and resolved by individuals, rather than collectively. This was due primarily to the constraints imposed by the production line – the system needed "*release to use it, otherwise it had to be done in overtime*".

However, of the 115 risk resolutions generated, only 77 individual risk resolutions were recorded within the 5-minute limit. Moreover, using a Pearson rank order correlation analysis of the number of words in each risk resolution and the elapsed time between the start and end of the risk and resolution recording, there was a correlation between the two variables [$r = 0.41$, $n = 115$, $p < 0.00001$], indicating that, perhaps unsurprisingly, more time was needed to generate and document more complete risk resolutions.

Analysis of the system usage log data revealed that not all risk resolutions generated with the system were generated when the employee accessed information created from one or more of the system's generative rules, see Table 5.

	Number of generated risk resolutions	**Average word count of risk resolution**	**Average elapsed time from starting to record risk to submitting each risk resolution**
Without access to information generated by the generative rules	47	12	2m44s
After access to information generated by the generative rules	68	24	5m13s

Table 5. The average word counts of risk resolutions generated with the *Risk Hunting* system after access or otherwise to information generated by the system, and average elapsed time from starting to record risk to submitting each risk resolution

Of the 115 risks, 47 were resolved without employee access to any information generated by the generative rules, and the employees spent less time. These 47 resolutions had, on average, half the number of words generated after employee access to the creative guidance. In the post-period focus group one health-and-safety captain reported: "… *sometimes we* [just] *know the answers*". Even so, compared to use of the paper forms, system use even without access to the creative guidance was associated with risk resolutions with more words.

Employees who accessed the creative guidance prior to submitting a risk resolution took on average 5m13s to document each risk resolution. Unpaired t-tests revealed significant differences in the elapsed time between starting to record each risk and submitting the resolution to that risk with access to generative rule information (*Mdn=369.3, SD=313.4*) and without access to generative rule information (*Mdn=164.4, SD=154.1*) conditions; $t=4.146165$, $p<0.05$), and in the numbers of words to describe each risk resolution generated without (*Mdn=12.4, SD=6.34*) and with access to generative rule information (*Mdn=41.5, SD=23.7*) conditions; $t=8.200626$, $p<0.00001$). In short, access to the creative guidance was associated with both longer periods of system use and risk resolutions described with more words. Moreover, the average length of time needed to generate risk resolutions was longer than the 5-minute constraint imposed by the plant's production lines. Almost half, 33 of these 68 risk resolutions were generated outside of the 5-minute constraint.

5.2.3 Risk resolutions generated with the *Risk Hunting* system more complete?

To answer research question RQ3, an analysis of the means and ranges of the word lengths of all risk descriptions and resolutions documented by the employees in both usage periods was undertaken. The analysis treated word counts as proxies for the completeness of risk descriptions and resolutions. It revealed that system use was associated with risk resolutions that employees described with more words, see Table 6. An unpaired t-test revealed no significant difference in the numbers of words written to describe each risk with the system (*Mdn=14.5, SD=7.5*) and with the paper forms (*Mdn=11, SD=15.7*) conditions; $t=0.721$, $p=0.23$. This indicated that system use was not associated with changes in the number of words used to describe risks. However, there was a significant difference in the numbers of words used to describe each risk resolution with the system (*Mdn=21.5, SD=24.12*) and with the paper forms (*Mdn=4, SD=6.0*) conditions; t=10.26708, p<0.00001). Risk resolutions documented with the system were described with more words than resolutions that were documented with the paper forms.

	With system	With paper forms
Number of resolved risks	115	119
Average number of words in risk description	15.2	14.1
Range of words in risk description	2 – 45	4 – 162
Standard deviation of words in risk description	7.5	15.7
Average number of words in risk resolution	29.6	6.3
Range of words in risk resolution	2 – 129	0 – 28
Standard deviation of words in risk resolution	24.12	6.29

Table 6. Quantitative data about risks documented and resolutions generated with the *Risk Hunting* system and with the paper forms in the comparison period

A content analysis of all risk resolutions generated with the *Risk Hunting* system and the paper forms revealed 3 possible reasons for this result. The plant's health-and-safety management team had already identified the first factor – many of the resolutions documented on the paper forms only recommended doing the opposite of the risk cause, or taking simple actions. The employees used fewer words to describe these types of resolution, for example:

```
do not leave parts on the unit;
bring to attention of operative at fault.
```

A second factor was that 23 of the 119 risks documented on the paper forms had no resolution at all, i.e. paper forms were incomplete, whereas all 115 of the risks documented with the system had a resolution. Unlike the paper form, the *Risk Hunting* system validated whether a resolution description had been generated prior to saving the new risk, and employees were required to enter a risk resolution description prior to being able to save then share it.

A third factor was that over half – 60 – of the risk resolutions documented with the *Risk Hunting* system incorporated at least one idea stem text string that had been generated automatically by the system's generative rules. Typical examples of these resolutions were:

> `make the boxes move and adjust - area needs to be moved around to insure all boxes are situated within the lines`

where '*make the boxes move and adjust*' was the stem text, and

> `make the pump more flexible; make parts or all of the pump move and adjust; consider a hoist either mechanical or electric to lift out and replace pump.`

where '*make the pump more flexible*' was the stem text. These 2 examples demonstrate the structure of many of the risk resolutions – the original idea stem text, followed by an extension of it to describe how to resolve the original risk. As such, the inclusion of these idea stem texts appeared not only to contribute to the resolution word length, and hence completeness, but also provided evidence that this text also provided relevant content for most of the resolutions, for example:

> `remove a step from fountain overflow container full; Empty on a routine basis not wait until 3over-spilling`

> `make the items self-sustaining, so that it uses all of its waste; Give toolbox about items left on tractors and possible outcomes`

> `remove a step from wear no safety cap, look into how that job process could be performed without the need to wear a safety cap; change the density of the knees, have a trolley that allowed low level working without the need to be on your knees.`

Furthermore, the content analysis revealed little evidence of repeated use of the same generative rules that produced creative clues, which might have indicated possible employee learning about and/or preferences for certain ones. Of the 100 different creativity clues selected by the employees, 60 were used only once to generate a risk resolution idea, and no single employee used the same creative clue to generate more than 3 different ideas.

5.2.4 Different types of creative guidance that the employees selected to use?

To answer research question RQ4, *Risk Hunting* system usage log data was analyzed to investigate differences between risk resolutions generated after employee access to the information produced by the different types of generative rule. Results reported in Table 7 revealed that employees used information generated with some types of generative rule more than others.

Information generated by different types of generative rule accessed by the employees during the resolution of a single risk	Number of generated risk resolutions	Average word count of each generated risk resolution	Average time from starting to record risk to submitting each generated risk resolution
Superheroes only	2	28	10m9s
Creative clues only	27	35	5m5s
Previous risks only	15	34	5m44s
Creative clues and previous risks	21	51	6m45s
All 3 forms of content	3	79	11m0s

Table 7. Risk resolutions generated with the system after the different types of creative guidance

One-way analyses of variance (ANOVAs) were undertaken to compare associations between the risk resolution word length and the time taken to generate the risk resolutions after access to the guidance produced with the different types of generative rule. The analyses showed that the effect of the access to the information generated by the different type(s) of generative rule on the time to generate risk resolutions was not significant, $F (4,63) = 1.332$, $p = 0.268$, but the effect of access to information generated by the different type(s) of generative rule on the risk resolution word length was significant, $F (4,63) = 4.717$, $p < 0.003$.

Therefore, a content analysis of the risk resolutions was undertaken on the risk resolutions generated with the different types of creative guidance. Just 2 risk resolutions were generated after accessing the Superheroes creative guidance, and neither revealed clear evidence of the use of superhero powers as part of each resolution. The 2 risk resolutions were:

> `To have stock in a safe standard rack or investigate issues`

And

> `operator stock to be delivered direct to workstation thus avoiding any necessity to move the hubs and avoid travel across moving line. Moving line to be made safe by keeping floor even and covering line wheels... keep all foot traffic from walking across line`

The system usage log data revealed that the superheroes creative guidance was viewed for only 1m25s and 3m29s before idea generation took place, suggesting that idea generation might have taken most of the time. The post-period focus group revealed that the superheroes guidance: "*... was a little around the houses, too time-consuming*", but it did consider this content to be "*good for training*".

By comparison, employees generated more risk resolutions that were, on average, of greater length in less time after accessing the creative clues, see Table 6. For example, one employee generated the resolution:

> `provide a shell or cover for the vacinity; Do not use in unventilated area or near other operators`

in response to the risk:

> `Operator from garage using gasket remover in vacinity of line operators, could be inhaled or caught by spray,`

It took this employee an elapsed time of 4m 51s to document the risk then generate and document the resolution in the system. In contrast, another employee generated the following resolution more quickly, in just 1m 3s:

combine the bracket with something else- a buffer to prevent people bruising if they were to walk into the bracket.; make the bracket work before it is needed- change the process so the hd bracket is not needed therefore removing the risk entirely

in response to the risk:

hd bracket - people keep walking into it.

In comparison, the employees generated fewer risk resolutions when accessing the previous risks creative guidance, even though the system usage log data revealed that the system retrieved and presented 5 different previous risk resolutions with match scores to the new risk description above the score threshold in all but one case. An example was:

use materials that are composed of many things during tip over on uneven slats; use materials that are composed of many things during tip over on uneven slats, operator could push trolley along if it was fitted with a handle; make the trolley do lots of different things , add a handle so trolley can be pushed along instead of being kicked;

in response to the risk:

Kicking a trolley along, could become a trip hazard

The employees also accessed information produced by more than 1 type of creative guidance prior to generating ideas to resolve single risks, see Table 6. The employees generated 21 risk resolutions when accessing information generated from the creative clues and past risk resolution generative rules – resolutions that had more words and took more time to record, for example:

replace something mechanical in the roof with something that is sensory - mechanical aid to lift the roofs from packaging; remove something from the roof - how about the roof coming in designated racking without packaging; make the roof cheap and disposable - maybe not the roof but the packaging, so that the roof does not need to be lifted off.

```
Contract Manager spoken to, contractors reinducted; make the door do lots of
different things- Visual Aids to remind contractors to wear the correct PPE; make
do with more of the contractors, or less of the contractors- make them wear head
protection or else they cannot work here; change the density of the area- make
the area safer so no need for head protection;
```

```
combine the operator with something else - posibility of using the hoist for
removing the exhaust from the bin; make the bin more flexible - means of delivery
to be modified; Engineering Controls - process to be improved to eliminate the
risk of cuts; do the opposite of what is expected with the operator- changing the
process so there is not the oppurtunity for the operator to get his fingers
trapped.
```

Moreover, 3 risk resolutions were generated when accessing all 3 types of creative guidance, and these risk resolutions were longer still with an average of 79 words, for example:

```
Remove something from the models - have all exhaust pipes standardized to allow
one attachment to handle all tractor models; make the models work before it is
needed - fitting of the exhaust on the station before so that the lights are not
in the way of the manipulator/attachment; make parts or all of the operator move
and adjust - attachment to pick up the exhaust from the top rather than from the
side to prevent from clash with the lights and mirrors; make parts or all of the
shoulder move and adjust - not the shoulder but perhaps attachment with
flexibility of height adjustment for different models; PlasticMan - parts of the
attachment that can potentially come in contact with the mirrors and lights to be
made of softer material or silicone coated.
```

In the post-period focus group one of the captains reported: "*if you have an idea, chuck it in, as it might stimulate something else*".

6. CONCLUSIONS AND DISCUSSION

The 3-month evaluation revealed the potential of a new form of information system to support human creative thinking in a workplace, even though the system was available on just 2 tablet devices and some desktop computers in a 40-hectare plant. This potential was underlined when the system continued to be used in the plant after the end of the evaluation, and the plant's health-and-safety captains called for wider rollout of the system using more devices.

The reported analyses of the evaluation results provided answers to the 4 research questions RQ1 – RQ4. The answer to RQ1 was *yes*, a sampled subset of the risk resolutions generated by employees with the *Risk Hunting* system were rated to be more novel and more useful than risk resolutions generated with the paper forms. Using established definitions that creative outcomes are novel and useful (Maher & Fisher 2011), employee use of the system was associated with risk resolutions that were more creative than risk resolutions reported by the same employees 12 months earlier. Moreover, employee decisions to share the risk resolutions with colleagues, with possible implications for their professional reputations, indicated the potential usefulness of the system-generated ideas.

The answer to RQ2 was *no*, employees generated some but not all risk resolutions using the *Risk Hunting* system within the 5-minute constraint. Rather, the average time to use the system to generate new risk resolutions with the creative guidance was over 5 minutes. The deployment of the system as reported, as a direct replacement for the paper forms, did not deliver within the time constraint imposed by the production lines.

The answer to RQ3 was *yes*, the risk resolutions generated with the *Risk Hunting* system were more complete than resolutions generated with the paper forms. The results revealed several possible reasons for this. Not only did the system require an employee to record a resolution to every documented risk, but also the employees retained idea stem text automatically generated by the system as part of many resolutions.

The answer to RQ4 was also *yes*, employees selected to use one type of creative guidance more than others. The superheroes creative guidance, which did not incorporate information specific to health-and-safety in manufacturing or provide employees with idea stem text, was used rarely, and the focus groups revealed that the guidance was not sufficiently directed. The previous risks creative guidance might have been more difficult to use. Task conditions such as time pressure have been reported to affect activities such as analogical processing (Gentner & Maravilla 2018). By contrast, the creative clues guidance was used to document almost double the number of risk resolutions, and might have been easier to use. It required fewer user interactions, and referred to objects and actions of the current rather than previous risks.

6.1 Threats to Validity

Of course, the results of the evaluation are subject to different multiple threats to their validity (Wohlin et al. 2000). Threats to construct validity limited the generality of the evaluation results to the underpinning theory. The research was underpinned by human-centred creative cognition (Kerne & Smith 2004), a process of concurrent idea generation and information search to support effective creative thinking. The results provided only indirect evidence that the system's information search and employee's idea generation by employees took place concurrently. Another construct validity threat was the use of word counts to measure completeness to answer RQ2. This measure ignored both domain knowledge and words that added little semantic content to the risk resolutions. However the alternative, an expert analysis of the semantic completeness of the 115 risk resolutions by the 4 experienced risk analysts, was beyond the resources of this evaluation undertaken in a real-world work setting.

More threats to the validity of our conclusions about the relations between the introduction of the *Risk Hunting* system and the different reported outcomes (Wohlin et al. 2000) were identified.

The plant was a complex work environment, and other external variables that might have increased the completeness and creativity ratings of risk resolutions included other health-and-safety training courses, changes to the plant's health-and-safety procedures, and the increasing health-and-safety expertise of employees. However, the inclusion of idea stem text from the system's generative rules in over half of all recorded risk resolutions provided evidence of direct system use to generate the more creative and complete risk resolutions.

Threats to the internal validity of the evaluation were influences that could have affected independent variables related to causality (Wohlin et al. 2000). External pressures exerted by the health-and-safety management and by the researchers on employees to use the *Risk Hunting* system during the evaluation period were present. To mitigate these threats, employees were allowed to use paper forms without penalty, and the researchers made only 2 site visits over the 3 months to minimize their influence. After the evaluation, the plant continued to offer the system, and other employees used it to record risk resolutions for at least another 18 months (Maiden et al. 2017) under non-evaluation conditions.

Threats to the evaluation's external validity were conditions that limited our ability to generalize results from the evaluation of one (albeit robust) research prototype information system – it took place in just one plant over just 66 workdays, and the novelty and usefulness ratings were about just 40 of the 234 risk resolution by just 4 risk analysts from a single organisation. As such, the evaluation outcomes provided only a first case study in the use of 1 prototype system in 1 workplace. We present this research primarily to demonstrate and encourage other researchers to design, experiment with and evaluate other information systems to support human creative thinking in non-creative work environments.

6.2 Final discussion

This empirical research is one of the first to demonstrate that a creativity support system can support complex daily work tasks over a period of months. But, in spite of this success, it also revealed diverse forms of barrier to this support, from the users (e.g. who lacked creative thinking skills) to the socio-technical (e.g. no work redesign was permitted to exploit system capabilities) and resourcing (e.g. low numbers of tablet devices).

Another important barrier was the time needed to use the *Risk Hunting* system in the context of production lines. Using it as a direct replacement for the paper forms did not lead to the completion of risk resolutions quickly enough. Possible reasons for this included the typing speed of many of the employees and some forms of the system's creative guidance. Presenting ideas semantically different to a current problem can slow ideation (e.g. Chan et al. 2017), and the *Risk Hunting* system's *superheroes* and *previous risk* generative rules, which exploited semantic differences, might have impeded quick completion of risk resolutions.

After the evaluation period, alternative deployments to speed up the *Risk Hunting* system use were explored. The *superheroes* generative rules were removed to streamline the system. The health-and-safety captains requested one tablet device for each of the plant's 30 production groups to increase access to the system, but the request was rejected. Team leaders redesigned their work on the production lines to be able to work off the line with the system as employees reported detected risks, but a reduction in the number of employees in the plant resulted in the team leaders and health-and-safety captains to need to fulfill other production roles. Instead, the *Risk Hunting* system's design was modified to resemble more closely the paper forms, and also implemented on large digital touchscreens in the plant. More details of this redesign and their impact are reported in Maiden et al. (2017).

The purpose of the *Risk Hunting* system contrasted with that of many existing and standalone creativity support systems (e.g. Kerne et al. 2008, Jain et al. 2015, Andolina et al. 2017, Magallanesa et al. 2018) – systems that supported divergent idea exploration during irregular activities. Instead, the *Risk Hunting* system support daily work tasks, but also enabled employees to invoke creativity support with a single click.

One feature that distinguished the *Risk Hunting* system from other creativity support systems (e.g. Kerne et al. 2008, Jain et al. 2015, Andolina et al. 2017) was the automatic generation of multiple incomplete ideas that employees often selected between, reasoned about and completed to generate risk resolutions. Not only did this feature require employees to type less and generate risk resolutions more productively, but also it also appeared to make work that the plant managers believed was disengaging more engaging. On reflection, simple linguistic guidance for creative thinking found in methods from Synectics (Gordon 1960) to TRIZ (Altshuller 1999) was reinvented using computer algorithms in more dynamic, domain-specific forms, so that it could be taken up and used in constrained work settings.

Furthermore, use of the *creative clues* generative rules was consistent with supporting employees to be in a cognitive state of actively exploring possible similar little-C ideas (Kaufman & Beghetto 2009) in one space (i.e. risk), rather than spaces of dissimilar ideas (Nijstad & Stroebe 2006) often associated with less productive idea generation.

Indeed, the automatic generation of incomplete ideas might have compensated to some degree for the employee's lack of creative thinking skills. Amabile & Pratt (2016) assume 3 major components necessary for creativity in any domain: expertise, intrinsic task motivation, and creative thinking skill. Most plant employees had work expertise and some intrinsic motivation to improve health-and-safety. Indeed, health-and-safety captains that might be expected to be most motivated to use the system also generated the most risk resolutions with it. But most lacked creative thinking skills, in spite of an exposure to manual creativity techniques reported in (Zachos et al. 2015). Whilst more training in creative thinking skills and the establishment of a climate that fosters creative thinking could both increase system uptake (e.g. Cougar et al. 1993), our results suggest that system-generated creative clues did compensate, to a degree, for the lack of training.

To conclude, this research reported a creativity support system designed for use daily work processes. Although the empirical evaluation demonstrated the need for the system to be streamlined, its generated creative clues enabled employees to explore multiple ideas to resolve a health-and-safety risk efficiently. The automatic generation of incomplete ideas that employees selected and completed provided an important means of increasing employee creativity and productivity, and compensated to some degree for employee's lacking creative thinking skills. The research provides a basic blueprint to design new creativity support systems for regular use in other work domains.

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