A multi-method approach towards identifying situational factors and their relevance for X-ray screening

Stefan Michel, Nicole Hättenschwiler, Milena Kuhn, Nadine Strebel and Adrian Schwaninger
School of Applied Psychology
University of Applied Sciences and Arts Northwestern Switzerland
Olten, Switzerland
and
Center for Adaptive Security Research and Applications (CASRA)
Zurich, Switzerland

Abstract—In the last decade, large investments have been made to improve airport security for safeguarding air transportation. X-ray screening of passenger bags is a key component of airport security procedures. State-of-the-art X-ray screening systems provide high quality images, yet the decision whether a passenger bag has to be further investigated (e.g., using manual search) still relies on human operators (X-ray screeners). The primary work task of X-ray screeners is to visually inspect X-ray images of passenger bags for prohibited items and decide whether a bag is OK or not in a reasonable amount of time. It is well-known from scientific research that human performance depends on a variety of situational factors. Understanding which situational factors are relevant for X-ray screening at airports can provide important insights for increasing efficiency and effectiveness at airport security checkpoints. A multi-method job analysis was developed to identify situational factors which influence X-ray screeners’ primary work task in cabin baggage screening (CBS) at a European airport. First, qualitative work observation was applied to identify situational factors. Then, interviews with experts were conducted to gain further insights on which situational factors could be relevant for X-ray screening by human operators. These methods provided the basis for a survey conducted with X-ray screeners in order to obtain ratings of how relevant situational factors are and how often they occur. A list of main situational factors that influence X-ray screeners’ primary work task was elaborated throughout the process and summarized in a categorical system using impact and frequency. Factors of high impact and frequency were bag content depending on different kinds of materials; bag complexity and how bags and trays are packed and put on the conveyor belt. Factors of medium relevance were factors of the work environment (noise, light, air, temperature and quality of X-ray images), team specific factors (communication, time pressure and team atmosphere) and other factors affecting X-ray screening (operational processes of secondary bag search, loading of bags, passengers causing fuss and hassle). The reported results indicate the presence of several situational factors affecting X-ray screeners’ primary work task.

Keywords—job analysis; aviation security; human factors; situational factors; X-ray screening; human-machine interaction; triangulation

I. INTRODUCTION

The relevance of aviation security has increased dramatically since the terrorist attacks of September 11th 2001 and subsequent terrorist attacks (for a review, see for example [1]). In particular, airport security screening has become an indispensable need for securing civil air transportation. X-ray screening of passenger bags is the default method for detecting prohibited items in passenger bags. State of the art X-ray screening machines provide good quality images with high image resolution, yet the actual detection of prohibited items remains a challenging task for human operators (X-ray screeners) depending on a variety of factors (e.g., [2]; [3]; [4]; [5]; [6]; [7]).

Several studies have identified X-ray screeners’ abilities and aptitudes as well as initial and recurrent training as important performance factors ([8]; [9]; [10]). [8] and [11] have identified three image-based factors influencing detection performance of X-ray screeners: view difficulty (viewpoint) of prohibited items; superposition by other objects and the complexity of a bag depending on the number and type of objects contained in a bag. Computer-based training can be a powerful tool to acquire, increase and maintain knowledge on which objects are prohibited and what they look like in X-ray images (knowledge-based factors) (for more information see [9]; [12]; [13]; [14]; [15]).

Besides knowledge-based and image-based factors, several other factors can have an impact on screener performance. [2], [7] and [16] reviewed situational factors such as the usability of the security screening system, workload, fatigue, stress, anxiety and motivation as variables to take into consideration for enhanced understanding of determinants of X-ray screener performance. [17] argue that especially in studies about complex phenomena the systematic combination of various types of data is an indispensable aspect and leads to a broad data set. To increase the scientific knowledge regarding situational factors relevant for X-ray screener performance, we used a multi-method approach, also called triangulation.
According to [18], triangulation can be distinguished as follows: triangulation by data source (data collected from different persons, or at different times, or from different places); triangulation by method (observations, interviews, analyses of documents, etc.); triangulation by researcher (comparable to interrater reliability in quantitative methods); triangulation by theory (using different theories, for example, to explain results) and triangulation by data type (e.g., combining quantitative and qualitative data). Qualitative studies in the social sciences often involve choosing triangulation sources that have different strengths, foci, and so forth, so that they can complement each other.

An often applied multi-method approach making use of the concept of triangulation is job analysis. [19] defines job analysis as the collection of information on the following components: (a) job-oriented behaviors including tasks and work procedures; (b) worker-oriented behaviors such as providing supervision and making decisions; (c) working with machinery and equipment; (d) performance evaluation criteria such as error rates and productivity; (e) work environment factors; (f) and personnel requirements such as personality characteristics, physical abilities, and skills. [20] defines the three main goals of task-oriented job analysis as the description of observables, the description of work behaviors that are independent of the worker, and collecting data that is replicable and verifiable.

Based on the concept of triangulation, job analysis can include different methods to collect data such as observations, questionnaires, interviews etc. that can be combined according to the aim and scope of the analysis ([19]; [21]). A variety of job analysis methods and commercially available job analysis instruments have been developed over the years differing by the type of data they collect [21]. So far, there are no instruments directly applicable to the work of airport security X-ray screeners. Hence, a new approach had to be created using the concept of triangulation to identify situational factors affecting X-ray screeners’ primary work task at the security checkpoint. To this end, we made use of the concept of triangulation by data source, method, researcher and data type.

The aim of this study was to investigate which situational factors have an impact on X-ray screeners’ primary work task, i.e. to visually inspect X-ray images for prohibited items in passenger bags and decide whether a bag is OK or not in a reasonable amount of time. A multi-method job analysis approach was applied containing three main steps: a qualitative work observation, expert interviews and an online questionnaire survey. A categorization system was developed to group situational factors based on impact and frequency. To our knowledge, this is the first multi-method approach in aviation security research to identify situational factors. Therefore, it could serve as a starting point for future investigations on situational factors.

II. METHOD AND PROCEDURE

The job analysis was conducted at an international European airport with the aim of identifying situational factors affecting X-ray screeners’ primary work task. The main steps in this multi-method approach include a qualitative work observation, expert interviews and an online questionnaire survey (see Fig. 1).

Fig. 1. The three main steps of the multi-method job analysis conducted in this study.

The aim of the qualitative work observation was to gain a first impression of situational factors affecting X-ray screeners’ primary work task at the airport security checkpoint. Observations took place on three occasions covering different work areas (one centralized security checkpoint and two transfer checkpoints). Based on these qualitative observations, guidelines for semi-structured expert interviews were created. The interviews aimed at differentiating previously observed situational factors and at identifying additional relevant situational factors. Subsequently, in order to investigate impact and frequency of situational factors affecting X-ray screeners’ primary work task, a representative online questionnaire survey was conducted.

A. Qualitative Work Observation

Fig. 2. Illustration of a security checkpoint with the four positions of an airport security officer (bag loading, pat-down search of passengers, X-ray screening of passenger bags, secondary search of passenger bags).

In order to understand the work environment of X-ray screeners and variables that might affect their primary work task an understanding of the work routine at the checkpoint is required. Airport security officers (ASOs) work in a crew with typically four positions through which crew members rotate periodically during a work day1 (Fig. 2). The ASO at the position of the loader supervises the placing of bags on the conveyor belt. Meanwhile, the security officer at the position of X-ray screening (i.e. the X-ray screener) visually inspects X-
ray images for prohibited items in passenger bags and decides whether a bag is OK or not in a reasonable amount of time. If the X-ray screener decides that there is a suspicious item present (NOT OK decision), the bag will be handed over to the position of secondary bag search for follow-up action (e.g., manual search, rescreening or trace detection of explosives). The fourth position involves resolving alarms of metal detectors by pat-down search of passengers [16].

A guideline for qualitative work observation was prepared based on an existing schema [22] and researchers expertise focusing on topics of work tasks (uncertain situations, monotony, time pressure, interruptions), working environment and workplace (influence of noise, temperature and lightening). A final optimization of this guideline was achieved by creating a keyword list through a pilot observation intended to assist researchers while observing. Keywords were categorized by the above mentioned topics: work tasks, working equipment and workplace.

Observations took place on three different occasions by three researchers during four to six hours covering different checkpoints (centralized security checkpoint and transfer checkpoints), and work shifts (morning and afternoon shifts). While gathering data through observation, one has to consider that human observations might be biased [23]. Therefore, triangulation by researcher is a way to ensure the cross-checking of the observed data by more than one researcher and to enhance reliability [17].

B. Expert Interviews

18 experts (50% female) participated in a semi-structured interview that was created based on the results of the qualitative work observation. The area of expertise of the interviewee varied between ASO, team manager, sector manager, employee of the personnel dispatching center and employee of the instruction center. The mean age of the experts was 41.29 years (SD = 9.15) with an average job experience of 9.56 years (SD = 7.34) and employed between 50 and 100%. Interviews took between 70 to 90 minutes and were held by two researchers, where one researcher was asking questions and the other researcher was writing the protocol.

The outline for the semi-structured interviews was prepared based on the results of the qualitative work observation. Depending on the employment function of the interviewee, the outline was adapted to suit the knowledge and expertise of the interviewee. Questions were constructed to re-examine results gained from the qualitative work observation and to differentiate situational factors affecting the X-ray screeners’ primary work task. The outline further contained questions prompting the interviewee to present additional and relevant situational factors, as well as questions relating the work process and tasks concerning the four positions of ASOs (bag loading, X-ray screening, secondary bag search and resolving alarms of metal detectors by pat-down search of passengers). More specifically, the semi-structured interviews started with a brief introduction and the presentation of the aim of the study. Then, relevant situational factors were first asked in a general manner and afterwards more specifically with questions like "What would you say is influencing the work as an X-ray screener the most?" and "Do you think the passenger queuing has an influence on the X-ray screener? If yes, how and when?"

To conclude the interview, more general questions were asked regarding differences between security checkpoints, shifts and seasons.

Before interviewing the experts, a test interview was conducted with a former security officer to verify the comprehensibility of the questions.

C. Online Survey Questionnaire

In order to investigate impact and frequency of situational factors affecting X-ray screeners’ primary work task and to complement the results of the expert interviews, an anonymous online survey questionnaire was conducted.

All participants were certified X-ray screeners of an international European airport, meaning they were all selected, supervised, trained and certified according to the standards set by the national appropriate authority (civil aviation administration) compliant with the regulations of the European Commission [24]. Altogether, 73 ASOs completed the online survey. The average age of the participants was 38.28 years (SD = 11.33), 50.68% of the participants were female and the average amount of job experience was M = 5.03 years (SD = 6.41).

The survey instrument was composed of questions concerning situational factors evaluated in the expert interviews. These situational factors were frequently reported by experts or considered as relevant by the authors. Each factor had to be rated using a 10-point scale regarding frequency (e.g. "How often do you feel time pressure?") and impact (e.g. "How much does time pressure influence the X-ray screeners’ primary work task?")). A response of 1 indicated that frequency/impact of the factor was very low and a response of 10 indicated that frequency/impact was very high. Attempts were made to keep questionnaire length and reading difficulty to a minimum.

III. RESULTS

Results for each step of the multi-method approach are summarized below.

A. Qualitative Work Observation

Main findings can be summarized by the following categories: passengers and their bags, time pressure, team work and team constellation, interpretation of X-ray images, work environment and work equipment, and further situational factors and processes.

Passengers and their bags can be subdivided into frequent flyers (e.g. business people) and infrequent flyers (e.g. holidaymakers). The process of screening might be affected differently depending on experience and habit of the passenger as they differ regarding time to pass the checkpoint, amount, size and complexity of bags, number of prohibited items and bulkiness of items.

Time pressure might vary depending on the number of passengers waiting to pass the checkpoint. Despite passengers...
causing fuss and hassle, the work of the X-ray screener analyzing X-ray images seemed not to be affected too much according to the qualitative observation.

Team constellation and team work might play an important role as it could be observed that the different positions within the team affect each other. For example, depending on how precisely the loader works and instructs the passengers, the throughput at the checkpoint and screening of X-ray images either goes smooth or passengers have to wait longer. Further, a fast throughput relies on the availability of a male and a female officer working both at the metal detector because pat-down search of passengers can only be conducted by a same sex ASO. A lot of communication could be observed between the X-ray screener and the ASO carrying out secondary search of bags, as coordination is needed with the X-ray screener regarding the type of secondary search. (i.e. trace detection, bag separation, rescreening of bags etc.).

In addition, the observation of the work environment also implied other factors such as light, noise and temperature having an influence on the primary work task.

B. Expert Interviews

Expert interviews were analyzed independently by two researchers using qualitative content analyses [25] resulting in an indicative categorical system. Qualitative content analysis is defined as an approach of empirical, methodological controlled analysis of texts within their context of communication, following content analytical rules, and a step by step model, without rush quantification [25]. Based on this, the aim of our analysis method was to identify a content structure, namely categories and subcategories, throughout the interview protocols. Categories were based on the results of the qualitative work observation and complemented the results of the expert interviews. This led to the development of an exhaustive categorical system including all information gained throughout the first two steps of our multi-method approach. The resulting categories and exemplary subcategories are shown in Table 1:

<table>
<thead>
<tr>
<th>Category</th>
<th>Example Subcategories</th>
</tr>
</thead>
<tbody>
<tr>
<td>Work environment</td>
<td>Noise, light, temperature</td>
</tr>
<tr>
<td>Work processes</td>
<td>Monotony, procedural autonomy1, standard operating procedures</td>
</tr>
<tr>
<td>Decisions</td>
<td>Secondary search processes (e.g. rescreening, bag separation, trace detection etc.)</td>
</tr>
<tr>
<td>Workplace</td>
<td>Changes of work processes, checkpoint</td>
</tr>
<tr>
<td>Passenger</td>
<td>Passenger volume, passenger type, assignment of bags to passengers</td>
</tr>
<tr>
<td>Bags</td>
<td>Type of bag, bag content</td>
</tr>
<tr>
<td>Further information</td>
<td>X-ray image interpretation, search strategy, positions at the checkpoint</td>
</tr>
<tr>
<td>Team</td>
<td>Constellation of team, distractions</td>
</tr>
<tr>
<td>Further factors</td>
<td>Seasonal factors, expertise, experience, TIP</td>
</tr>
</tbody>
</table>

C. Online Survey Questionaire

Based on means of impact and frequency ratings, each factor was assigned to one of nine categories of relevance using the scheme illustrated in Fig. 3. Using this system, situational factors were categorized as follows:

- High relevance (1a,1b,1c): nature of bags (bags with many electronic devices; bag complexity).
- Medium relevance (2a,2b,2c): large bags; transport trays (nature of loading); bad quality of X-ray images; liquids with more than 100ml content; passengers (fuss and hassle); team (communication, work of loader and secondary search; time pressure; poor mood); work environment (noise, light, screen reflection, temperature, poor air quality, draughts).
- Small relevance (3a,3b): passenger (stressed passengers, delayed passengers, high passenger volume, fluctuation, asking questions, distractions); team (distractions, working speed of loader and secondary search); briefings of supervisor.
- No relevance (4): amount of trays (too many, not enough); amount of bags for secondary search; characteristics of passengers (e.g. effect of age in uncertain situation); allocation of bag to passenger.

Fig.3. Categorization system defining relevance as a function of frequency and impact using a 3 x 3 grid.

Some differences for gender on frequency of some situational factors revealed that female X-ray screeners perceived the frequency of some situational factors higher as male X-ray screeners. Furthermore, some differences were found for age of service regarding frequency and impact for some single situational factors.

IV. DISCUSSION

The main aim of this job analysis was to investigate the relevance of situational factors for X-ray screeners’ primary work task at the security checkpoint. Following a multi-method approach the concept of triangulation was applied using qualitative work observation, expert interviews, and an online survey questionnaire.
In this study, we conceived of triangulation as a process of combining and synthesizing results that are gathered using different data sources (data collected from different persons, at different times); different methods (observation, expert interviews, questionnaire) and data types (combining qualitative and quantitative data). The data gathered using this multi-method approach was combined to develop a comprehensive set of situational factors influencing X-ray screeners' primary work task. Thereby, main situational factors were elaborated throughout the process and summarized in a categorical system.

High relevance for nature of bags (bags with many electronic devices or high bag complexity) can be explained with image-based factors affecting detection performance. The findings from this study confirmed the importance and the influence on detection performance of the three image-based factors which were defined by [8]. As prohibited items can be more or less superimposed by other objects (effect of superposition), the presence of many electronic devices may lead to areas in the X-ray image of the bag which appear dark and therefore could obscure prohibited items ([9]; [28]). Furthermore, bag complexity (depending on the number and type of other objects in a bag) can impair detection performance ([8]; [9]). Also, the attributed relevance of large bags, transport trays (nature of loading), quality of X-ray images and number of prohibited liquids (> 100ml content) should be interpreted carefully by taking into account the above mentioned image-based factors.

The influence of passengers causing fuss and hassle and communications between ASO team working at the airport security checkpoint has already been identified as a relevant factor in previous research [27]. Often, passengers are not pleased to have to pass through security control and therefore ASOs need high interpersonal skills (e.g. good communication skills). Thus, communication within a team and with passengers can be assumed to play a key role in ensuring an efficient workflow. This factor becomes even more important taking into consideration the fact that screeners mostly are randomly assigned to a crew and especially at bigger airports sometimes might not even know each other [28]. Also, the relevance of a good cooperation between the team members seems important when considering the dependencies between the different working positions of ASOs (e.g. bag loading, X-ray screening etc.).

[16] indicate that humans often perform worse when placed under a time pressure as opposed to normal conditions. Such pressure can cause stress and promote risky or biased decision making. X-ray screeners are often required to perform under time pressures where there may be a large queue of passengers waiting to pass the security checkpoint. Therefore, the relevance of time pressure can be understood as a relevant situational factor and resistance to stress could be an important characteristic of the personality of an X-ray screener. Further, the relevance of the work environment (noise, light, screen reflection, temperature, air quality and draughts) has already been found to have an impact on performance in past research (e.g. [29]). However, other situational factors such as image-based factors have been attributed as more significantly ([15]; [29]).

SUMMARY AND CONCLUSION

The results of this study suggest that several situational factors affect X-ray screeners’ primary work task (i.e. to visually inspect X-ray images of passenger bags for prohibited items and decide whether a bag is OK or not in a reasonable amount of time). Factors of high relevance were bags content, which is dependent on different kinds of materials; bag complexity and the way bags are packed and put on trays. Factors categorized as medium relevant were factors of the work environment (noise, light, air, temperature and quality of X-ray images), team specific factors (communication, time pressure and team atmosphere) and other factors (operational processes of secondary bag search, loading of bags and passengers causing fuss and hassle).

In our opinion, this multi-method approach may serve as a starting point for future research on situational factors. First, it would be interesting to investigate whether the multi-method approach used in this study would reveal the same results when applied at another international airport. Moreover, seasonal aspects could have an impact and should also be investigated. In addition, it could be explored for example how team compositions or communication skills affect performance.

REFERENCES


[12] S. Koller, D. Hardmeier, S. Michel, and A. Schwaninger, "Investigating training, transfer and viewpoint effects resulting from recurrent CBT of


