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Improved Safety Science: Utilizing a Design Hierarchy

Ulrica Pettersson

***Abstract*—**Collection of information on incidents is regularly done through pre-printed incident report forms. These tend to be incomplete and frequently lack essential information. One consequence is that reports with inadequate information, that do not fulfil analysts' requirements, are transferred into the analysis process. To improve an incident reporting form, theory in design science, witness psychology and interview and questionnaire research has been used. Three experiments have been conducted to evaluate the form and they have shown significant improved results. The form has proved to capture knowledge, regardless of the incidents' character or context. The aim in this paper is to describe how design science, in more detail a design hierarchy can be used to construct a collection form for improvements in safety science.

***Keywords*—**Design science, data collection, form, incident report, safety science.

I. INTRODUCTION

ACCIDENT and incident prevention is, to some extent, dependent on collected information e.g. the one gained through incident reports or after action reports. Such reports are normally written by people who took part in, or observed, an occurrence, predominantly at the sharp end of the organization [1] (The sharp end often represents the place/edge were the accident occurs, while the blunt end represents the organization and structure that supports activities at the sharp end). However, one serious problem is that many incidents are poorly reported or not reported at all [2], [3]. Today, the Swedish Armed Forces (SwAF) use a form (template) recommended by NATO for reporting [4]-[6]. This form provides the respondent with only a few headings and does not in fact facilitate or lead the respondent to write a useful report [1]. A serious consequence of this is that analysts receive inadequate foundation, which makes further analysis difficult or sometimes even impossible [4]. It seems like the incomplete forms might be due to the method with which they were designed.

In purpose to improve information collection after incident, a design science perspective has been used to design an incident report form that may plausibly provide analysts with the information they require. In this article, we will present a design suggestion and also results from three previous experiments. Then, we will compare our new structured, more detailed incident reporting form the form used at present in the SwAF.

A. Learning Organizations and Culture

A learning organisation can learn and improve through several activities; safety board work, formal training, follow-ups procedures, incident investigations, briefings and risk analysis are a few examples. Nonaka [7] argues that organizations which operate in changing environments ought to collect, process and create new knowledge frequently to make improvements. This is supported by Centre for Army Lessons Learned [8]. They stress that the lesson learning (LL) process is dependent on the unit operational data and that this data is regular and accurately collected. If the LL process becomes a natural part of the organisation and its members' daily work. The sooner the organisation can respond, the quicker and more efficient the current and future threats will be dealt with. In addition, Espejo et al. [9] argue that organisational learning will be effective when a distinction is observed, a solution created, acquired, and transferred in to the organisation.

Organizational learning takes place through individual learning in the organization [10]. All members within an organization constitutes a vital part of the learning process; the process can also be improved by incorporation of new members [11]. However, it is vital to understand that the organization itself cannot know or learn something, so what one must do is to identify *who* has learned a special topic and *where* the knowledge is stored. Most of the organizations' memory and 'what has been learned earlier' seem to be stored into its member's heads; however, just a smaller part is actually stored in databases or other files [11]. There is a variety of methods and technologies to provide support and facilitate the learning process, but learning is done by humans. According to that, personnel turnover (quitting, relocation, etc.) is *"…a great enemy of long-term organizational memory"* [12]. Further, they argue that transmission of information between individuals or groups is especially important.

Castaneda and Rios [13] also stress that organisational learning takes place when individuals can meat and create new ideas and share their knowledge through interaction with each other. This can be compared with Popper's [14] description of, knowledge; when it is transferred from world two to world three. Popper defines three worlds where the first one represents the physical world; the second mental world and the third is the world of intelligible or world of ideas, theories and objects of thoughts. Knowledge need to be transferred into world three, into a community sharing equal tasks, experience and competences, such as the Armed Forces, before it can be considered learned.

Argyris [15] emphasizes action in the learning process: learning occurs every time a mistake is observed and then corrected, while the mistake is defined as an occasion with conflicts between intention and consequence. Further, there is no grantee what so ever for learning just through experiences [15]. Organisational learning demands all individuals'

Ulrica Pettersson is with the Swedish National Defence University, Stockholm, Sweden (phone: 0046-73-394 37 68; e-mail: ulrica.pettersson@fhs.se).

engagement but unfortunately, this is seldom the case [16]. If staff is not willing to share accurate and timely information within the organization, they must be motivated to do so [17]. Simon [11] stress that the organisation itself and its goals is maybe the most important issues regarding organisational memory, since it *"provides the basis for defining the roles of organisations member"* [18].

Learning from experience is often associated to incidents and accidents; however, it can also concern positive occurrence) [19]. Notable is that the effort to reform and improve is not a new phenomenon. Previously, during the Roman Empire, Julius Caesar wrote, what sometimes is defined as the first after action reviews (AAR), over the war of Gaul (58 BC to 51 BC, Commentarii de Bello Gallico).

Learning from incidents can be archived through analysis from a single, or through clustering of multiple occurrences [20]. After an incident organisation often strive to collect as much information as possible about what happened, in purpose to understand and act to prevent it from being repeated in the future. To retrieve information concerning incidents and possible mistakes done by individuals, calls for an organizational culture that is built on trust and were staff can admit mistakes without being exposed to negative consequences [21]-[23]. Punishing staff for human error will not decrease errors, only the number of errors reported [21], [23]. This demonstrates two things, at first an organization needs to create a culture where members *want* to report. Secondly the members need to be provided with guidelines in *how* and *what* to report [1].

II. Design Science

Design research (DR) is a relatively new research field which started to grow during the sixties and the first conference was hosted in London in 1962 [24]. This was also the decade when the first methodology books appeared, e.g. Asimow 1962, Alexander 1964 and Archer 1965. Production and creation is no longer reserve to 'art', since DR is focused on utilizes research knowledge to useful solutions in the field [25]. Notable is that DR thoughts is not new observable fact, it was accepted a clearly a part during the old learning. We can trace it back all the way to Galileo, Bacon and Newton. However, during the fourteenth to sixteenth century a new school, containing the liberal arts of the western world started to grow, *where theory was highly prized and production was normally ignored*. Design was no longer included as it was during the old learning [25]. Buchanan also stress that design is not all about designing symbols and products, one should also include action and environment. E.g. *interaction design* includes experiences, activities and services because DR also focuses on how people relate to other people through the mediating influence of products.

Production and creation is no longer just an 'art', since design research is focused on utilizing research knowledge to achieve useful solutions in the field [25]. In 1969 Simon proposed *a science of design* [26]. During the 1980's the first journal was emerge and the Design Research Society initiated Design Studies [24]. DR has continued to grow and is today used in several disciplines. The design science perspective differs from research in natural science; it is normative and aiming at producing knowledge, useful for practitioners who will use it to design solutions in their own fields. *"...a design science does not limit itself to understanding, but also develops knowledge to the advantages and disadvantages of alternative solutions"* [27]. This can be compared to 'explanatory science' which is more theory driven and aiming at understanding the existing world, to the triplet describe, explain and perhaps predict. The same distinction can also be seen between basic and applied science [27], [28].

Simon [26] argues that beside the natural physical world, there is also an artificial world with a great number of man-made artefacts. Further Simon [26] stresses, that adaptation to a goal include the relation between the character of the artefact, the purpose to achieve and the environment where it is supposed to perform.

Gregor and Jones [29] have distinguished eight criteria's that gives explicit prescription on how to design an information system (artefact). These criteria are: 1. purpose and scope 2. constructs 3. principles of form and function 4. artefact mutability 5. testable propositions 6. justificatory knowledge 7. principles of implementation and finally number 8. an expository instantiation [29].

A. Design of a New Incident Report Form

According to Brehmer [30] the design process ought to start with the purpose of the artefact, and be built from criteria that support the purpose. For design to be satisfactory (evaluation) the designed 'system' needs to meet with criteria given before the design process. Brehmer [31] suggests a design hierarchy in five levels (Table I), based on Rasmussen's well-known abstraction hierarchy [32].

TABLE I
Design Hierarchy

Level 1	Purpose	*why* artifact exists and what it is supposed to achieve
Level 2	Design Criteria	represent *how* the artifact is supposed to attain the purpose
Level 3	Function	*what* the artifact must do to achieve the purpose
Level 4	General Processes	previous research that can inspire on how to accomplish the functions
Level 5	Form	*how* it achieves the functions

Design is a complex procedure and one should keep in mind, that design work is not only to design, it is work surrounded by many meta-activities e.g. preparation, shaping the design environment, seeks inspiration and also works on a relationship with the stakeholder/customer [33].

As said earlier, the design process should start with the artefacts purpose and be built upon the criteria that will support this purpose [34]. Our new form is designed with the purpose to facilitate for and lead the respondent to write an incident report that holds information required by analysts. The new form is designed with foundation from interview and questionnaire methodology and memory/witness psychology (Table II). It is rather general, to fit a wide range of incidents.

We also followed principles from questionnaire, such as limited number of questions in regard to limit the length of the form (time to fill in). A few examples are given to the respondent and the questions are focused on a specific topic. Finally, the form holds a space for 'Supplementary Information', which asks if the respondent wants to add any previous areas/issues, that the respondent might believe in having affected the incident.

TABLE II
THE DESIGN HIERARCH UTILIZED IN PURPOSE TO DESIGN A NEW FORM

Level 1	Purpose	Receive incident reports with the information that analysts require
Level 2	Design Criteria	Increase Scope and Quality and the information NATO and CALL requires
Level 3	Function	Remember what happened Able to report what happened
Level 4	General Processes	Memory psychology (cued recall) Interview and questionnaire methodology
Level 5	Form	Design propositions built on general processes, the New Form

B. Level 1: Purpose

After a huge accident or a somewhat smaller incident a number of questions are usually raised. The purpose of an incident report is to explore knowledge, analyse what happened and find basic contributing factors and circumstances of the incident. The incidetn report will help to find the right facts and circumstantial conditions and in the longrun increse the organisations possibilities avoid similar incidents in the future [34]. Incident forms are used in several organisations, however many experiences after incidents are not or at all or in some cases poorly reported [35]-[37]. Excellent information storage and high-speed techniques are not enough to preserve records of incidents according to the the US Army [37]:

> "*The importance of writing a good report cannot be overstated, because as good as the analysis results may be, they are worthless if you cannot successfully communicate them to others. Reporting is more than just writing things down, it is about conveying your message*" [38].

The collection of knowledge/unit operational data and the collection process is highly valued at the US Centre for Army Lessons Learned (CALL). It is further stressed that this is a commander's responsibility [19], [37]. That incident reports are poorly written was also confirmed regarding Swedish officers after their return from international missions [39].

C. Level 2: Design Criteria

Managers of the incident reporting process can request reports from a specific unit or domain, so called top-down driven reporting. Alternatively, the report process can be initiated by the individuals working in the field, bottom-up driven reporting. Either way, analysts or other receivers of the report expect to find certain specified information in the report. Jacobsson [40] argues that content in an incident report is basis for further learning and that reporting qualification of the reporter is vital. Jacobsson stresses *scope* and *quality* of a report is most essential, for further analysis. In this case scope is represented by; description of the event, type of equipment, damages, date and time, location, direct cause and contributing cause etc. While quality stands for the level of details of the aspects reported under scope [40]. The form should be designed to help the reporter to provide good information and recommendations and Jacobsson suggest that the reporter should be able to leave additional information [40].

The minimum of information CALL request in a report is: contact information, operation and location and an observation title. Further, they need background information (including relevant items) and insight in; what happened, under what conditions, how the unit was affected and why. Finally, what should be learned by the event [37].

At JALLC one argues that quality of a report is dependent on if it contains a cause (why) of the incident occurred, and if the explanation seems to be correct? They also argue a report should be credible, logically convincing and easy to read. Further on every report should contain a recommendation which preferably address the cause. [41].

D. Level 3-4: Function and General Processes

The general processes, established research, in this section constitutes of memory psychology and eyewitness testimony and memory research. Recognized research results from those fields will help the respondent to obtain the function; *remember* what happened and *report* what happened.

From a reporting perspective, a witness testimony contains three related steps. *Encoding* which represents the individual's observation and registration of a certain occurrence, secondly *storing* the time period between encoding and testimony. Finally, *retrieval* where observations are recalled [42]. Eyewitnesses might need support as they try to retrieve information. Results in eyewitness research strongly recommend beginning with free recall and to avoid close-ended questions [42]. Examples can be fruitful however they should be considered carefully [44]. One way to do so is to reinstate features present at the time of the event; one should ask the eyewitness what took place before the event, time of the day, weather conditions. The process assumes to facilitate (provide additional cues for) the eyewitness retrieval of the original encoding of the event [43]. Forms or questionnaires should be constructed with the intention to facilitate and guide the respondent to recall and report the information requested for.

Purpose, audience and *culture* are three important corner stones in the design of a questionnaire. A questionnaire needs to be tailor-made for the context where it is used [46].

In interview research, one will find two different methods, written questionnaires and verbal interviews [44], [45]. Regarding questionnaires there will be no second chance to rephrase the question as during an interview, therefor one must During the design of a questionnaire, one must therefore carefully analyze what the questionnaire is supposed to answer [45]. There will be no opportunity to explain the questions or to clarify the answers. Nor will there be opportunities to make supplementary questions [44]. However, digital questionnaires manage to make predefined supplementary questions to some

extent. Likewise, pauses and encouragement are not practicable using questionnaires.

1) Simple introduction that catches the respondent's attention might facilitate getting started and making them feel comfortable,
2) Consideration of the questions' position carefully.
3) All questions should be clear, easy to understand and possible to answer.
4) Be aware that the total length must not be repellent.
5) Remember to avoid leading questions [46].

A respondent's interest seems to decrease after a certain time [45], [47]. It is extremely difficult for respondents to try to predict the future or even to answer hypothetical questions. Avoid those kinds of questions or at least considerer them carefully [46].

Close-ended questions forces the respondent to choose from a limited number of answers in the meantime open-ended questions gives the respondent a chance to answer in any way they find appropriate [45]. Using open-ended questions is normally more burdensome to answer and requires extra analysis, although might be preferred when one cannot define in terms of *well-known* variables of interest. Do not squeeze in several questions in one. Instead it is better to divide them into several sub questions [46], [47]. Questions should flow logically, from least sensitive and more general into more sensitive and more specific [46]. To avoid misunderstanding expression, phrases and vocabulary need to be known to the informants [47]. Open-ended questions give additional information however they tend to take longer time for the respondents to complete. Analyse of open-ended questions are also time consuming [16], [44]. Reason [16] stress that format, length and content are essential.

E. Level 5: Form

The new form represents the form, viz. the artefact designed through use of the design hierarchy.

III. Evaluation of the Designed Artefact: Previous Experiments

Our form has previously been evaluated in three experiments [34], [48]. In all three experiments the participants were randomly divided into two equal sized groups; one group reported in the form used by the SwAF and the other reported in the new form.

The first two experiments were conducted with 40 undergraduate students from Swedish National Defence University (SNDU). In the first experiment, all participants wrote an incident report after been watching the very same film sequence (incident) and then. The second experiment was conducted to test the form's generality; ten altered film sequences (incidents) were used to approximate the situation. To confirm that the *new* form also would be useful in a military context a third experiment was conducted, including 30 officers (rank of Captain (army, air force) Lieutenant (navy) or Major (army, air force) or Lieutenant Commander (navy)). All participants were given instructions to describe an incident they had participated in or observed during recent international missions [34].

INCIDENT DESCRIPEION

Topic:

_____

Observation:
What happened? (describe your observation as detailed as possible)

_____

Facts:
Who were the main actors/components? (describe them in detail)
Where did the incident occur? (e.g. country, city, area/region, organization)
In what context did the incident occur? (e.g. environment, climate, weather, °F/°C)
When did the incident occur? (e.g. dd/mm/yyyy, hh:mm)

_____

Conclusion:
What could be possible reasons for this incident?

_____

Recommendation:
What should be done to avoid/decrees, this kind of incident in the future?

_____

Complementary information:
Where there any previous areas/issues, that might have affected the incident?
Are there other vital areas/issues of interest or uncertainty, relation to this observation?

Fig. 1 New Incident Report

To achieve independent evaluation, without influence of the researcher, evaluation in every experiment was done by two independent reviewers. In the two first experiments two civilians (political scientists) at SDU did the evaluation. Master reports was created, in consultation with analysts from the SwAF intelligence service, later used as keys by the evaluators. In the third experiment, all reports were individually evaluated by two male officers from the SwAF, one Lieutenant (navy) and one Lieutenant Colonel (air Force), both of them holding a PhD.

Results from all three experiments proved significantly enhanced information in the reports, regardless of the character of the incidents and the context in which they occurred. The two first experiments demonstrated substantial validity since we had the advantage of knowing exactly what happened before, during and after each incident since the participants reported what they had seen in films. This was of course not possible when studying incident reports from real life situations [1], [34].

Complete procedure, evaluation result and statistics can be found in two articles published by Pettersson: *A New Incident Report Form Leads to Improved Foundation for the Lessons*

Learned Cycle [48] and *A form to collect incident reports: Learning from Incidents in the Swedish Armed Forces*" [34].

IV. Discussion and Conclusions

As described in the introduction, incident reports appear to lack vital information and do not meet with analysts' requirements. This leads to that analysts are unable to analyze and understand what happened and also to find adequate improvements to prevent it from being repeated [1]. There seem to be at least two plausible explanations for the prevalence of weak reports. At first, members of the organization do not want to report incidents. This explanation is associated with organizational culture and it has received a great deal of attention in previous research into safety science. The second explanation is that the organizations members may not be able to report incidents, in absence of sufficient guidance.

We argue that the information obtained in incident reports are closely related to the questions asked in the form, and have through design science constructed a new form. Design science perspective facilities, for designing a new form that significantly improves the quality of the information collected. The *design hierarchy* provides guidance with respect to how one could enable respondents to retrieve and report more of the required information, viz., by using previous research in memory psychology. The use of cues (viz. the examples provided after some questions) turned out to be particularly fruitful. The design hierarchy also helped us to understand how interview and questionnaire methodology could be used to enhance respondents to report the by analysts required information incidents.

Our results imply that it is not less important to enable employees to report incidents (capable of), than it is to create a culture in which they dare to report (want to). The series of three experiments have shown that the new form significantly increases the quality of collected information after incidents, regardless of the incidents' character or context and thereby provides means to improve the foundation for the lessons learned cycle.

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