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Understanding the relations between crowd density, safety perception and risk-taking behavior on train station platforms: A case study from Switzerland

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ABSTRACT

Railway platforms are becoming increasingly crowded, especially at peak hours. In this observational study, we investigated how the density of people is perceived by passengers and how this perceived density correlates with safety perception and risk-taking behavior. Risk-taking behavior here means stepping into the danger zone, the area of the platform bordering the tracks where individuals are at risk to their physical integrity by a train passing through, arriving at or leaving the station. The investigation of perceived density and actual behavior on the platform poses methodological challenges. Therefore, we used a stereo sensor technology to collect anonymized behavioral data on a train station platform over two months. Data regarding passenger density and oversteps into the danger zone was collected during rush hours and analyzed for this study. Additionally, subjective data, such as estimation and perception of passenger density and safety perception were collected in a survey with 179 participants. Survey links were distributed during rush hours in three different train stations on platforms over two weeks. While distributing the links for the online survey in the field (two-hour sessions during rush hours), an observation was conducted (i.e., oversteps into the danger zone, general passenger behavior). The results indicate that increased measured passenger density is related to more oversteps. Subjective perception of crowd density, regarding how comfortable someone feels in the given situation, correlates with safety perception and also significantly predicts overstepping into the danger zone. Increased estimated density also correlates with reduced safety perception but is not a predictor of oversteps. We suggest optimizing the passenger distribution on the platform by motivating passengers to move to less crowded areas, e.g. with approaches such as "nudging" so that passengers feel more comfortable on the platform. This can both improve both safety and the customer experience on the platform.

1. Introduction

Social changes bring new challenges to the railway industry. Demographic growth and increasing mobility push existing infrastructure at neuralgic points to its limits (Stölzle et al., 2015). Trains are highly occupied and train station environments exceedingly frequented, especially at peak times. In this respect, train station platforms present a particular interesting case, not only because they are departure points for rail journeys, but also because they are safety relevant, meaning that certain areas of the train station pose a risk to the physical integrity of passengers when a train passes through, arrives at or leaves the station. Yet, in contrast to research about the experience in crowded trains (Li and Hensher, 2013) or in train station areas in general (Cox et al., 2006; Tirachini et al., 2013), research about the experience or behavior of passengers, specifically on train station platforms, is rare (Schneider et al., 2018; Thurau et al., 2019). However, knowledge about those aspects could help to find smart design and planning solutions within the given infrastructure in the future to ensure safe travels and a good experience for passengers. Thus, the goal of this study is to research experience and behavior of passengers on train station platforms to explore the given situation.

1.1. Crowds and safety – Objective and subjective realities

Even though to this day, research on the impact of high frequentation on rail platforms on passengers is limited, a large body of litera-

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ture is concerned with the effects of crowds, meaning an aggregation of people in the same space at the same time (Adrian et al., 2019), on humans in other areas. Older studies between 1970 and 1990 focused on psychological aspects of humans in crowds, whereas more recent research usesed the new technological possibilities to create prediction models or simulation tools (for an overview see Haghani and Sarvi, 2018; Templeton et al., 2015). However, computational models and simulations often lack an understanding of the highly complex nature of human crowds and the numerous variables that influence behavior, like e.g., (1) irregularities of human behavior because of decision making, (2) flexibility in pedestrian movements, (3) complexity of the environmental context or (4) context dependency of pedestrian behavior; different scenarios, contexts or situations may trigger different responses (Haghani and Sarvi, 2018). For example, crowds can be subdivided into *physical crowds* of unconnected individuals (such as commuters) and *psychological* crowds whose collective behavior is based on a shard social identity (such as sightseeing tourists who see themselves as a group) (Reicher, 2011; Adrian et al., 2019). It is possible that a physical crowd contains one or more psychological crowds (e.g. sightseeing tourists and football fans on a train station platform). Thus, physical crowds or psychological crowds may respond differently in similar scenarios. Therefore, current trends are moving towards models which integrate cognitive heuristics (e.g., Moussaid et al., 2011), empirical studies in specific contexts and the consideration of individual perceptions within a crowd.

1.1.1. Physical crowd density and perceived density of a crowd

In context of crowds and human safety, the term *crowd density* is used to describe how close the distance between the aggregated people is in the given space (Fruin, 1993; Cheng, 2009). Crowd density can be subdivided in two distinct concepts: *Physical crowd density* and *perceived crowd density*. The density of people can be described as a numerical measure of the concentration of individuals within a given geographical unit. Therefore, the physical *crowd density* can be measured objectively as the number of people per given area (Cheng, 2009). However, from an individual perspective, there is also a subjective experience within the crowd to be measured (Rapoport, 1975; Li and Hensher, 2013). The *perceived density of a crowd* can be defined as an individual’s perception of people present in a given area (Rapoport, 1975). The physical and objectively measurable crowd density and the subjective perception of crowd density do not have to be related in a linear way (Cox et al., 2006; Li and Hensher, 2013).

Studies in the field of rail transport, urbanization or tourism management have shown mostly negative effects of crowd density on human behavior, cognitive control or affective responses (e.g. decreasing tolerance for frustration (Sherrod, 1974) or aggression (Regoeczi, 2002). The term *crowding* is often used to describe the psychological tension produced in environments with a high population density (Stokols, 1972). Crowding is often associated with negative impacts on experience, like psychological or physical discomfort, perceptions of risk to personal safety or security or actual risks to safety (Cullen, 2001; Cox et al., 2006).

1.1.2. Objective safety and subjective safety

Safety in an environment consists of objective safety and subjective safety (Sørensen and Mosslemi, 2009). *Safety risks* originate from unintentional failures, errors, or misfortunes; *security risks* arise from deliberate or malicious attempts to disrupt, disable, or destroy (Ranger, 2010). The term *safety* refers to the methods and measures taken to protect people from the risks directly related to and arising from transport, whereas the term *security* means the prevention of unlawful interference with passengers and transport infrastructure (Sørensen and Mosslemi, 2009). However, *objective safety* or security, meaning the actual number of accidents or incidents, does not have to be congruent to *subjective safety perception,* the feeling of perception of safety, i.e., how people subjectively experience accident risk. Research shows that the divergence between one's feeling and reality occurs due to applied heuristics and biases in risk assessment (Schneier, 2008). For example, people see risks different for themselves than for others because they assume that they can control their own risks and others cannot or do not want to. Thus, own competences are overestimated, and those of others underestimated (Sjöberg, 2003). The evaluation of risk then influences our risk-taking behavior.

1.1.3. Risk-taking behavior

Risk-taking behavior is defined as any consciously or unconsciously controlled behavior with a perceived uncertainty about its outcome and/or possible benefits or costs to the physical, economic, or psycho-social well-being of oneself or others (Trimpop, 1994). The reasons for taking risks are still debated and not yet clear. In the context of train station platforms, risk-taking behavior, meaning stepping into the danger zone, could bring possible benefits, like e.g., withdrawing from the potentially stressful density of people on the platform (Bell et al., 2001; Manning and Valliere, 2001). Bell et al. (2001) and Manning and Valliere (2001) identified coping strategies as mediators between overcrowded places and comfort. Bell et al. (2001) found attempts to cope with crowding by avoiding crowded situations or by reducing the associated discomfort in some way. Manning and Valliere (2001) found coping strategies serving as mediators between overcrowded places and visitor satisfaction in the area of tourism research. To respond to high crowd densities “displacement” i.e., spatial or temporal changes were observed in tourist areas. Visitors moved, e.g., to less crowded spaces in the area. Therefore, the expression of coping behavior is to withdraw from the potentially stressful and uncomfortable density of people.

1.2. Railway platforms and safety

This study focuses on railway platforms, where passenger safety plays an important role. The term *passenger* is used for pedestrians moving or waiting on the platform. Railway platforms are simultaneously used as walking and waiting areas. Both functions can alternate over time and, therefore, cannot easily be spatially separated. The safety aspect is also crucial for these facilities, as passengers should not enter the unsafe zone next to the railway tracks. In Switzerland, where the present study was conducted, a white line, the safety line, marks the border between the safe and the unsafe zone at the platform edge, referred to as the danger zone (Bundesamt für Verkehr (BAV), 2011). The *danger zone* is the area of the platform, where individuals are exposed to a risk to their physical integrity when a train passes through or arrives at and leaves the station. The Swiss Federal Office of Transport thus states that pedestrians should not enter the danger zone. Trains passing through or arriving at the station could cause suctions that can be dangerous within the unsafe zone. Also, passengers standing too close to the railways could be caught directly by trains. The *safety zone* is the area of a platform that passengers can access and lies outside of the danger zone.

The purpose of the safety line is, therefore, to safeguard the physical safety of people and thus to prevent unacceptable risks, such as death or injury. However, any uncomfortable, but not dangerous situation, on the tracks is permissible and lies within the responsibility of the railway companies. It is, therefore, the responsibility of the railway company to create good and comfortable experiences at the train stations.

1.3. Previous studies on perception and behavior on platforms

There are few studies that address passenger perception and behavior on railway platforms. One branch of the existing literature presents general design guidelines rather than context-specific information on passenger behavior and perception on platforms (Fruin and Benz, 1984; ProRail, 2006). Fruin and Benz (1984) propose the level-of-service concept, a method that allows calculating the level of service for walking pedestrians based on available space and amount of people waiting for a given time period. However, this method is not able to consider the layout of the platform. ProRail (2005) describes the functional layout of the platform, similar to the implementation of the Swiss Federal Railways. A danger zone (marked with two white lines on the platform ground) is located next to the platform edge, followed by the walking zone. This zone contains a tactile surface as an orientation aid for visually impaired people and should be free of hindrances. Next to the walking zone is the waiting zone. The central area of the platform is the circulation area, which allows passengers to spread out along the platform. In this area, information screens, commercial activities, and railway shelters are usually be located.

Other more recent research investigates the distribution of passengers in space and time (Bosina et al., 2015; den Heuvel et al., 2019; Schneider et al., 2018; Thurau et al., 2019). In a qualitative study, Bosina et al. (2015) identified the location hindrances and the size queuing zones next to the platform access as key factors for the distribution of pedestrians along the platform. Thurau et al. (2019) propose a model that distinguishes between forced and unforced oversteps. Unforced overstepping means that passengers decide to step into the danger zone, either willingly or unconsciously. When a passenger is forced to step into the danger zone (e.g., because the platform is too crowded and there is no other possibility) to reach his or her destination, it is described as forced overstep. A stereo sensor technology was used to measure density. Stereo sensor technology is capable of anonymously tracking individual pedestrians within a predefined area under high-intensity conditions. This allows the measurement of pedestrian paths on the platform and the assessment of walking speed and passenger density. Den Heuvel et al. (2019) have shown that the pedestrian measurement technology can deliver a high degree of accuracy of pedestrian measurement at train stations. They propose that this opens up the possibility to research passenger behavior patterns. In their study on security perception in train station environments, Schlüter et al. (2016) encouraged that new observation-based methodological approaches should be further explored. In their study, they found a correlation between the density of passengers and security perception. Using a camera-based system, the density of passengers was also assessed on an objective level. They recommend that further research should be conducted to investigate methodological approaches that combine subjective and objective measurements and to identify further influencing factors. Li and Hensher (2013) conducted a review of objective and subjective measures of crowding levels. They reveal a significant gap between objective and subjective measures. They argue that the measurement of objective crowd density is insufficient and encourage the addition of subjective measurements to objective measurements to capture the subjective side of crowding experience.

In summary, the previous literature indicates that high people density influences the experience and safety in train stations. More recent literature describes correlations between people density and oversteps into the danger zone based on sensor data measurement. But the underlying motivations for the measured oversteps are yet to be further researched. Still unanswered is the question on how the estimation of people density corresponds with actual physical density on platforms, and how the perception of people density correlates with both factors and safety perception.

1.4. The present study

In the present paper, we distinguish the following concepts: objectively measured passenger density, subjectively estimated passenger density, perception of passenger density and safety perception. With *objectively measured passenger density* we mean the physical density of a crowd that can be measured objectively as the number of people per given area (Cheng, 2009). The term *subjectively estimated people density* means the subjective estimation of the number of passengers with the help of the Level of Service scale (Fruin and Benz, 1984). With the term *subjective perception of passenger density*, we mean the subjective experience or the perceived comfort from a subjective perspective. This characterization is based on the definition of Rapoport (1975; the perceived density of a crowd can be defined as an individual's perception of people present in a given area) or the construct *crowding*. Further, we will use the term *subjective safety perception,* the feeling of perception of safety, i.e., how people subjectively experience accident risk (Sørensen and Mosslemi, 2009).

Hence, we want to further analyze crowd density, perception of passenger density, perception safety or security and the occurrence of oversteps into the danger zone on train station platforms and how those factors are related. First, we explore the factors leading to oversteps and explore the relationship between the estimated and the perceived density of people. We assume that perceived passenger density could play a role and that discomfort could lead to oversteps into the danger zone, comparable to the coping mechanism "displacement" described by Manning and Valliere (2001). Second, we compare estimated passenger density, perception of passenger density (comfort) and safety perception on three different train stations. Based on existing literature, we assume that safety perception and perception of passenger density are related to passenger density (Cox et al., 2006). Regarding safety perception, we assume that especially situations, in which passengers have little control, lead to decreased safety perceptions (Sjöberg, 2003). Third, we compare safety perception on the train station to other areas within the train station to assess how passengers perceive the platform environment in comparison to other areas. Fourth, we want to evaluate adherence and knowledge of the existing safety line, which separates the danger zone from the safe zone on the platform.

In attempt to obtain data as close to real-time as possible to avoid memory biases, a combination of survey (subjective data) and observation (objective data) is used as proposed by previous studies (e.g. Li and Hensher, 2013; Schlüter et al., 2016; Thurau et al., 2019). To control our assumption that oversteps in the danger zone are actual risk-taking behavior patterns, we analyze the time and frequency of the oversteps during the observation periods. With the help of these observations, we investigate how often and when overstepping occurs to control the frequency of oversteps during our survey. In the present study, we address these questions by combining existing data with subjective and new objective data based on observation.

2. Methods

2.1. Study design and train station platforms

An observation and an online survey were conducted on platforms of three different train stations in Switzerland: Bern, Lenzburg, and Visp. The train stations were chosen according to the following criteria: Lenzburg is highly frequented by train passengers with many passing through trains. This means that oversteps in the danger zone are especially critical on platforms in Lenzburg. Due to the narrow platforms, the passenger density is high during rush hours. Bern is the capital train station and is, therefore, a nodal point. This means that the train station is frequented by a lot of commutes. Visp was chosen because it is a tourist hub. Tourists often carry skis and luggage which can cause movement restrictions and additional space problems on the platform. All three train stations are located in urban and highly frequented areas.

The observations were made over two weeks during rush hours (7–9 am and 5–7 pm). During the observations, two different survey links were handed out – one link for passengers observed stepping into the danger zone (safety zone leavers), and one link for passengers not directly observed overstepping the safety line (safety zone stayers). The surveys were identical, and the sub-division helped us to identify whether the survey was filled out by a person who crossed the safety line or not. To motivate the passengers to answer the survey, we handed out 2000 cookies (1200 with a link for safety zone leavers and 800 with a link for safety zone stayers), with a QR Code and a link to the online survey printed on the wrapper. The two-week period, in which the observation and survey were conducted, was during a two-month period in which objective data on passenger distribution were automatically collected.

2.2. Material and measures

2.2.1. Stereo sensor

Using stereo sensor technology, we tracked the number of passengers on the platform and passenger behavior (oversteps into the danger zone). For a description of the stereo sensor technology and calibration, see Van den Heuvel et al. (2019). The data was anonymous. The data were collected over a two-month period.

2.2.2.2. Observation. During the observation we used an observation protocol. Measures included: (1) the number of oversteps, (2) point of time of oversteps in relation to the train entrance, (3) noticeable behavior patterns and (4) free observations such as if the observed person is walking alone or in group or walking pace. Observations took place during the distribution of the survey links.

2.2.2.3. Survey. In the survey, we examined the subjective feeling of safety and the subjectively perceived passenger density. The subjective responses included (1) demographic data and frequency of train use, (2) estimated passenger density, (3) subjective perception of passenger density, (4) subjective safety/security perception on the platform, (5) recognition of the safety line, (6) awareness of oversteps into the danger zone (7) reasons for overstepping and (8) feeling of safety/security in other train station areas.

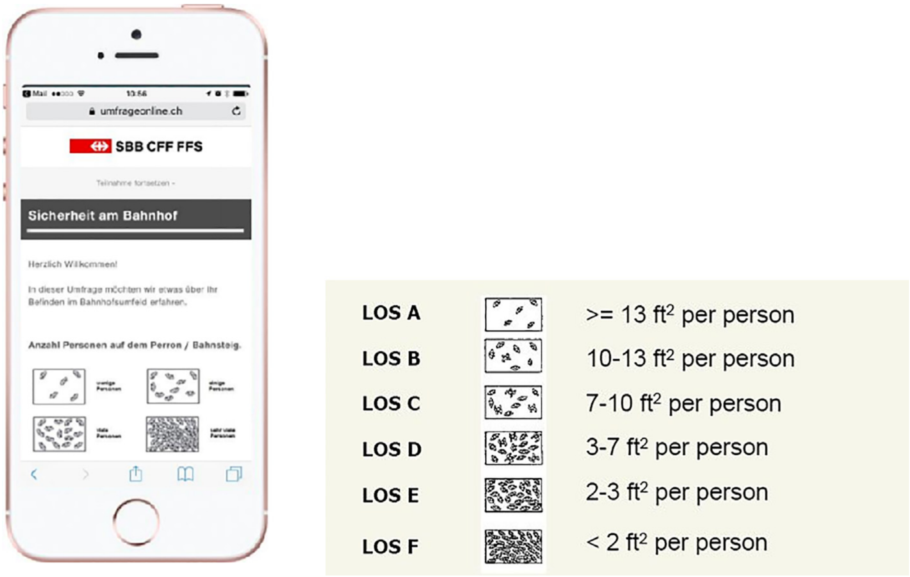
The estimated passenger density (2) was measured following Fruin's Level of Service Scale (1971, see Fig. 1). Each picture displays a different passenger density (low passenger density, rather low passenger density, rather high passenger density, high passenger density). Participants had to choose the picture that most closely corresponds to the current passenger density on the platform ("Which of the following pictures corresponds to the number of people standing on the platform today when receiving the link?"). The subjective perception of passenger density (3) was assessed on a 6-point scale ("How did you perceive the passenger density?" *very uncomfortable, uncomfortable, rather uncomfortable, rather comfortable, comfortable, very comfortable, cannot answer this question).*

The safety/security perception (4) on the platform was rated with the following question: "In general, I have a good safety/security feeling on the platform." *Fully agree, agree, more likely to agree, more like to disagree, disagree, completely disagree.* (Note: In German, there is no semantic differentiation between safety and security; there is only one word to describe both. Hence, the question said, do you feel safe/secure on the platform). To assess whether safety or security-related issues lead to the corresponding rating of safety/security feeling, situations in which passengers feel unsafe/insecure were assessed. ("In which situations or during which incidents do you feel the most unsafe/insecure on the platform?"

To measure if the safety line is known (recognition of the safety line) (5), we showed a picture of the safety line and asked: "What do you think the line on picture A means?" This question aims to investigate if the safety line is known as a demarcation of the safe and the danger zone or if it is only known as a guide for blind people. To measure awareness of crossing into the danger zone (6), we asked whether "there have already been situations in which you crossed the safety line (except when entering or leaving the train). If the answer was yes, we asked for the reasons (7) for overstepping. To understand why oversteps happen, the reasons for crossing the safety line were assessed. "In what situations did you cross the safety line? Were there already situations in which you crossed the safety line (except when entering or leaving the train)?" If the answer was yes, we asked for the reasons for overstepping. To understand why oversteps happen, the reasons for crossing the safety line were assessed. "In which situations did you cross the safety line?"

To control for the participants' safety perception in general (8), we asked them to rate their feeling of safety during shopping at the train station, at the meeting point, in the train, on the platform, in an underground passage, and while waiting for the bus. *(Very safe, safe, rather safe, rather unsafe, unsafe, very unsafe).*

The survey was run under the Swiss Federal Railways brand. The survey links were handed out during rush hours (approximately 7–8 am or 5–6 pm). The handout of the links was combined with observation.



Sicherheit am Bahnhof

Herzlich Willkommen!

In dieser Umfrage möchten wir etwas über Ihr Befinden im Bahnhofsumfeld erfahren.

Anzahl Personen auf dem Perron / Bahnsteig.

LOS A	>= 13 ft^2 per person
LOS B	10-13 ft^2 per person
LOS C	7-10 ft^2 per person
LOS D	3-7 ft^2 per person
LOS E	2-3 ft^2 per person
LOS F	< 2 ft^2 per person

Fig. 1. The online survey could be filled out on the smartphone (*left*). Level of Service Scale (Fruin, 1971) (*right*).

2.3. Survey participants

A total of 179 participants answered the surveys (2000 survey links were handed out, participation rate = 8.95%). A revision of the completed surveys led to the exclusion of nine participants because they did not declare at which train station they received the survey link. Therefore, a total of 170 (64 = female, 102 = male, 4 = no answer; age $M = 47$, $SD = 13$) participants were included in the analysis. Of these, 32 (13 = female, 16 = male, 4 = no answer) participants could be assigned to safety zone leavers, 143 (51 = female, 86 = male) to safety zone stayers. There were no significant differences in terms of gender ($F(1,164) = 0.823$, $p = .33$) and age ($F(1,164) = 0.16$, $p = .68$) between safety zone leavers and safety zone stayer. Of the safety zone leavers, 52% of the answers were from Bern ($n = 14$), 48% from Lenzburg ($n = 13$) and 0% from Visp; 63% of the participants commute daily (n = 18), 27% more than once a week ($n = 7$), 10% ($n = 10$) once a week or less. Of the safety zone stayers, 73% of the answers were from Bern ($n = 100$), 18% from Lenzburg ($n = 25$), 9% from Visp ($n = 12$); 65% commute daily ($n = 90$), 28% more than once a week ($n = 38$), 6% once a week or less ($n = 9$).

2.4. Statistical analysis

2.2.4.1. Stereo sensors

The platform was divided into five zones to differentiate between areas with and without hindrances. The average number of uses of the danger zone per meter of platform length and second was calculated. The results were compared with each pedestrian density within the zone. Each second was divided by the area available for passengers in the safety zone. The data was only analyzed when no train was waiting on the platform, as in this scenario, crossing the safety line is allowed and does not imply risk-taking behavior. More information on sensor data analysis is described in Thurau et al. (2019).

Fig. 2 shows platforms 3 and 4 in Bern. Zones one, two, and three contain hindrances (staircase and ramp); zones four and five contain no hindrances. The platform can be entered and left in zones one and three. The number 1.4 describes the part of zone 1 belonging to platform 4, while 1.3 belongs to platform 3.

2.2.4.2. Observational and survey data

Descriptive statistics were used to analyze the observational data. The survey data were normally distributed (Shapiro-Wilk-test, all p-values > 0.05). A 2 (safety zone leavers, safety zone stayers) × 3 (Bern, Lenzburg, Visp) ANOVA was calculated on the basis of the dependent variables safety perception and perceived passenger density. Post-hoc comparisons were calculated using the Scheffé test. A Pearson correlation was calculated between safety perception and estimated passenger density, safety perception and perceived passenger density, and estimated passenger density and perceived passenger density. A multiple regression analyis was used to test which factor (perceived passenger density, safety perception) predicts overstepping. To test if recognition of the safety line moderates the relation between perceived passenger density an overstepping into the danger zone, a moderation model was calculated.

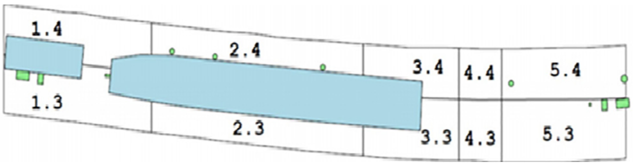


Fig. 2. Platforms 3 and 4 in Bern divided into ten different zones (Thurau et al., 2019).

3. Results

3.1. Sensor data and observational data – Number of oversteps in relation to pedestrian densities

Sensor data analysis showed a general rise of people stepping into the danger zone with rising pedestrian densities (see Fig. 3). The analysis showed that some zones seem to reach a point when the number of overstepping persons starts rising disproportionately. Next to hindrances, a higher number of uses of the danger zone was recorded. The median share of people using the danger zone next to hindrances and with smaller safety zone (11%) is higher than the share of people using the danger zone at wider safety zones (3%). The lower quartile of small safety zones (9%) is higher than the upper quartile of wider safety ones (4%). (Results were presented by Thurau et al. at the 9th international conference on Pedestrian and Evacuation Dynamics 2018 in Lund, Sweden).

The maximum number of oversteps was measured using the observation protocol during peak times (7:25 – 7:30 am) in Lenzburg (Table 1). Within those 5 min, 279 oversteps were measured. In Bern, the peak time was measured between 7:30–7:35 AM with 119 oversteps. In Visp, 178 oversteps were measured during the peak time (7:25 – 7:30 am). The average times between oversteps were one second in Lenzburg, 2.5 s in Bern, and 1.5 s in Visp. The number of oversteps was accumulated just before the train entered the station (see Fig. 4, the example of Lenzburg).

Qualitative observations showed that the danger zone was used by passengers as a “fast line” when the platform was crowded. This usually happened before the train entered the station. During less crowded periods, we observed people looking at their smartphones, talking on the smartphone, or talking to another person when strolling in the danger zone.

3.2. Subjective data – Safety perception, estimated passenger density and perceived density

A t-Test revealed that survey participants have a significantly lower feeling of safety on the train station platforms ($M = 4.08$, $SD \pm 1.22$) compared to other places in the train station like shops ($M = 4.8$, $SD \pm 1.25$, $t(1\,7\,2) = 50.49$, $p < 0.05$, n = 170), at the meeting point ($M = 4.52$, $SD \pm 1{,}39$, $t(1\,7\,2) = 42.59$, $p < 0.05$, n = 170) or in the train (M = 4.84, SD ± 1,25, $t(1\,7\,2) = 50.84$, $p < 0.05$, $n = 170$). More than 60% of the participants (safety zone leavers = 50%, safety zone stayers = 66%) cited a crowded platform as a reason for feeling unsafe (see Fig. 6). In the qualitative statements, the participants added that they feel afraid of being pushed onto the rail by someone when the platform is crowded. Of the participants, 53% of the safety zone leavers state that not enough space is a factor, whereas only 31% of the safety zone stayers picked that answer. Of the participants, 56% of the safety zone leavers and 61% from safety zone stayers choose “trains passing through.” Only 13% of the safety zone leavers and 15% from safety zone stayers choose entering trains. A narrow platform is also a relevant factor that makes participants feel unsafe (safety zone leavers 53%, safety zone stayers 44%). Noise was also picked as a factor by 15% of the safety zone leavers and 25% of the safety zone stayers. A steep platform and poor lighting was chosen only by <10% of the participants (see Fig. 5).

With regards to subjective safety perception, a Pearson correlation test (see Table 2) showed a highly significant correlation between safety perception and perceived passenger density ($r(1\,7\,8) = 0.39$, $p < .001$). The safety perception correlates significantly with the estimated passenger density ($r(1\,7\,8) = -0.44$, $p < .001$). The higher the passenger density on the platform is estimated, the lower is the perceived safety on the platform. The perceived passenger density correlates significantly with the estimated passenger density (r(1 7

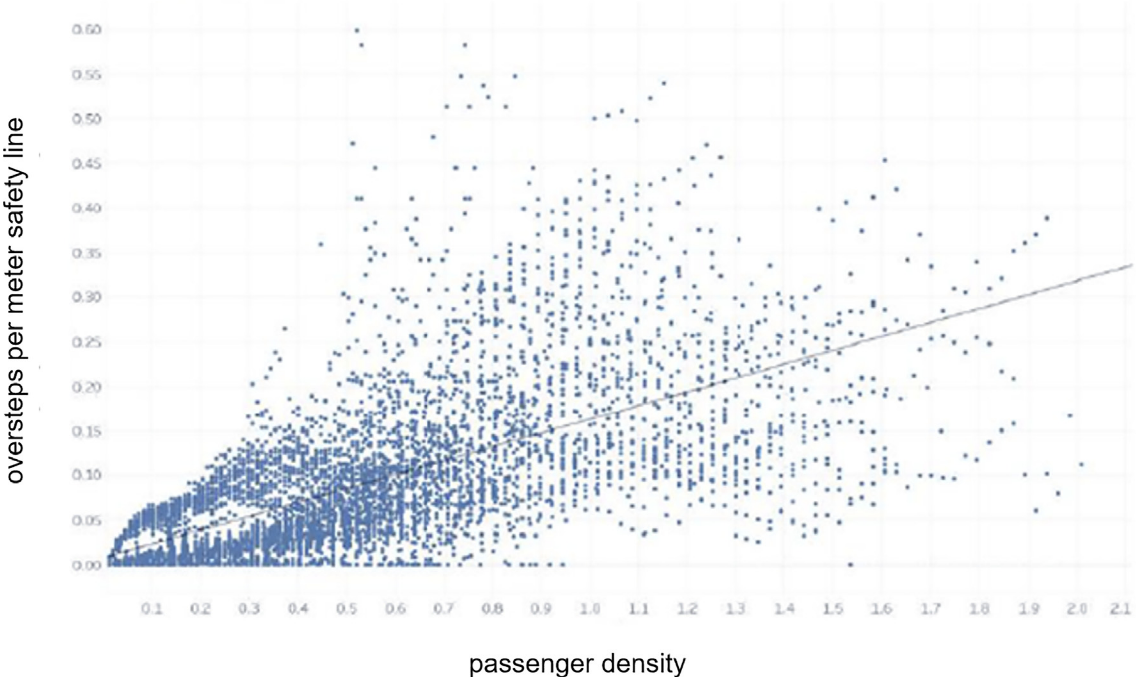


Fig. 3. Oversteps at different densities. Oversteps increase in relation to increasing passenger density on the platform.

9) = −0.46, $p < .001$). Higher estimations of passenger densities correlate with a less comfortable perception of passenger density.

Table 3 shows the calculated means and standard deviations for all dependent variables (safety perception, estimated passenger density, and perception of passenger density) as a function of train station platform and group. The ANOVA revealed a significant main effect for platform on the safety feeling ($F(2,164) = 7.66$, $p = .001$, $\eta^2 = 0.07$) and the perceived passenger density ($F(2, 164) = 6.01$, $p = .003$, $\eta^2 = 0.05$). No significant effect of the platform was found on the estimated passenger density.

Table 1
Description of the number of oversteps during a five minute peak period. Peak periods happened shortly before and after most incoming and departure of the frequented train connections.

	Bern	Lenzburg	Visp
5 min peak	7:30–7:35	7:25–7:30	7:25–7:30
Number of oversteps	119	279	178
Mean time period between oversteps (in seconds)	2.5	1	1.5

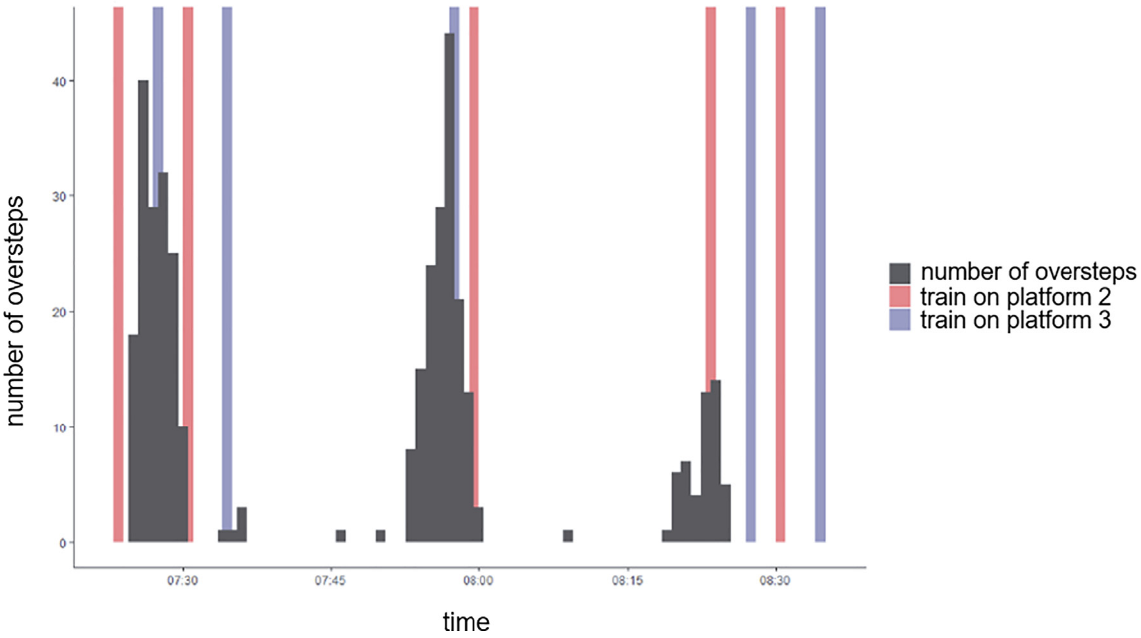


Fig. 4. Oversteps accumulate before train entrance. Illustration of the number of oversteps in Lenzburg, platform 2.

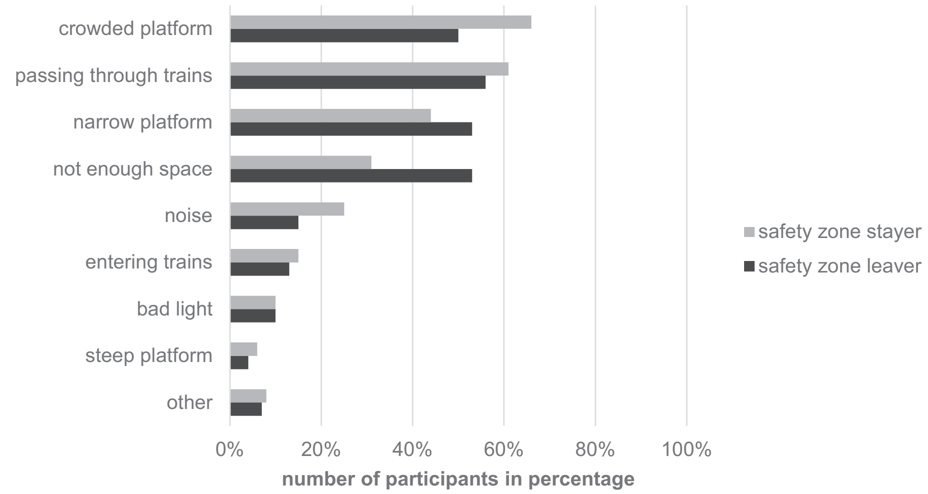


Fig. 5. Factors that make participants feel unsafe/insecure on the respective platform.

Table 2
Correlations of safety perception, estimated passenger density and perceived passenger density.

	M (SD)	Safety perception	Estimated passenger density	Perceived passenger density
Safety perception	2.577 (1.36)	–	−0.44**	0.39**
Estimated passenger density	2.88 (0.8)	−0.44**	–	−0.46**
Perceived passenger density	3.34 (1.35)	0.39**	−0.46**	–

Note: Safety perception $n = 168$, estimated passenger density $n = 169$, perceived passenger density $n = 170$, ** = $p < 0.005$.

Table 3
Mean values and standard deviations are given for all dependent variables as a function of train station platform and group.

	Variable	Lenzburg (I)	Bern (II)	Visp (III)	Total Platform	I–III		I–III		II–III	
		M (SD)	M (SD)	M (SD)	M (SD)	MD	95%CI	MD	95%CI	MD	95% CI
Safety zone leavers	Estimated passenger density	3.23 (1.09)	2.92 (0.61)	–	2.96 (0.89)						
	Perception of passen-ger density	2.15 (1.46)	3.14 (1.29)	–	2.87 (1.45) *						
	Safety perception	3.7 (2.00)	2.07 (0.91)	–	2.83 (1.66)						
Safety zone stayers	Estimated passenger density	3.16 (0.55)	2.80 (0.86)	2.66 (0.65)	2.85 (0.80)						
	Perception of passen-ger density	3.04 (1.05)	3.47 (1.36)	4.33 (0.77)	3.46 (1.30) *						
	Safety perception	3.00 (1.50)	2.40 (1.19)	2.41 (1.44)	2.51 (1.28)						
Total partici-pants	Estimated passenger density	3.28 (0.76)	2.82 (0.84)	2.66 (0.65)	2.88 (0.82)	0.36	[−0.01, 0.74]	0.51	[−0.14, 1.18]	0.14	[−0.46, 0.75]
	Perception of passen-ger density	2.73 (1.26)	3.40 (1.36)	4.33 (0.77)	3.34 (1.35)	−0.69*	[−1.29, −0.09]	−1.59**	[−2.65, −0.53]	−0.91	[−1.87, 0.06]
	Safety perception	3.26 (1.70)	2.37 (1.17)	2.41 (1.44)	2.57 (1.36)	0.91*	[0.29, 1.51]	0.84	[−0.23, 1.92]	−0.05	[−1.04, 0.93]

Note: Safety zone leavers Bern $N = 14$, Safety zone leavers Lenzburg $N = 13$, Safety zone stayers Bern $N = 100$, Safety zone stayers, Lenzburg $N = 25$ Safety zone stayers, Visp $N = 12$, Total Bern $N = 115$. Dependent variables are estimated passenger density (scale from 1 = *little* to 4 = *many*), subjective perception of passenger density (scale from 1 = *very uncomfortable* to 6 = *very comfortable*), safety/security perception (scale from 1 = the statement “I feel safe on the platform” *fully applies* to 6 = “I feel safe on the platform” *does not apply at all)*.

Post hoc comparisons using the Scheffe test revealed a significant difference ($p = .02$) in the perceived passenger density between Lenzburg and Bern (−0.69, 95%-CI [−1.29, −0.08]). The perceived passenger density in Lenzburg also differs significantly ($p < .001$) from the perceived passenger density in Visp (−1.59, 95%-CI [−2.66, −0.52]). The perceived passenger density did not differ significantly between Visp and Bern. The passenger density was perceived less comfortable in Lenzburg ($M = 3.28$, $SD = 0.76$) compared to Visp ($M = 2.66$, $SD = 0.65$) and Bern ($M = 3.40$, $SD = 1.36$).

A significant difference ($p = .002$) was revealed in perceived safety between Lenzburg and Bern (0.91, 95%-CI [0.28, 1.51]). The participants felt less safe in Lenzburg ($M = 3.26$, $SD = 1.70$) compared to Bern ($M = 2.37$, $SD = 1.17$) and Visp ($M = 2.42$, $SD = 1.44$).

A significant main effect of the group on the perception of passenger density was found ($F(1, 164) = 4.437$, $p = .037$, $\eta^2 = 0.03$). Safety zone leavers view the perceived passenger density as less comfortable (M = 2.87 = SD = 1.45) compared to safety zone stayers ($M = 3.46$, $SD = 3.46$). No main effect of group was found on safety perception or estimated passenger density.

The results of the regression indicated that perceived passenger density significantly predicts overstepping into the danger zone (Beta = 0.2, $p = .02$). The predictor explained 4% of the variance ($R^2 = 0.04$, $F(2, 165) = 3.38$, $p = .036$). Safety perception did not predict overstepping into the danger zone (Beta = 0.00, $p = .99$). A model containing all the subjective factors (age, frequency of train use, estimation of passenger density) was not significant.

A moderation model was calculated to test if recognition of the safety line moderates the relation between perceived passenger density and overstepping into the danger zone. However, the model was not significant $\chi 2(1) = 0.99$, $p = .31$. In the tested mediation model (safety perception as a mediator between perceived passenger density and overstepping into the danger zone, $R^2 = 0.19$, F(1, 164) = 40.13, $p < .001$), there was no indirect effect of safety perception on overstepping into the danger zone (95%-CI [−0.15, 0.16]).

3.3. Subjective data – Recognition of safety line and awareness of oversteps

Of the participants, 82% identified the safety line correctly (81% safety zone leavers, 83% safety zone stayers, see Fig. 6). Of the safety zone leavers, 50% recognized the safety line as both a safety line and a guide for blind people, and 31% recognized the safety line as a safety line only. However, 16% of the safety zone leavers recognized the line as a guideline for blind people but not as a safety line, and 3% did not recognize the safety line as either a guideline nor a safety line. Of the safety zone stayers, 51% recognized the safety line as both a safety line and a guide for blind people, 32% recognize the safety line only as a safety line, 16% recognize the safety line as guide for blind people, and only 1% did not recognize the safety line as either a safety or a guide line. A chi-square test revealed that the recognition of the safety line and the group assignment are not related ($\chi 2$ (2) = 0.29, $p = .864$).

To the question “Have there been situations in which you had to cross the safety line (except when entering or leaving the train),” 40% of the safety zone leavers answered with no and only 60% with yes. Of the safety zone stayers, 70% said yes, and only 30% said no (see Fig. 7). A chi-square test revealed that the subjective assessment of whether the safety line was crossed and the actual group assignment (safety zone leavers, safety zone stayers) were not related ($\chi 2$ (1) = 1.33, $p = .247$).

4. Discussion

In our observational study, we tried to identify how the perception of passenger density, safety perception, and risk-taking behavior of passengers on train station platforms are related. We operationalized risk-taking behavior when leaving the safety zone and entering the danger zone on the platform. We identified that most of the oversteps occur during rush hours and that an accumulation of oversteps occurs just before a train arrives. Our results indicate that an uncomfortable feeling about the current passenger density on the platform (perceived passenger density) is a factor leading to unforced oversteps. Qualitative observation showed that inattention is also a factor leading to unforced oversteps. High passenger densities were identified by stereo sensor measures and analyses as a factor leading to forced oversteps. The subjective estimation of passenger density, safety perception, age, or frequency of train use, on the other hand, were not identified as predictors of oversteps. However, high estimated passenger densities and a negative perception of passenger densities were associated with low safety perception. In other words, if the number of people is perceived as high or uncomfortable, then the passengers tend to feel unsafe. However, the perception of safety was not related to oversteps; i.e., it is not that passengers generally feel too safe and step into the unsafe zone.

4.1. Passenger density, perceived passenger density and risk-taking behavior

Regarding the objective measurement of passenger density, we found that that it correlates with the oversteps into the danger zone. The stereo sensor analysis showed that a higher passenger density is related to more overstepping. We conclude that higher passenger density reduces the available space in the safety zone on the platform and therefore leads to forced oversteps in the danger zone. This may happen due to a lack of space in the safety zone. The results imply that high passenger densities mainly occur in certain areas of the platform, meaning that other areas on the platform are not crowded. Next to the hindrances, a higher number of oversteps, compared to other areas without hindrances, was recorded. Therefore, a high passenger density was identified as a factor for forced oversteps. These findings are in accordance with previous studies (Thurau et al., 2019). Observation showed that passenger density and oversteps increase before train entrance. This indicates that most oversteps happen in potentially dangerous situations. Yet, it could be possible that passengers who are

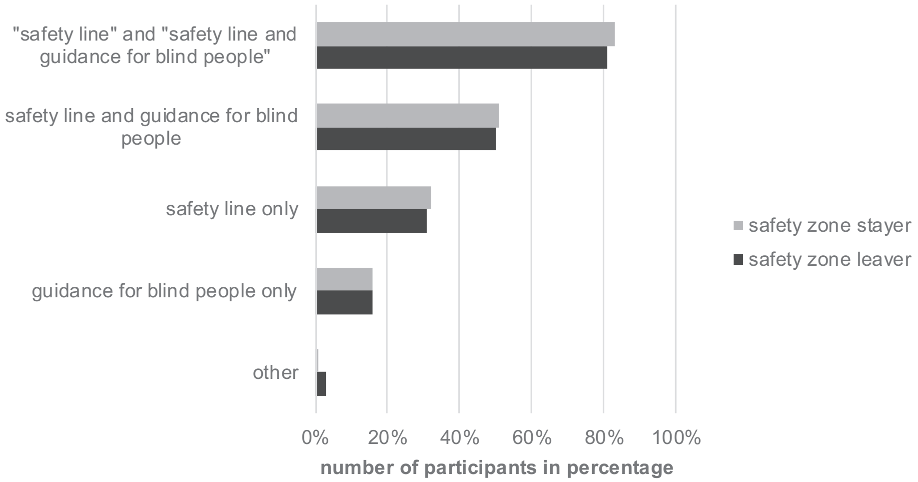


Fig. 6. Recognition of the safety line.

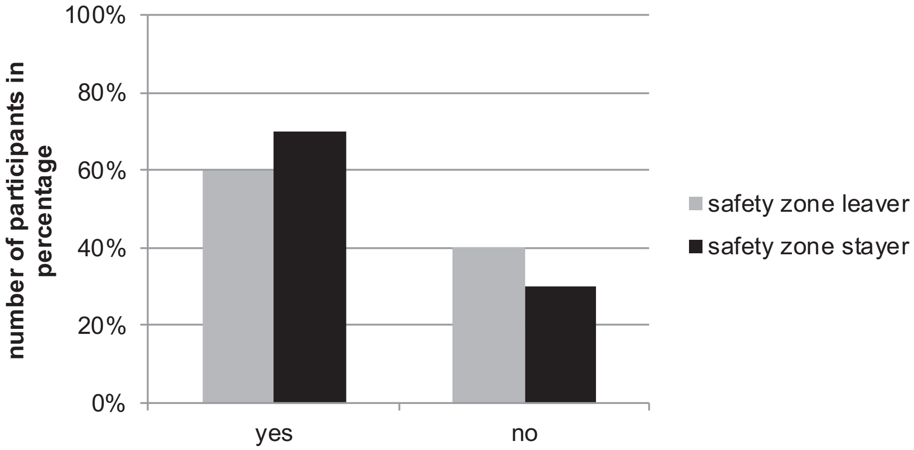


Fig. 7. Awareness of oversteps.

forced to overstep in crowded areas before train entrance are especially alert and aware that a train could drive in any time.

Not only the objectively measured passenger density had an effect on behavior. Passengers who left the safety zone experienced the respective passenger density as less comfortable compared to safety zone stayers, while their estimation of the passenger density is the same as that of the safety zone stayers. In our regression model, the perceived passenger density proved to be a predictor of overstepping. Also, our ANOVA showed that the safety zone leavers perceived the same estimated passenger density differently than safety zone stayers. Safety zone leavers perceived a higher passenger density as less comfortable compared to the safety zone stayers. This suggests that risk-taking behavior is motivated by an uncomfortable perception of passenger density, which then creates a negative perception of passenger density (i.e., the perceived passenger density is experienced as uncomfortable), a factor leading to unforced oversteps. To avoid the unpleasant feeling of high passenger density, they might step into the danger zone because this zone is less crowded compared to the safe zone. These findings fit in with the study of Manning and Valliere (2001), who found that people use displacement as a coping strategy when the density of people in a particular area feels uncomfortable.

Subjective estimation of passenger density using the Level of Service Scale (Fruin, 1971) did not differ between the train stations. Therefore, passenger density using the Level of Service Scale was estimated high in all three train stations. Thus, we conclude that objective measures of people density are necessary to reliably assess the given situation but that subjective measures of perception are relevant to assess the experience of the passengers. In general, we were able to confirm studies that indicate negative impacts of crowding on individual experience like discomfort (Cox et al., 2006; Li and Hensher, 2013; Tirachini et al., 2013). In our study, we conclude that higher passenger densities correlate with a decreased perception of comfort on the platform. Even though, as mentioned above, safety zone leavers experience the discomfort more pronounced than safety zone stayers.

4.2. Safety perception and risk-taking behavior

The perceived safety on the platform decreases with increased perceived passenger density. This is fits previous literature saying that crowding is associated with perceptions of risks to personal safety ((Cullen, 2001); Cox et al., 2006). Yet, safety perception itself was not a predictor of oversteps and therefore is not a factor leading to unforced oversteps. Therefore, we conclude that oversteps do not happen because passengers feel too safe on the platforms and thus do not mind the safety rules. In contrary, our results indicate that passengers seem to be aware of the situation on platforms. Participants felt less safe on the platform compared to other areas in the train station. While in Schlüter et al. (2016) security issues seemed to be the reason for a bad feeling, we identified safety issues in our study as reasons for the unsafe feeling. Passing trains, crowded or narrow platforms, as well as not enough space, were named as factors leading to an unsafe feeling. Interestingly, the factor “not enough space” was mainly cited by the safety zone leavers, supporting the interpretation above, that safety zone leavers feel have a less comfortable perception of passenger density comparted to safety zone stayers. This might imply that feeling pressured or stressed might lead to stepping into the danger zone to either have more space or to pass other passengers, an interpretation that seems plausible regarding existing literature (Bell et al., 2001; Manning and Valliere, 2001), and that the aspect of safety perception itself was not decisive for oversteps.

Whereas “passing through trains” were named by more than half of the sample as factor leading to a decrease in safety perception, entering trains were only named by a < 20% of the participants. This leads to the interpretation that passengers on the platform consider the risk posed by arriving trains to be assessable for themselves. When a scheduled train approaches, passengers may become more alert and try to perceive their surroundings more consciously. This could also be an explanation why nearly no accidents occur during rush hours even though the platforms are crowded. On the other hand, passing trains seem to be rather unpredictable. Therefore, they might catch passengers off guard and are therefore rated as a factor that makes participants feel unsafe. These findings are congruent with literature stating that a feeling of control can influence the evaluation of risk (Sjöberg, 2003).

The fact that mainly concerns about safety, but not security, were voiced could be due to the choice of station and location of this study. Safety concerns could be particularly serious at the stations investigated because all three stations have frequented platforms and therefore outweigh security concerns. This assumption could be investigated with studies at other stations.

4.2.1. Signaling systems

Traditionally, signaling systems, rules, or prohibitions are used to steer passengers (ProRail, 2006; Bundesamt für Verkehr (BAV), 2011). However, as our results show, signaling, in this case the safety line, might be overlooked due to unawareness or misinterpretation. We discovered the occurrence of unforced oversteps during less crowded periods. We observed situations in which passengers where focused on their smartphone or conversation partner, when being part of a psychological crowd (Reicher, 2011) and therefore did not pay attention to signaling. Our moderation analysis showed that the recognition of the safety line does not moderate the relation between perceived passenger density and overstepping into the danger zone. Thus, rules or prohibitions might not always be effective because, as our results indicated, escaping uncomfortable feelings, inattention or the sheer inevitability might still lead to risk-taking behavior.

4.3. Practical implications

Even though we found that the general implications (e.g., the correlation between passenger density and safety perception, or passenger density and the number of oversteps) held true for all three train stations, we found differences between the train stations when it comes to finding practical measures. In Lenzburg, the passenger density was generally higher compared to Bern and Visp. However, the measures were more challenging because of the limited space available. In Visp, however, the space conditions are less critical. A deeper analysis of the type of passenger would be helpful in finding a suitable practical measure. Based on observation, we assume that passengers in Visp are-rather tourists carrying luggage and skis. Therefore, they could be guided to a different place on the train station by nudging them e.g. by placing a ski holder in less crowded spaces on the platform. In Lenzburg, however, where most of the passengers are commuters on their way to work, the motivation to guide them to less crowded places on the platform would have to differ.

Therefore, we propose to use inducements to motivate passengers to move to less crowded areas of the platform. This concept is known as nudging (Sunstein, 2014). Stereo sensor technology can help to identify those less crowded areas. In this regard, we encourage the current trend in crowd research, which suggests considering contextual factors and conducting empirical studies in specific contexts (Haghani and Sarvi, 2018). In future studies, nudges then have to be prototyped and tested for impact. The results suggest that passenger distribution on the platform should be improved to lower passenger density in crowded areas and to increase awareness about the danger on the platform and the corresponding signaling.

4.4. Methodological approach

With regard to recommendations from previous studies (Li and Hensher, 2013; Schlüter et al., 2016; Thurau et al., 2019), our methodological approach was an attempt to collect data in context and connect objective with subjective data. This approach helped us to connect behavioral data with subjectively measured data. With new digital possibilities, the generation of customer insights to create human-centered design solutions will offer possibilities to deliver a more holistic and real picture of our passengers. The use of stereo sensor data is only one of many possible solutions. Even the smartphones that passengers carry with them contain a lot of behavioral data that, combined with personal data, would lead to deeper insights. For example, it would be possible to investigate different behavioral patterns for different passenger groups, differentiated by age or professional activity. Or it would be possible to send specific survey questions to passengers who exhibit a certain pattern of behavior. With the help of beacon technology, it would be possible, for example, to track whether some passengers cross into the danger zone, and it would allow connecting survey data directly to this passenger in the danger zone. However, this would necessarily require consent of the test participants, data protection clauses and privacy policies to maintain ethical and data security standards.

4.5. Limitations and future research

In this study, we focused on researching relations between crowding on the train stations and its effects on behavior and perception. Therefore, data collection was set during rush hours. However, in our study, we discovered also unforced oversteps during less crowded periods. During the observation, we discovered that unforced oversteps occurred due to inattention. We observed situations in which passengers were focused on their smartphone or conversation partner. However, we were not able to collect data regarding this subject in a systematic matter. We did not systematically differentiate between physical and psychological crowds (Reicher, 2011); two concepts, which could be helpful in the pursuit of this matter. Further studies should investigate this point systematically during less frequented periods.

On the other hand, most of the oversteps were measured during rush hours before train entrance when the platform is crowded. Interestingly, hardly any accidents happen during those time periods. Our data indicates that most of the participants do not perceive entering trains as a situation that makes them feel unsafe. Thus, our interpretation that passengers feel more alert during those situations and maybe even consciously observe the surroundings before oversteps into the danger zone should be further researched. This could give answers to the phenomena why almost no accidents happen during rush hours, despite the occurrence of oversteps into the danger zone.

4.6. Conclusion

The perception or subjective estimation of the number of people on the platform is a decisive factor for behavior and well-being on the platform. The actual passenger density seems to be less relevant for the experience. Nonetheless, the actual passenger density is an important factor, because when a certain limit is reached, it forces passengers into leaving the safety zone because there is no other space available or because they want to escape the uncomfortable feeling in the crowded safety zone. However, because crowded platforms usually occur before a train entrance, passengers potentially seem to be alert and aware. Therefore, accidents hardly occur during rush hours. Unforced oversteps during less crowded times should be further researched. Although the perception of safety is an important part of a good experience at a train station, it does not seem to be the decisive factor leading to risk-taking behavior. This study suggests improving passenger distribution on the platform to reduce risk-taking behavior, like overstepping the safety line, and enhance customer experience on platforms.

CRediT authorship contribution statement

Andrea Schneider: Conceptualization, Methodology, Visualization, Formal analysis, Investigation, Data curation, Project administration, Writing - original draft. **Eva Krueger:** Conceptualization, Supervision, Methodology, Project administration, Investigation, Writing - review & editing. **Beat Vollenwyder:** Conceptualization, Methodology, Investigation, Writing - review & editing. **Jasmin Thurau:** Conceptualization, Methodology, Visualization, Investigation, Formal analysis, Software, Project administration, Writing - review & editing. **Achim Elfering:** Conceptualization, Supervision, Writing - review & editing.

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