Evaluating Digital Creativity Support To Improve Health-and-Safety in a Manufacturing Plant

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ABSTRACT
This paper reports an evaluation of digital support for human creativity to improve health-and-safety in one manufacturing plant. It reports the use of this support as part of the plant's risk management process over 66 working days. Results revealed that this use led to more complete, more useful and more novel risk resolutions, compared with the original paper process, and informed how digital creativity support can be rolled out across manufacturing plants, as well as to other domains not recognized as creative.

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 advances in the use of digital support for human creative activities in disciplines recognized as creative, such as music, and film and television [1,12]. In contrast, there has been little digital support for human creativity in other domains, even though work undertaken in them often seeks to produce results that are novel and useful – accepted characteristics of creative outcomes [25]. Two of these other domains are manufacturing and health-and-safety. Increasing the health and safety of people is an aim of both organisations and governments. In the United States, for example, there were 4,500 workplace deaths in 2010, over 250,000 work-related injuries in 2011 [22], and in the European Union 2.5 million workplace incidents led to at least 3 person-days off work in 2012 [7]. More systematic, analysis-based systems have improved health and safety in manufacturing plants, but deaths and injuries continue to happen, so some organizations are now exploring other approaches, such as creative thinking, to complement their health-and-safety management systems.

CNH Industrial is one of these organisations. The established process for managing health-and-safety in its manufacturing plants involves all of its employees in the systematic detection and reporting of risks. Research had already extended the process with digital support for creative thinking about risk resolutions [31]. This paper reports the evaluation of the support in one CNH Industrial manufacturing plant near London. The plant's previous risk detection and resolution process and the digital support that extended it are reported at length in [31]. This paper's main contribution is to report, for the first time, the evaluation of this support through a systematic investigation of risk resolutions documented with and without the application. The paper ends with implications for rolling out the digital creativity support in a sister manufacturing plant, and deploying creativity support in domains not recognized as creative.

RELATED WORK
The digital support for creative thinking was designed to enable plant employees to generate risk resolutions that were both novel and useful to CNH Industrial's health-and-safety process. Novelty and usefulness are established measures of creative ideas and products [18, 23]. Different forms of creativity anticipate different degrees of novelty and/or usefulness, so models have emerged to distinguish between these different forms of creativity – often referred to as little-c and big-C creativity. The digital support developed for CNH Industrial was to support little-c creativity – everyday activities in which the non-expert may participate each day [15], to generate novel and useful risk resolutions.

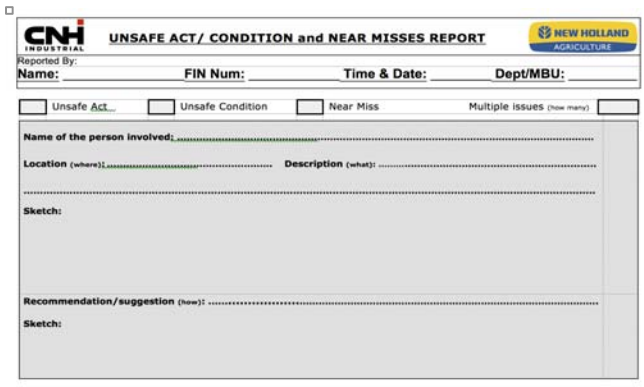
Most related research to develop digital support for humans to generate new and useful outcomes has been targeted at domains in which people are trained to have creative skills, for example the performing arts, music, and film and television [1,12]. This support has been developed using different types of algorithm from, for example, computational linguistics [21], creative search [16], analogical reasoning [9] and case-based reasoning to support innovation [8]. Beyond the creative industries, interactive creativity support is limited. Some has been developed to support creative thinking in science and engineering, for example in the forms of new tabletop visualizations to support biological discoveries [29] and social media to support collaborative creativity in

education [4]. Businesses often seek to support the creativity of their employees, but most of this support has been delivered as methods (e.g. [14]), techniques (e.g. [20]) and collaboration spaces (e.g. [6]) rather than interactive software. Limited creativity support for healthcare work also relies on techniques to encourage creative problem solving by nursing administrators [3] and family carers [13].

The health-and-safety and the manufacturing domains are no different. The few reports of creative thinking for use by employees in health-and-safety processes in manufacturing have been with techniques such as brainstorming, for example in BMW to improve health awareness on production lines [17] and Toyota to engage employees to improve work environments [30]. No digital support has been reported. Therefore, this research evaluated digital support for creative thinking about health-and-safety in manufacturing as an example of support in one domain outside of the creative industries. The research adopted a design science approach [28] – one that sought improvements to a problem in order to achieve a goal. The research goal was to increase creative thinking by plant employees in the health-and-safety management process of one CNH Industrial plant.

RESOLVING RISKS AT CNH INDUSTRIAL

The CNH Industrial plant east of London covers 40 hectares and produces 20,000 tractors each year at a rate of 1 every 4 minutes. Each tractor weighs several tons, so health-and-safety is a priority. The plant's established risk detection and resolution 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 on their person during shifts, in order to facilitate risk recording.


CNH INDUSTRIAL

UNSAFE ACT/ CONDITION and NEAR MISSES REPORT

NEW HOLLAND AGRICULTURE

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:

Figure 1. The CNH Industrial plant's paper form for reporting health-and-safety risks

The form offered limited space for an employee to write the risk location, description and recommended resolution, as well as to sketch the risk and/or resolution to supplement the text description. Periodically, a member of the health-and-safety team picked up all completed forms from collection points across the 40-hectare site. He used a desktop computer to transfer the text information from the forms to a *Sharepoint* database, then assigned each incident to the relevant manager or team leader. This manager or team leader investigated and resolved the risk, often based on the employee's original recommendation documented on the form. The form was then updated with the implemented resolution. Communication of these risk resolution implementations across the plant was simple – after the successful resolution of a risk, the health-and-safety team updated each form, generated A4 photocopies of it, and placed the photocopies on physical noticeboards across the plant. A more detailed description of this process is reported in [31].

The plant's management team identified that this current process, although fit for purpose, 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 asking someone else to investigate, for example: *ask maintenance to inspect*, in response to the risk: *wear strips falling from monorail*, and preparing 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*. Reasons for these short and incomplete types of resolution, suspected by the management team, included lack of sufficient engagement by plant employees in the risk resolution process, too much focus on exploring the causes of the risk, and insufficient support for recording complete and creative risk resolutions. Therefore, the team sought to empower the employees in the plant to participate more in the redesign of their work to be more safe through creative thinking, consistent with participatory and co-design approaches [24]. It requested digital support to achieve requirements that were specified as part of the research's design science approach: employees shall document more complete and creative descriptions of risk resolutions. This paper reports research that collected data to investigate 2 research questions associated with these requirements:

RQ1: Are risk resolutions generated by and with the digital support rated to be more novel and useful than risk resolutions generated with the paper system?

RQ2: Are risk resolutions generated by and with the digital support more complete than risk resolutions generated with the paper system?

The research questions investigated if employees would incorporate machine-generated creative guidance into the risk resolutions that were submitted to their managers and team leaders. Although such guidance had the potential to increase resolution creativity and completeness, it was not known if employees would accept or reject it for use during professional work activities.

To implement the design science approach, the digital support was deployed in a work context for a usage period. The research reported in this paper analyzed the data collected from that period to seek answers to the 2 research questions.

THE NEW DIGITAL SUPPORT FOR RESOLVING RISKS

A user-centred development process reported in [31] resulted in a new *Risk Hunting* application for individual employees to use to resolve risks before involving their managers and team leaders. The application supported human-centred creative cognition [16], an activity in which idea generation takes place with information search. An employee used the application to document a new risk, search retrieved information to discover new ideas with which to resolve the risk, then compose the generated ideas into a resolution that might be novel and useful. The resolution was then shared digitally with plant employees. The application was developed to provide digital support for:

1. User engagement and guided creative thinking that employees with no prior experience of this thinking could use within the constraints imposed by production lines. These constraints allowed employees just 5 minutes to record and resolve a detected risk;
2. In-situ form filling that was as simple as or simpler to use than with the paper process, so that risk resolutions would be described more completely. The application supported interactions with unrestricted written natural language entry and simple pull-down menus.

The application was optimized to run on Samsung Galaxy Tab 3 GT-P5200 tablets available in the plant. When a new risk was detected, the employee who detected it entered information to describe the risk, its location, type and effect using unstructured natural language and simple pull-down menus. Figure 2 demonstrates this use of the application to describe a new risk, in which an employee received a cut to the head when a duckboard sat on in order to check for oil leaks moved unexpectedly. One or more photographs taken with the tablet could be attached to the new risk description, to replace the sketches on the original paper form.

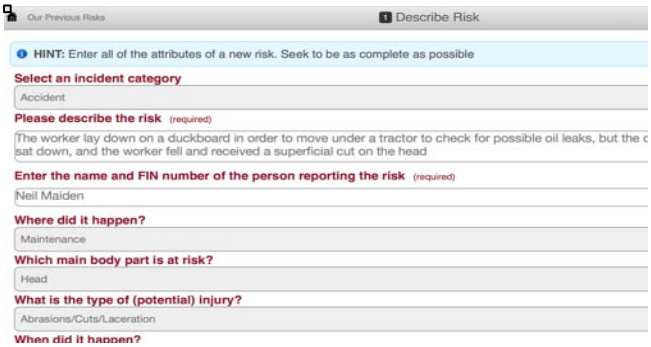


Figure 2. Entering a natural language new risk description into the *Risk Hunting* application

The application then presented 3 different creativity techniques. Each presented information content that was automatically generated by the application, to the employee to search and create new ideas with:

1. ***Ideas from new risk***: lists of creative clues generated automatically from patterns of creative manufacturing outcomes, instantiated with information that was extracted from the entered description of the new risk;
2. ***Ideas from superheroes***: descriptions of superheroes and their powers, retrieved from a library;
3. ***Ideas from previous risks***: descriptions of previous successful risk resolutions, retrieved from a repository.

The application invoked different computational services to retrieve the information for employees to search and generate new risk resolution ideas with. The application and services are described at length in [31]. This paper summarizes each only to provide an understanding of the creativity support that was evaluated.

The *Ideas from New Risk* Technique

To implement the ***ideas from new risk*** technique and generate information about creative clues specific to the current risk, the computational service retrieved patterns of different creative manufacturing outcomes from a library using a randomized search algorithm, then instantiated each retrieved pattern with partial information about the new risk retrieved using a second randomized search algorithm that shallow-parsed the risk description to extract names of objects and actions. The library was populated with 85 patterns of outcomes considered to be novel and useful in manufacturing by the researchers, and extracted from a larger library of creative outcome patterns in the TRIZ method [2]. Each pattern was re-written as a natural language creative clue. Some of the patterns were applied to generate creative clues based on mechanical or human objects, for example *think about dividing the [object] up*, and others to generate clues based on physical actions, for example *think about how to introduce feedback into the [action]*. Each invocation of the service returned 8 creative clues that instantiated the different patterns, and the *Risk Hunting* application displayed lists of these creative clues as shown in Figure 3. Example clues generated from the description of the slipping duckboard risk included to *think about providing a shell or cover for the worker*, and *deactivating the duckboard*. The employee could search these creative clues to generate new ideas to resolve the risk, such as *deactivating the duckboard with a brake*.

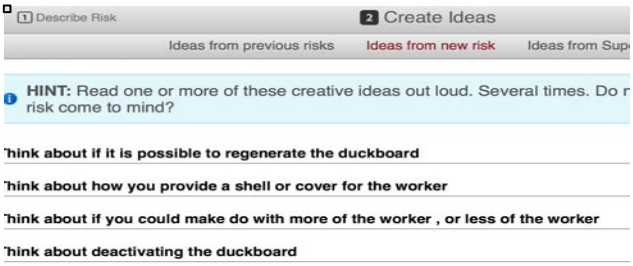


Figure 3. Some creative clues information presented by the application to guide the employee to generate new ideas

The *Ideas from Superheroes* Technique

To implement the ***ideas from superheroes*** technique and generate information about superheroes and their powers, the application invoked a second computational service that

automated support for a creativity technique called Superheroes [20]. The service applied a randomized selection algorithm twice, firstly to retrieve information about one superhero from a library of 26 pre-selected superheroes, and secondly to retrieve creative thinking guidelines from a second library of 32 pre-defined guidelines developed to support employee use of the technique. The application then presented this information to the employee to support creative thinking. For example, the application might present information about *Spider-Man*. The employee could search this information to generate new ideas to resolve the entered risk, for example to exploit a *spider-sense that warns of danger* to generate an alert if the duckboard slips.

The *Ideas from Previous Risks* Technique

To implement the ***ideas from previous risks*** technique and generate information about previous risk resolutions, a third computational service automatically retrieved similar risk resolutions using information retrieval algorithms adapted to implement creative search strategies. The service searched a repository of over 9000 resolved risks in an eXist native XML database. Each record in the repository was a natural language description of a previous risk and its successful resolution, with no additional semantic or ontological information. The service retrieved previous risks from the repository by dividing the entered risk description into sentences, tokenizing, part-of-speech tagging and modifying each sentence term to include each term's morphological root (e.g. *shifted* to *shift*, *leaks* to *leak*) using the Brill Tagger [5], then applying procedures to disambiguate each term by discovering its correct sense using context knowledge from other terms in the risk description (e.g. defining a *cut* to be *a wound made by cutting* rather than *a share of profit*) [19, 26]. The service then implemented different creative search strategies that expanded each term with other terms that have similar meanings to retrieve previous risk-resolution cases (e.g. the term *cut* is synonymous with the terms *gash* and *slice* which were then also included in the query based on the creative strategy). Each time that the service was invoked, it returned an ordered set of the 5 highest-scoring risk resolutions that the application presented to the employee, as shown in Figure 4.

One risk retrieved for the example slipping duckboard was *T-junction: curved blocks that encourage the entering driver to cut the corner, but this sets them on the wrong side of the road, and there is a greater risk of a head-on collision with another vehicle*. Although superficially different to the slipping duckboard risk, elements of the applied resolution to this risk, which included *squaring off the curved wall*, could guide creative thinking to avoid duckboard slippage, such as to square off rounded parts to prevent the duckboard from moving unexpectedly. The application enabled the employee to search descriptions of not only elements of the resolution to each retrieved risk, but also creative clues automatically generated by applying the same service from the ***ideas from new risk*** technique to the described risk resolution, as shown in Figure 5.

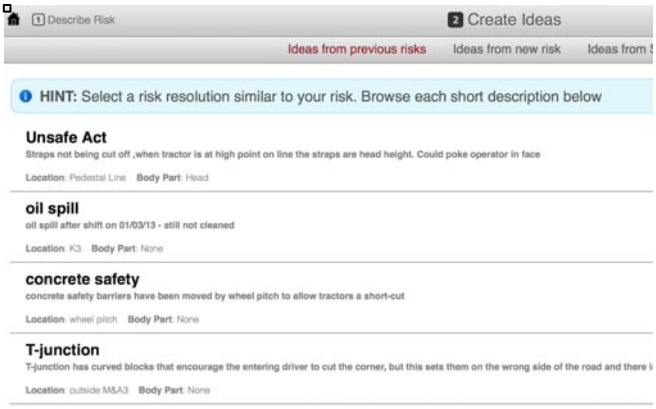


Figure 4. Previous retrieved risks: name, description, location and employee body parts put at risk

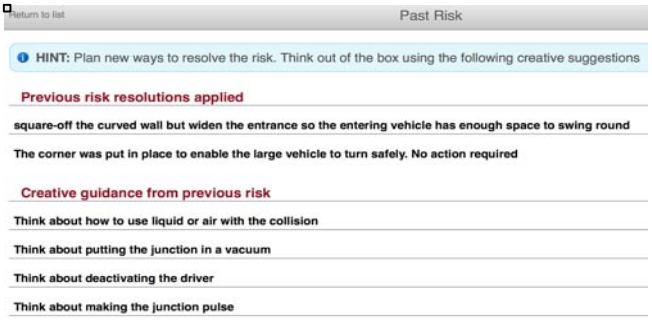


Figure 5. One retrieved previous risk - the different successful resolution actions (above) and generated creative clues (below)

At any stage, the employee could use the application to document ideas to resolve the risk. To encourage more effective creative thinking with creative clues, new idea textboxes were prefilled with idea stem text from the selected creative clue, which the employee could then extend, edit or overwrite, as shown in Figure 6. The idea stem text is *do the opposite of what is expected with the shift*, which could be extended with an idea to have a second person hold the duckboard in place.

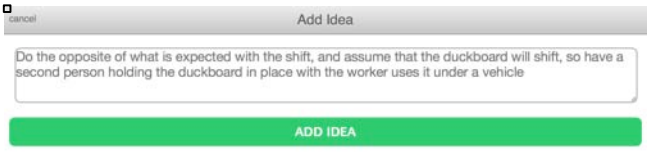


Figure 6. Use of the application to record a risk resolution idea from idea stem text automatically generated by the application

Inclusion of this feature enabled the researchers to explore if employees included machine-generated creative guidance into risk resolutions that they shared with the health-and-safety team.

To complete use of the application, the employee saved the resolution as a set of composed ideas with comments, and shared it with the managers and team leaders, who remained responsible for investigating and resolving the risk.

USE OF *RISK HUNTING* APPLICATION IN THE PLANT

Controlled formative evaluations of the *Risk Hunting* application revealed that plant employees were able, with minimum training, to use the application both to document encountered health-and-safety risks and to generate and document resolutions to these risks. Therefore, the summarized version of the *Risk Hunting* application was made available for use by plant employees from 16th March to 30th June 2015 – a usage period of 66 consecutive working days – to generate data with which to investigate research questions RQ1 and RQ2 – whether use of it resulted in risk resolutions that were more creative and/or more complete than risk resolutions documented with the paper system.

A potential user of the *Risk Hunting* application 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 application and the plant's Samsung Galaxy Tab 3 GT-P5200 tablets that the application ran on. These captains and advisors then provided the same training to employees in different roles on their production lines – mainly team leaders, assembly operators, repair operators and electricians. Although incentivized by the plant's management to use the application to record and to resolve risks, all of the employees were free to also use the paper system. Incentives to use the application included access to new digital support for resolving risks, faster sharing of employees' risk resolutions, and opportunities to inform the future development of the application. All employees had email and telephone access to the research team for help and support throughout the usage period. A limited budget at the plant meant that only 3 tablets were made available by the plant for application training and use, so some employees used the application on workplace desktop computers.

Preliminary data from the first 21 days of the 66 days usage period, summarized in [31], revealed that employees used the *Risk Hunting* application to document risks and resolutions. It revealed use of the creativity techniques, and some resolutions revealed evidence of creative thinking.

Therefore, at the end of the 66-day usage period, all of the data from the *Risk Hunting* application and paper system was collected and analyzed for the first time. Analysis of this new data revealed that plant employees documented risks and resolutions with it across the period – the longest gap without a new risk being documented was 2 working days. The employees did not report any major usability problems, although wireless coverage in some areas of the plant was poor and occasionally impeded application use. A total of 33 different plant employees used the application to document at least one risk and resolution, and 21 of these employees also used the paper system to document at least one other risk during the same period.

Informal analyses of the resolutions documented with the application revealed that the employees documented both simple and complex risk resolutions. One example of a simple risk was: *Buggy driver leaping off his buggy before it came to a standstill*, which was resolved simply with: *Drivers to be advised to stay in control of their vehicles at all times*. This style of resolution – only to advise the employee not to undertake the action that led to the risk – was also typical of resolutions that had been documented with the paper system in the same period, such as the resolution: *nothing to be left on drivelines*, to resolve the risk: *bolts left on rear of driveline by med line operatives*.

On the other hand, the more complex risk resolutions were described with more words, in multiple parts, and had more diverse content. One example of a more complex risk resolution was documented in response to the risk: *operator pulled exhaust stack from box and trapped his fingers between stack and metal bin*. The resolution was: *combine the operator with something else - possibility 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 opportunity for the operator to get his fingers trapped*. This resolution proposed both the use of a hoist combined with a more flexible box and changes to the work process for the health-and-safety team. Moreover, the wording of the resolution indicated the inclusion of idea stem texts that were automatically generated by the application from creative clues selected by the employee as part of the ***ideas from new risk*** and ***ideas from previous risks*** techniques. This text included: *combine the operator with something else*, which the operator had used to generate the resolution element: - *possibility of using the hoist for removing the exhaust from the bin.*

Another risk for which a more complex resolution description was documented was: *Engineering problem - app used in a group. Exhaust lift attachment does not fit all the tractor models forcing the operators to lift it by hand and carry it to the station on their shoulder*, and the risk resolution was: *remove something from the models - have all exhaust pipes standardised 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*. This risk resolution was described in more words than most generated with the application. It provided evidence of not only the use of idea stem texts automatically generated by the appli-

cation with the ***idea from new risk*** and ***idea from previous risks*** techniques, such as: *make parts or all of the shoulder move and adjust*, but also use of the superheroes technique, for example through reference to the Plastic Man character, to *use softer materials or silicone coating*.

Some managers and team leaders also implemented some of the 115 risk resolutions during the usage period. An example of one such resolution is shown in Figure 7. The left side depicts the risk reported in the application: *crush risk when decking the cab onto the unit on Pedestal Line*. One employee used the application to document the resolution: *introduce a clip with that can hold the washer in place and be easily removed when decking cab. Introduce clip that holds washer in place*, which removed the need for employees to place their hands under heavy equipment. The implementation of this resolution by the assigned team leader is shown on the right side of Figure 7.

Figure 7. The crush-hand risk on the plant's cab line – the original risk on left and its implemented resolution on right

EVALUATING RISK RESOLUTION CREATIVENESS AND COMPLETENESS

This first and informal analysis of all of the documented risks and their resolutions revealed preliminary evidence for increases in the completeness, usefulness and novelty of the resolutions documented with the *Risk Hunting* application, compared to the resolutions documented on the paper forms. Therefore, a systematic analysis was undertaken to compare all of the risk resolutions documented during the usage period using the *Risk Hunting* application to risk resolutions documented by the same employees during a corresponding earlier period using the paper system.

Evaluation Method

The evaluation method collected and analyzed 3 sources of data: (1) the application usage log, which recorded the date and time that each application feature was used by each plant employee; (2) the descriptions of the risks and resolutions documented using the application, and the total numbers of words used to describe these risk resolutions, as a surrogate measure of resolution completeness, and; (3) expert ratings of the risk resolutions documented using the application and the paper system, taken from a corresponding period. This corresponding period was 12 months earlier – the 16th March to 30th June 2014. Adverse weather conditions (e.g. cold temperature) and annual production targets (higher volume runs) were identified as two important factors that might have influenced occurrences of health-and-safety risks in the plant, so this comparison was chosen to ensure that the weather and production targets in both evaluations were similar. The application usage log data and the descriptions of risks and resolutions documented with the application and the paper system in the corresponding period by the same employees were all downloaded into MS-Excel spreadsheets, and analyzed statistically. The method did not collect measures of employee effort.

To generate the expert ratings of risk resolutions documented using the application and the paper forms, 4 risk analysts from the parent FCA 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 application and the paper system in the corresponding period. It was assumed that each risk analyst would be able to rate up to 40 risks and resolutions accurately in each available 1-hour session, therefore a random number generator algorithm at *random.org* was used to select 20 risks resolved with the application and 20 risks resolved with the paper system 12 months earlier: 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 application, 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*. Each risk and its resolution were presented on a new page above two 1-7 scales to capture the perceived novelty and the usefulness ratings of the resolution to each risk, see Figure 8.

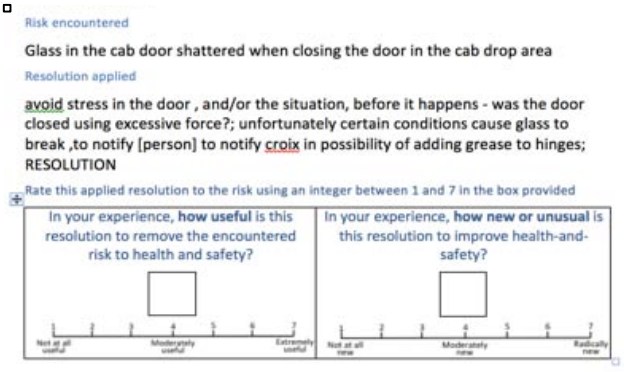


Figure 8. An example risk, resolution and the rating questions answered by the 4 risk analysts

Novelty and usefulness are oft-used measures to evaluate creative ideas and products [18, 23], and human expert judgment is an effective source of these novelty and usefulness measures [11]. This questionnaire format was selected to rate the resolutions. It asked each risk analyst to rate each risk resolution using this specialized definition of little-c creativity based on their own experiences [15] "*using measures using your own expertise and judgment, how useful is the resolution to remove the risk to health and safety, and how new or unusual is the resolution to improve health-and-safety?*"

Evaluation Results

During the usage period, a total of 33 plant employees used the new *Risk Hunting* application to document resolutions to 115 risks. In the corresponding period 12 months earlier, this set of 33 employees used the paper system to document 119 risks. Of this 33, 16 documented risks in that period, 14 were working in the plant but recorded no risks, and 3 joined the plant between the two periods. A similar ratio of health-and-safety captains and advisors documented risks in both periods – 9 of the 33 and 5 of the 16. Therefore, a decision was made to compare the complete sets of risks and resolutions from the 33 employees who used the application – the 115 risk resolutions from the application to the 119 from the paper system 12 months earlier – rather than any subsets of the data.

Comparing Risk Resolutions Documented with the Application and the Paper Forms

We investigated the expert novelty and usefulness ratings of the 20 selected resolutions to risks documented with the application and the 20 selected resolutions documented with the paper system. A Mann-Whitney test revealed that the usefulness ratings were greater for the risk resolutions documented with the application (Mdn=5) than with the paper system (Mdn=3.5), U=2371, $p<0.0001$. This indicated that the analysts rated the risk resolutions documented with the application to be more useful. A Mann-Whitney test also revealed that the novelty ratings were greater for the risk resolutions documented with the application (Mdn=4) than with the paper system (Mdn=2.5), U=1975, $p<0.0001$, indicating that the analysts also rated the risk resolutions documented with the application 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 application were more creative. Therefore, the risk and resolution descriptions were analyzed further, to discover possible reasons for the higher novelty and usefulness ratings attributed to the risk resolutions documented with the *Risk Hunting* application.

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 revealed that application use was associated with risk resolutions that were described with more words, see Table 1. An unpaired t-test revealed no significant difference in the numbers of words written to describe each risk with the application (*Mdn=14.5, SD=7.5*) and with the paper system (*Mdn=11, SD=15.7*) conditions; t=0.721, p=0.23. This indicated that application 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 application (*Mdn=21.5, SD=24.12*) and with the paper system (*Mdn=4, SD=6.0*) conditions; t=10.26708, $p<0.00001$). Risk resolutions documented with the application were described with more words than resolutions that were documented with the paper system.

	With application	With paper forms
Number of resolved risks	115	119
Mean number of words in risk description	15.2	14.1
Range of words in risk description	2 – 45	4 – 162
Mean number of words in risk resolution	29.8	5.6
Range of words in risk resolution	2 – 129	0 – 28

Table 1. Quantitative data about risks documented and resolutions generated with the application and with the paper forms

Furthermore, an investigation of the number of words used to describe the 20 risk resolutions documented with the *Risk Hunting* application that were rated by the experts for novelty and usefulness was undertaken, A Spearman Rank Correlation revealed that the experts rated resolutions with more words as more novel, r=.338, $p<0.005$, but not more useful, r-.205, $p>.05$. This association indicated that employees who used the application used more words to describe more novel risk resolutions, at least for some of the risk resolutions.

Employee roles in the plant appeared to have little effect on the differences in the numbers of words used to document risk resolutions. For example, the 9 health-and-safety captains and advisors documented risk resolutions with means of almost 33 words per resolution with the application and 8 per resolution on the paper forms. The 6 assembly operators documented risk resolutions with means of almost 20 words per risk resolution with the application and 3 per resolution on the paper forms. Similar results were found for other employee roles – the 33 employees documented risk resolutions with more words using the *Risk Hunting* application, regardless of their role.

A content analysis of all risk resolutions generated with the application and the paper system revealed 3 possible factors that might have influenced the higher word counts and novelty and usefulness ratings of the risk resolutions documented with the *Risk Hunting* application. The first had already been identified by the plant's management team – many of the resolutions documented on the paper forms only recommended doing the opposite of the risk cause, such as *do not leave parts on the units* or taking simple actions such as *bring to attention of operative at fault*. The employees used fewer words to describe these types of resolution. A second, related factor was that 23 of the 119 risks documented on the paper forms had no resolution at all, i.e. these paper forms were incomplete, whereas all 115 of the risks documented with the application had a resolution. Unlike the paper forms, the application 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 application – incorporated at least one idea stem text string that had been generated

automatically by the application's computational services. 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*, 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*. Both examples demonstrate the structure of many of the risk resolutions – the original idea stem text, followed by an extension of it to describe how resolve the original risk. As such, the inclusion of these idea stem texts appeared not only to contribute to the resolution word length, but also provided evidence that the employees used the creative clues to generate risk resolutions that the risk analysts rated as more novel, and used this clue content to communicate resolutions to managers and team leaders. Therefore, the research team analyzed the application log data for associations between the access to the 3 different creativity techniques and the documented resolutions.

Creativity Technique Use

The log data analysis revealed the numbers of risk resolutions documented after employee access to creativity techniques in the same session. Results of this analysis, and the means of the numbers of words of each set of risk resolutions identified in this analysis, are summarized in Table 2.

Creativity technique(s) accessed	**Number of risk resolutions**	**Mean numbers of words in risk resolutions**
None of the techniques	47	12
Ideas from superheroes only	2	28
Ideas from new risk only	27	35
Ideas from previous risks only	15	34
Ideas from new and previous risks	21	51
All 3 techniques	3	79

Table 2. Risk resolutions generated with the application after access to different creativity techniques in the application

Of the 115 risks, 47 were documented without the employee accessing any creativity technique. One example of these resolutions was: *re-instruct drivers of safety protocols,* for the risk: *buggy driver not wearing safety glasses, was wearing the on top of head whilst driving*. An unpaired t-test revealed a significant difference in the numbers of words written to describe each of the 47 risks with the application (*Mdn=11, SD=6.34*) and with the paper system (*Mdn=4, SD5.99*) conditions; t=5.818, p<0.0001. This indicated that, when the application was used only as a digital version of the paper form, employees documented risk resolutions with more words. Given the limited space available on the form shown in Figure 1, this result was not surprising.

These 47 risk resolution descriptions were then compared to the 68 risk resolution descriptions documented after an employee accessed at least one of the application's creativity technique in a session. An unpaired t-test revealed a significant difference in the numbers of words to describe each risk resolution documented without (*Mdn=12.5, SD=6.34*) and with access to at least one of creativity techniques (*Mdn=41.5, SD=23.7*); t=8.200626, p<0.00001) conditions, indicating that employees documented risk resolutions with more words after accessing at least one technique. Therefore, the risk resolutions documented after employees accessed the different creativity techniques were investigated.

Only 2 risk resolutions were documented after only accessing the ***ideas from superheroes*** technique, and neither resolution revealed evidence of superhero powers, for example: *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.*

Of the other 66 risk resolutions documented after accessing a creativity technique, 60 included idea stem text strings from the automatically generated creative clues. The use of these clues appeared to be important for the generation of resolutions that were more complete and more creative. Of these, 27 risk resolutions were documented after only accessing the ***ideas from new risk*** technique that presented only creative clue lists. An example of one of these resolutions was: *make the boxes move and adjust - area needs to be moved around to insure all boxes are situated within the lines*. Again, many of these 27 contained the original idea stem text followed by an extension that described how to solve the specific risk. Another 15 of the risk resolutions were documented after only accessing the ***ideas from previous risks*** technique. The research team received no reports about irrelevant previous risks being retrieved by the application, and at least some of the risk resolutions contained evidence of content transferred directly from previous resolutions. For example, to resolve the risk: *Tyres leaning possibility of falling and of rolling downhill, collision with vehicle or pedestrian*, the application retrieved the previous resolution: *DeRooy to enforce fitting of straps*, then documented the new resolution: *DeRooy to enforce fitting of straps; remove something from the stacks; balance the stacks with something else; Make sure tyres are stacked straight and not on edge of a hill. Using concrete poles in centre of tyres*. Like many of the 15, this resolution contained elements of the retrieved risk resolution and creative clues generated from information about that resolution within the ***ideas from previous risks*** techniques – elements that appeared to contribute to the novelty of the resolutions.

Furthermore, another 21 risk resolutions were generated after accessing both the ***ideas from new risk*** and the ***ideas from previous risks*** techniques, and described with more words than the resolutions generated after accessing just one of the techniques – a mean of 51 words per resolution. An example of one of these more detailed resolutions was: *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. Moreover, the most detailed risk resolutions, which were reported earlier in the paper, were documented after accessing all 3 creativity techniques – the 2 reported earlier were 73 and 129 words each. The analysis indicated that access to more creativity techniques was associated with more creative clue and resolution content.

CONCLUSION, DISCUSSION AND FUTURE WORK

The analyses of the risks and resolutions documented by the plant's employees revealed associations of the *Risk Hunting* application use with resolution completeness, novelty and usefulness. Unlike with the paper forms, use of the application was associated with all risks having documented resolutions, and these resolutions were documented with more words than the ones on the paper forms. Use of both the application's creative stem texts and more than one creativity technique were associated with risk resolutions that were described with more words, and this increase in the number of words to describe each risk resolution correlated with expert ratings for greater resolution novelty. Compared with risk resolutions that were documented one year earlier with the paper system, the risk resolutions documented with the application were rated by risk analysts to be both more novel and more useful. To answer the 2 research questions:

RQ1: Risk resolutions generated by and with the digital support were rated to be more novel and useful than risk resolutions generated with the paper system;

RQ2: Using word count as a surrogate for resolution completeness, risk resolutions generated by and with the digital support were more complete than risk resolutions generated with the paper system.

Overall, the results from the evaluation revealed that digital support for risk management with creativity techniques was more effective than a tried-and-tested paper process without this support. In particular, employee willingness to use auto-fill creative recommendations contributed to risk resolutions that were more creative and more complete.

Threats to the conclusion validity of the evaluation results concerned relations between the introduction of the application and the different reported outcomes [27]. The reported increases in the completeness, usefulness and novelty of the generated risk resolutions might also have been influenced by other creative activities, however none were available to the employees. The decision to use word counts rather than semantic content analyses to measure resolution completeness was another risk, but the plant management still considered it a good indicator of a complete resolution. Other threats arose from differences in the datasets from both periods that generated a possible bias towards employees who selected to use the application. However, both sets had similar ratios of captains and other roles, and employees had the same motivations to use the application and paper forms in both periods. Indeed, one important potential threat to conclusion validity was employee intentions – that they were not seeking to generate more creative and complete risk resolution. However their extensive qualitative comments, reported at length in a sister paper [32], did not reveal other motivations for application use apart from resolving risks in novel and useful ways. Threats to internal validity were influences that could have affected independent variables related to causality. One such threat was pressure from the management and research teams to use the application, however, employees were allowed to use the paper forms without penalty, and only 2 research team site visits took place during the usage period. Threats to the external validity of the results were conditions that limited our ability to generalize results – the evaluation took place in just one plant over just 66 workdays with 33 employees, and the novelty and usefulness ratings were about just 40 of the 234 risk resolutions by just 4 risk analysts from one organisation. To offset this threat, we are currently setting up the *Risk Hunting* application in a second CNH Industrial plant, as outlined below.

The findings informed refinements of the *Risk Hunting* application. Access to the most popular ***ideas from new risk*** technique was prioritized, to encourage its use. Not only did this technique require fewer interactions to use, but also the automatically generated creative clues referenced objects and actions extracted from the current risk (rather than retrieved previous risks), and this might have reduced cognitive effort needed by employees to use it. The little-used ***ideas from superheroes*** technique was removed, and interaction with the application was simplified and made responsive for use on web browsers on desktop computers on the production lines and in offices, and on large touchscreens positioned throughout the plant. This latter change was made to increase both access to the application and employee confidence with it, and from the summer of 2016, the application became the primary tool for capturing risks and resolution descriptions across the plant, replacing the paper forms. This digitization of the risk resolution process then offered the plant other capabilities, such as to visualize risks through time, in order to monitor risk trajectories. Furthermore, a new version of the application, called the *Caccia al Rischio*, is being rolled out for use in one Italian manufacturing plant of CNH Industrial. The 3 computational services were extended with automated language translation services to enable the application to process using English semantics with Italian language inputs.

The findings also provided insights into support for creative thinking in non-creative domains. Creativity support tools should afford pain-free search and exploration [10]. Results suggest that the *Risk Hunting* application affords these behaviours by manipulating written natural language that does not require user training. Use of the automatically generated creative clues and idea stem text were also important. One implication is that, in domains where users have not been trained to have creative skills, the machine will need to undertake creative reasoning. Indeed, this reasoning enabled the employees to be not only more creative but also more productive in the risk resolution process. Employees were

also able to resolve risks more thoroughly and quickly – an important win-win scenario that might have influenced the uptake and use of the digital support.

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