behind the gap

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reducing railway deaths

d4 final report

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abstract

Railway fatalities are a tragic issue of global nature. In the UK alone, around 300 people die on the railway network every year. Nine out of ten of these fatalities are suicides [1]. The emotional, human and financial costs are shockingly high, as they can take place in view of passengers, station staff and drivers. The current value for preventing a fatality (VPF 2018) has been set by the RSSB as £1,946,000 [2]. It is a summation of all the direct and indirect costs incurred by a fatality through compensation claims, consequential losses, train servicing, delays etc.

The objective of this project was to develop a number of anti-suicide measures that could be quantitatively evaluated. An initial research phase involved a literature review, primary research and industry outreach, giving rise to a number of insights and design constraints. In response, three solution concepts were developed for application in an underground train station environment. The selected concept aimed at using illusion and obstruction approaches to slow down the perception of an approaching train. The underlying premise was that the later an individual localises a train, the less likely he or she it to have enough time to jump in front of it.

Four audio-visual interventions were designed. They include directional audio and light illusions, as well as visual obstructions; all of which make it harder to localise an approaching train. Virtual Reality was chosen as a framework to perform a study that quantified the impact of these interventions. A study with a sample size of 20 was conducted, measuring the impression of train origin direction (Where do you think the train is coming from?) and the response time (When do you see the train?).

The results show that directional audio can effectively invert the perception of the train's origin direction. Furthermore, the light illusion produced a significantly higher response time than the control scenario, albeit with a relatively high spread. The visual obstructions in particular led to a significantly higher response times. There is strong evidence that audio-visual interventions could significantly delay localisation of an approaching train. At the chosen train speed of 20 m/s, even a one second delay in localisation corresponds to 20 metres of distance covered by the train. As a consequence, a suicidal individual might not have enough time to jump in front of the train, or hit the side of the train instead.

Future studies should confirm the efficacy of the proposed interventions and rectify some of the limitations of the VR test environment. If confirmed, implementation should take place at suicide hotspots in order to observe the impact on actual suicide rates.

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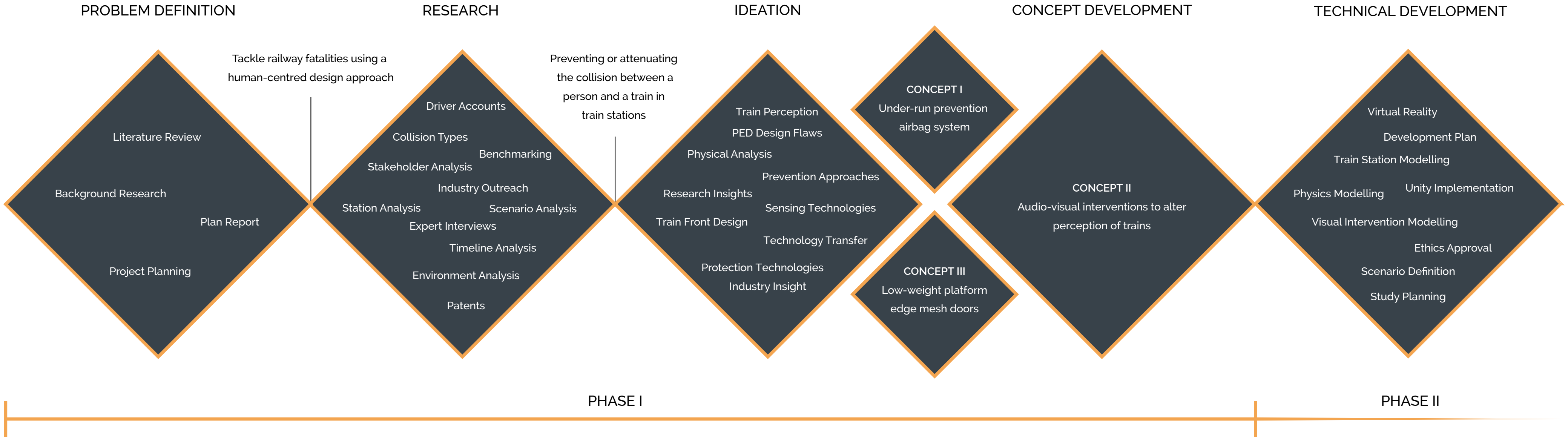
1. background

Around 300 people die on the UK railway system every year. Nine out of ten of these fatalities are suicides [1]. The emotional, human and financial costs are shockingly high, as they take place in view of passengers, station staff and drivers. The current value for preventing a fatality (VPF 2018) has been set by the RSSB as £1,946,000 [2]. It is a summation of all the direct and indirect costs incurred through compensation claims, consequential losses, train servicing, delays etc. In other words, a UK railway operator is ready to invest up to two million pounds to prevent a single fatality on their network [3].

2. reducing fatalities on the railway

This objective of this project is to save lives by developing a number of anti-suicide measures that can be quantitatively evaluated. Railway fatalities are a tragic issue of global nature and are most pronounced in developed nations with extensive rail infrastructure [4]. No solution can ever completely remove the risk of deaths on a railway network. Instead, prevention and rescue strategies work cumulatively and the success of one is measured by the ratio of its effectiveness to its cost. In this way, a low-cost solution with limited impact might still be better than a high-cost solution with a marginally higher effectiveness [3].



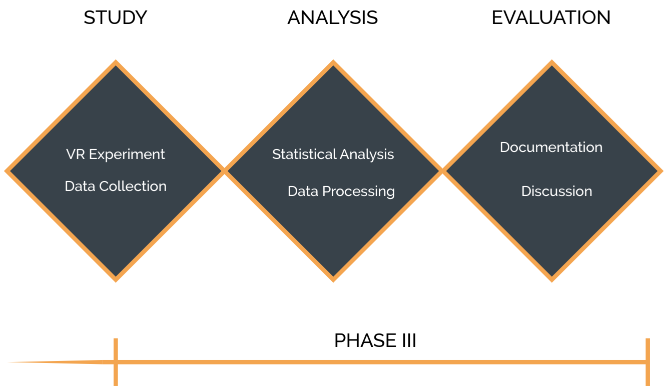


Figure 1: Design process. Keywords within the boxes are examples of activities undertaken during the different stages.

3. project management

The project was split into three phases. Phase I was research-driven and aimed at outputting three concepts. One of them was to be developed in Phase II and evaluated in Phase III, as shown on the timeline (Figure 1). This is the final project report, outlining research, concept development, technical development, testing, analysis and discussion of the results.

4. research outcomes

A fatality occurs within the frame of a few seconds, but has wide-ranging and complex consequences that can last for years thereafter. Pimary and secondary research was conducted to understand the highly complex cascade of events. The following pages capture some of the research activities and their outcomes.

stakeholder & timeline analysis (Figure 2)

A network of everyone involved in a suicide as well as the timeline of events was established. In order to meet the project objective, it was clear that any solution had to involve *preventing or attenuating the collision between the train and person.*

environment analysis (Table 1)

Railway suicides occur in different environments such as stations or high-speed sections. These environments were decomposed into four layers in order to qualitatively assess where suicides could be reduced most effectively. The project focuses on *the station environment*, where the rescue potential was deemed highest.

benchmark analysis (Figure 3)

Existing solution approaches were mapped out and analysed, as discussed in the following section. The outcome was to focus on solutions with *low technical complexity and cost*.

Documentary films were analysed to understand the psychological effects railway suicides have on drivers and other stakeholders. A relevant quote is shown on the bottom right. Furthermore, primary research was conducted by means of expert interviews with the former and current head of Health & Safety at Network Rail and SBB (Swiss Federal Railways), respectively. Figure 4 is an example of resources brought to these interviews.. The outcomes of these discussions are presented in the following section.

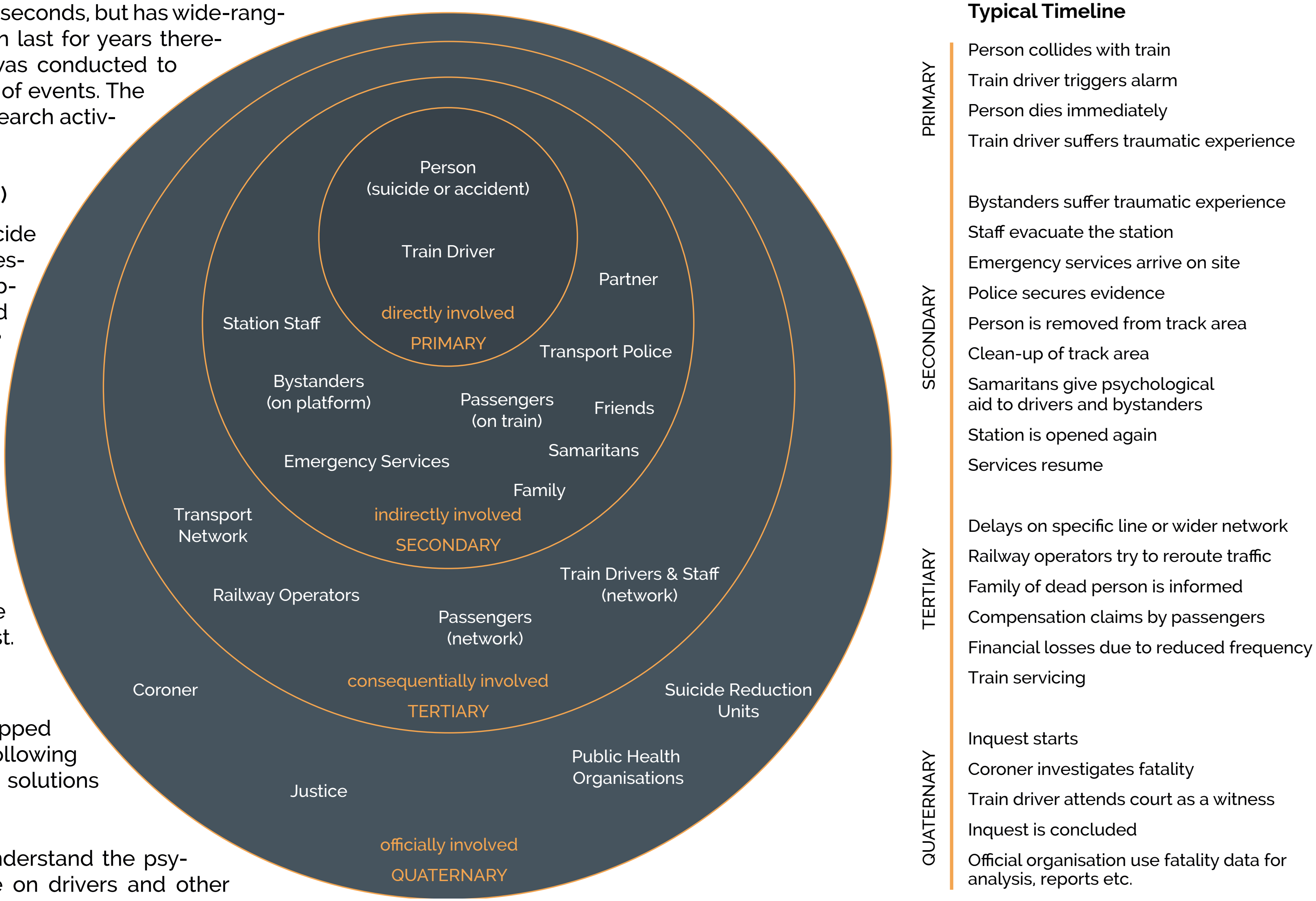


Figure 2: Stakeholder and typical timeline of a railway suicide.

> I just have nightmares and still have them, 35 years after..
>
> \- London Underground Driver [6]

Table 1: Environment Analysis. Hard data presented in the table is compiled from UK and Swiss Railway reports [1, 3, 7] and primary research.

		Station	**Urban Transit**	**High-Speed Transit**
Architectural Layer	*Access*	Usually exposed, sometimes restricted (Platform Edge Doors)	Restricted	Restricted
	Train Frequency	High	Medium - High	Low
	Environment	Space-limited and often underground. Often several platforms.	Urban with other architectural features (e.g. bridges, overpasses)	Suburb or rural, suicide hotspots are usually very remote
	Rescue Features	Trenches or under - platform shafts may exist	None	None
People Layer	*Suicide Frequency Percentage*	40% - 50% (CH / UK)	50% on running line, 10% on level crossings (UK)	
		9 out of 10 fatalities are suicides, data on accident location distribution n.A.		
	Suicide Characterisation	Generally less considered and more spontaneous.	Generally more considered and carried out by jumping from a bridge or at a very remote place (e.g. level crossing)	
	Collision characterisation	Uncertain, usually impacts within seconds	Uncertain, sometimes minutes can pass before impact. People may try different positions and often lay down on tracks	
	Staff and other passengers	Staff and bystanders often present	Staff and bystanders absent	
Technological Layer	*Relative Impact Forces*	Lowest	Medium	Highest
	Time to Deploy Rescue Device	Highest	Medium	Lowest
	Existing Solutions	Passive, rarely active	None	Some
	Potential Rescue Approach	Prevention and rescue feasible	Prevention and potentially rescue feasible	Prevention only
Operational Layer	*Network Impact*	Highest	Medium	Lowest
	Transferability	Rescue solutions	Rescue solutions	None

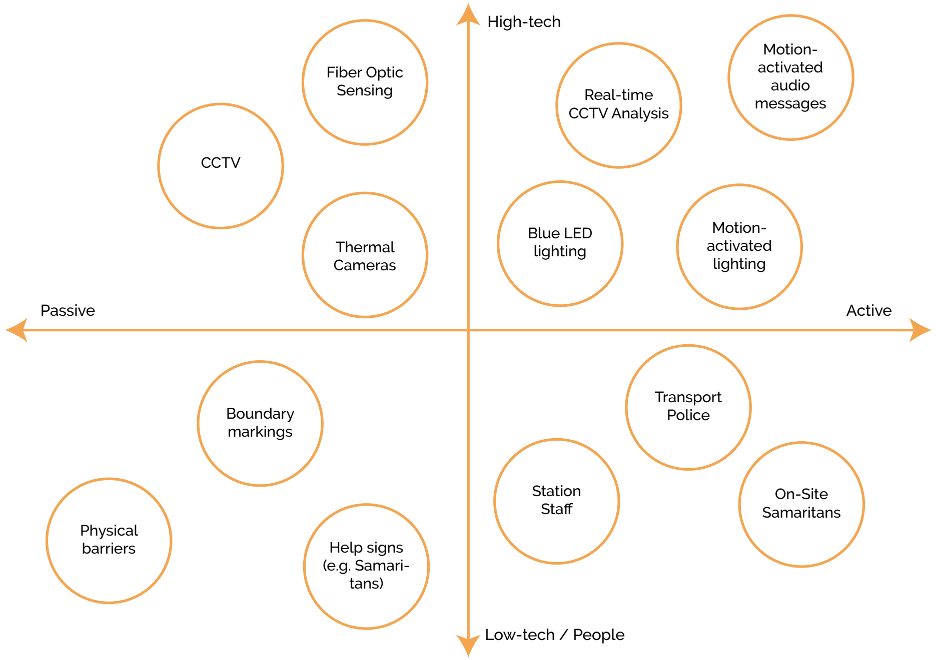


Figure 3: Benchmark Analysis. Data compiled from UK and Swiss sources [1, 7].

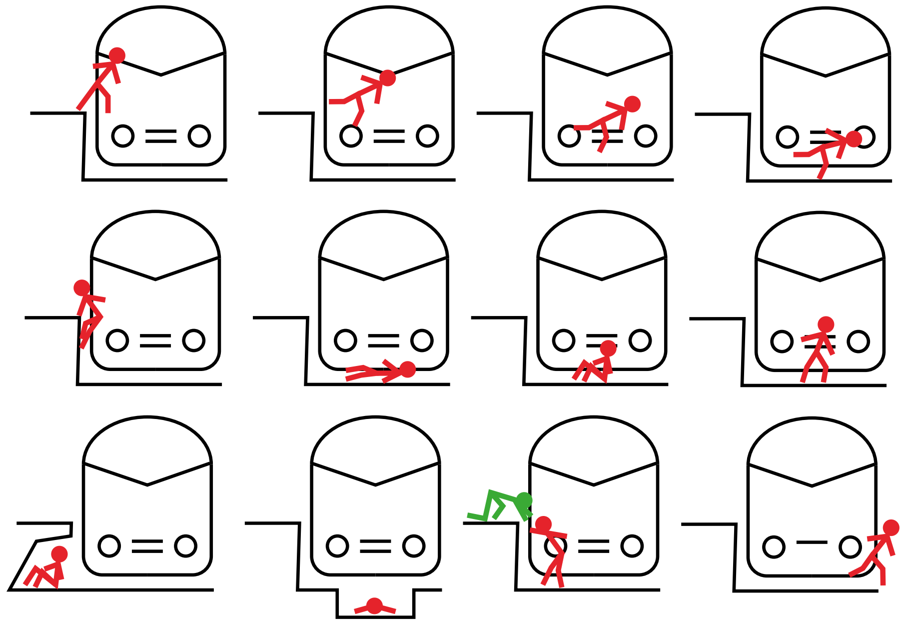


Figure 4: Scenario Analysis. Not enough data available to generalise collision types to any of the above. Instead, suicides vary by levels of consideration [3].

4.1 challenges with current solution approaches

Expert interviews and benchmarking of existing anti-suicide measures yielded a number of challenges and design constraints, which are presented as follows.

Behaviour near the tracks is individual and hard to quantify

The behaviour of a suicidal person immediately before jumping is highly individual and, so far, impossible to detect technologically. Some people leave their personal belongings, others make erratic gestures, but there is no common behaviour amongst all individuals [4]. This is one of the main reasons why many (active) technical solutions approaches have failed [5]. There are too many false positives i.e. the system detects a suicidal person when there is none. As an example, a machine vision system might pick up on someone missing several trains, which could serve as a predictor. Indeed, it could be someone thinking of taking their life, but it is most likely just someone waiting for a friend.

At this point it also needs to be mentioned that humans are the single most powerful preventers of railway suicides. Human interventions include everything from talking to a distressed person to pulling them away from the tracks. This project, however, focused on developing technological solution approaches.

4.2 characteristics of suicidal people

People attempting suicides on the railway are predominantly male and often have a preexisting psychiatric diagnosis. The mean age differs from country to country, but is generally around 40. The reader is referred to the UQAM source for a detailed overview of academic papers analysing the demographic and temporal distribution of railway suicides [4]. There are also local factors that can a correlation with suicide rates such as proximity to a psychiatric hospital.

Discussions with the former Head of Safety at Network Rail yielded that railway suicides can be roughly divided into two groups that vary by levels of consideration. Less considered suicides often happen as a result of acute mental breakdowns and are more prevalent at stations, mainly due to the ease of access [3]. The more considered type occurs with individuals that carefully plan their death and therefore choose remote locations on high-speed sections. They typically spend more time on the track area and often try several poses until the collision occurs [5]. The focus for this project was set on the former, more spontaneous type of suicide. The reasoning for that decision was based on the insight that less planned suicide attempts fail much more frequently. As such, any sort of intervention could have a significant impact on that group.

4.3 narrowing down the problem space

There is an almost unlimited amount of combinations of environment (station, transit, high-speed), demographic and behaviour that constitute the circumstances of a fatality. Similarly, It is not possible to prevent all of them through a context-independent solution. Informed by the research outcomes, a number of assumptions were made in order to narrow down the problem space:

- The environment was chosen as a London Underground train station.
- The solution would target the less considered type of suicide.
- The solution would be of technological nature.

5. concept development

5.1 design constraints

Throughout the research process, many design constraints emerged and are presented below. These arise due to the neccessity of passenger flow, safety considerations and the required discreetness of any anti-suicide measure.

- A solution must not permanently disrupt passenger flow.
- A solution must not be directly recognisable as an anti-suicide measure.
- A solution must not restrict the train driver’s ability to see the platform.
- A solution approach must not confuse passengers.
- A solution must not block visibility of advertisement.

Three concepts were developed from the research insights and are presented on the following page.

train-mounted airbag system

insights & description

Active airbag rescue devices for trains are not yet in existence [8]. There is high potential to transfer existing sensing and protection technology from the automotive sector, particularly thanks to advances in autonomous driving technology [9].

opportunities

- High rescue potential in low-speed transit
- Could potentially act as a deterrent [5]
- Transferable to other industries (trams, HGVs) [9]

challenges

- Expensive to develop and fit, since every train would need to be upgraded [5]
- Limited to low-speed environments
- Railway industry and market segmentation inhibit this type of innovation [5]

altered train perception

insights & description

Human perception of fast-approaching objects is inaccurate, leading to a high number of failed suicide attempts. The individuals often jump too late, hit the side of the train, and sometimes fall into the gap resulting in heavy injury [3]. Slowing down the perception of the approaching train by means of illusions or obstructions could encourage jumping 'too late', i.e. into the side of the train, thereby reducing fatalities.

opportunities

- Industry encourages low-tech innovations [5]
- Low-cost and deployable at stations and on trains
- Could potentially be implemented through regulations [3]

challenges

- Effectiveness not known
- Limited to station environments
- Needs to be coupled with carriage design guidances to avoid injury upon impacting side of train

platform edge mesh

insights & description

Many stations do not fulfil requirements to be upgraded with platform edge doors (PED) due to their high weight, cost and the effect of wind loads [3]. Most platforms are served by diverse trains with varying door-to-door distances, making current PEDs unsuitable. SBB estimates it will take at least 50 years until PEDs could be implemented on their whole network [5].

opportunities

- Minimises weight and wind loads
- Meshes suffice to prevent track access
- Adaptive nets could enable varying door-to-door gaps

challenges

- Significant technical challenge in achieving door opening within mesh
- Massive technical challenge in achieving varying distances in mesh openings
- Architectural installation difficulty unknown

6. concept selection & research question

Altered Train Perception was selected for development, because industry showed most interest in it and promising developments were possible within the time constraints. Discussions underlined that a driving requirement from industry was low cost. It was also stressed that the success of any measure is dependent on how it would be implemented, e.g. through regulations or industry.

The nature of railway station licensing in the UK makes upgrades to stations more viable than upgrades to an entire fleet [3]. An exception to that are features subject to regulations such as how a train's front is painted. Consequently, the *Train-Mounted Airbag System* was deemed too expensive. The *Platform Edge Mesh* concept received positive feedback, but the time frame was not sufficient for a detailed design. The initial research question was therefore formulated as:

"How can you slow down the perception of approaching trains using audio-visual interventions?"

The term ausio-visual intervention was defined as any form of stationary or train-mounted design feature aimed at slowing down the perception of the train.

7. technical development

Before any interventions were developed, a suitable framework to answer the research question was needed. It emerged that Virtual Reality (VR) could provide an ideal environment to quickly (i.e. digitally) implement audio-visual interventions, whilst retaining depth and perspective perception. It also allowed for experiment conditions that could be reproduced over many study participants. Phase II therefore involved building a VR representation of a train station, implementing a test procedure and to evaluate different interventions.

7.1 the station environment

Figure 5 shows the final iteration of the virtual train station environment that was assembled within the Unity game engine. To reduce development time, most 3D models were sourced from external providers. The bulk of technical development went into assembling the test environment, as well as program the dynamic behaviours within Unity (train motion, player interactions, data collection and storage, etc.).

Figure 5: Virtual train station test environment

7.2 train-mounted interventions

Initially, visual changes to the train front were investigated. They were intended to slow down the speed perceived by an observer. This represented the starting point of intervention design. The efforts were based on the premise that if an individual judges the train to be much slower than it actually is, he or she would be more likely to 'jump' too late. Previous studies have discussed that naturally occuring optical illusions might be a reason for accidents at level crossings [10].

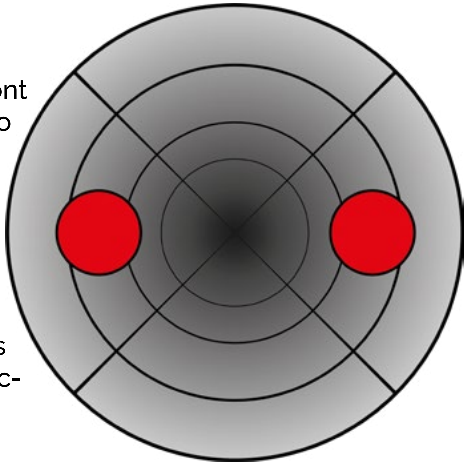


Figure 6: Static illusion based on linear perspective principles

optical illusions

This approach used static images that were mapped onto the front of train, as shown in Figure 6. The 2D image implied depth through a colour gradient and vanishing points. These artificial perspective grids could make it harder to interpret the real one-point perspective grid in which the train is approaching, slowing down the perceived train speed.

animations & mirrors

Time-variant illusions on the front of the train or within a station were also explored. Animations or mirrors were mapped onto the front of the locomotive. A specific intervention involved mapping squares, whose size varied with distance to the viewer (refer to Figure 7). As the train approached, the square decreased in size when it should have 'grown' larger due to the shorter distance. As a consequence of this perceptual mismatch, the viewer was expected to judge the train to be approaching more slowly than it actually was.

7.3 issues with train-mounted interventions

Preliminary results with train-mounted interventions were not promising enough to justify further work. There were a couple of key issues with this approach, listed below.

- The approaching train is too small in a subject's field of view to interpret detailed imagery or animations.
- The relative size of the train's side compared to its front increases the closer it gets. As a result, the whole train would need to be used as a canvas to upkeep an illusion.
- A train contains reference contours such as windows, which are easy for the eye to track therefore judge the object's speed
- The VR kit didn't offer enough resolution to exactly reproduce illusions beyond 30 metres,

Figure 7: Square illusion mapped to the front of the locomotive

Other solution approaches that could be evaluated in VR were needed. A couple of lessons learned from the initial development sprint are presented below.

It's easier to distract from an object than to change the perception of it.

Humans are remarkably good at judging the speed and position of objects in their field of view. Optical illusions work, but rarely become apparent outside of strictly controlled conditions. Motion processing studies that were benchmarked for this development sprint were not extendable to the realistic VR environment. As an example, motion perception is altered when observing a contrast-varying rotating disk at a fixed distance, without any other environmental information available [11]. These illusions appear to become harder to achieve the more environmental information is available, as was the case in the VR test environment.

Once a person sees a train, it is accurately localised.

Although some train-mounted interventions worked over a short time frame, the brain constantly reevaluates the optical information and the illusion tended to break down after a certain time. Vitally, the illusions got worse as the train drew closer.

7.4 stationary interventions

A different approach was taken due to the negative results of the first development sprint. Rather than be placed on the train, the illusions should work to distract from it. The goal was therefore to keep the subject's eyes off the train for as long as possible. However, the underlying premise remained the same: If a suicidal person sees the train only just before it passes by, that person is less able to jump in front of the train in time. The research question was rephrased:

"How can you delay the localisation of an approaching trains using audio-visual interventions?"

7.5 research insights: trainspotting

Firstly, it was essential to establish which localisation cues people rely on. Primary research was conducted on the London Underground in order to determine these, and are presented below.

sound (primary localisation cue)

The first sensory indication of an approaching train is the sound created at the wheel-rail interface that propagates through the rails. Humans can localise sound sources laterally to approximately two degrees [12]; hence, people can definitely rely on this localisation cue to indicate train origin.

light & wind (secondary localisation cues)

Underground trains have headlights in order for the driver to see the tracks ahead. This light illuminates the tunnel and tracks in front of the locomotive before it enters the station. This serves as a cue that a train is about to come in, seconds before the actual locomotive becomes visible. Furthermore, the train displaces air within the tunnel system; a phenomenon that is known as the Piston effect. The sensation of a breeze can also be used to sense a train's origin.

vision (tertiary localisation cues)

As soon as the locomotive enters a person's field of vision, the train is accurately and definitely localised.

7.6 stationary interventions

Three types of stationary interventions were proposed that distract from or obstruct the approaching train. In the followings sections, the term 'correct tunnel end' and 'correct direction' refer to the actual tunnel end and direction a train is approaching from. Conversely, the terms 'false end' and 'false direction' refer to the tunnel end or direction the train is *not* approaching from.

audio illusion (primary localisation cue)

This intervention used directional audio aimed at convincing a person that the train is coming from the false direction (Figure 8). The illusion needed to be created on top of the sounds that the train was already producing. A recording of the noise created by an underground train was added to the virtual train. Naturally, the sound was spatialised so that a listener had 3D sound perception. As a train enters the station, its loudness increases until it passes by the person. The same (linear) rolloff for sound volume was assumed for all audio sources, as shown in Figure 9.

A virtual loudspeaker, playing the same sound clip as the train, was added to the scene at the false end of the tunnel. Since the train is initially further away from the listener than the loudspeaker, the sound coming from the loudspeaker is perceived as louder. The human hearing system localises two similar audio signals at the loudest signal source. As such, given that the train and the loudspeaker play the same sound clip and that the loudspeaker is significantly louder, the sound will be localised towards the loudspeaker [13].

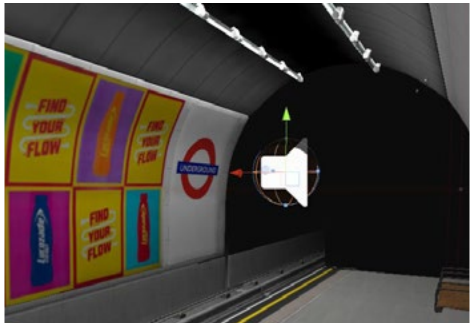


Figure 8: The loudspeaker was placed at the false end of the station

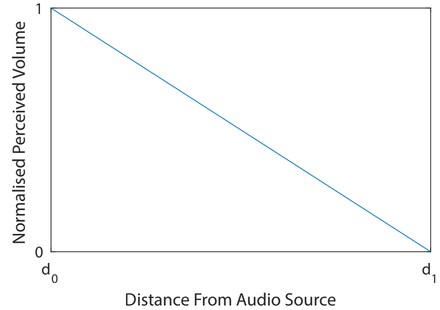


Figure 9: Volume Rolloff curve assumed for all audio sources

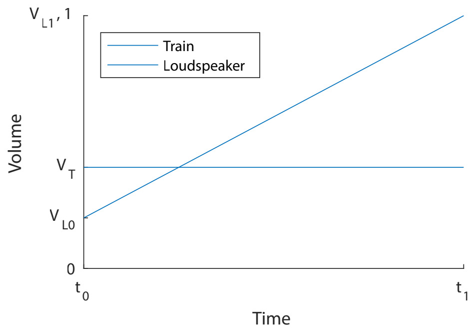


Figure 10: The Unity volume of train and loudspeaker audio sources vs. time

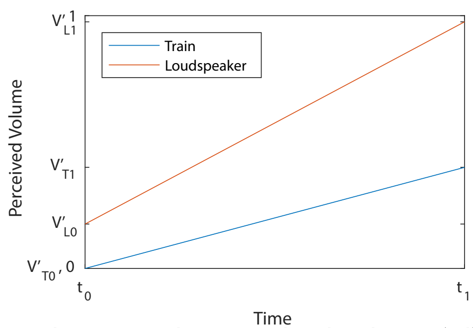


Figure 11: The perceived volume (V') i.e. loudness of train and loudspeaker audio sources vs. time

As the train approaches the subject, the distraction becomes harder to maintain, since it is moving audio source. The closer the train gets to the listener, the louder it is perceived, In turn, the loudspeaker needs to increase in loudness to maintain the illusion. A script was created to control the loudness of the loudspeaker as a function of the train's position in the tunnel. The audio source volumes and the perceived loudness are shown in Figure 10 and 11, respectively. Please note that the listener's position was fixed.

light illusion (secondary localisation cue)

The second intervention used range-varying spotlights to convince the person that a train was about to come out of the false end of the tunnel. As the train reached a predefined location in the tunnel (150 metres from the tunnel end), it triggered the spotlight to ramp up. This mimicked the light patterns that emerge on the tracks when a train enters the station (refer to Fig. 5). The spotlight did not only become lighter, but also illuminated a longer section of the tracks, thereby implying motion. The illusion and the time-variant behaviour of the light source are shown in Figure 12 and 13, respectively.

Figure 12: Light illusion placed at the false end of the station

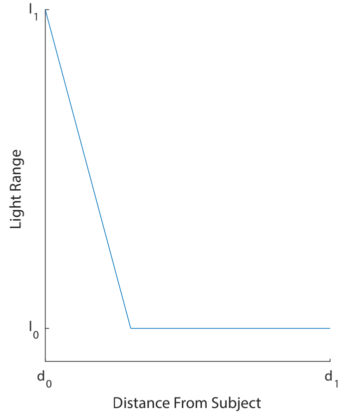


Figure 13: Light illusion range rampup vs. distance from subject

visual obstructions (tertiary localisation cue)

As soon as the train enters the subject's field of vision, it is accurately localised. In order to render this impossible, two visual interventions were developed that obstructed the view of the approaching train. The major issue with regards to obstructions was that they needed to be placed between the person and the train. The design constraints, conversely, required that any solution must not remove the view of the ads or disturb passenger flow. Two interventions were designed that minimised this conflict.

visual obstruction: blocks

The intervention consisted of angled poster walls that were periodically located at the intersection of individual carriages. In this way, the doors are never obstructed given that the train stops roughly at a defined position. Essentially, the view of the tracks is replaced by advertisement blocks, located in a way to minimise passenger flow disruption (Figure 14).

Figure 14: Blocks obstruction placed on the platform edge

visual obstruction: curtains

The final intervention was inspired by the curtains children often make from used plastic straws. They are suspended from the ceiling and you can easily walk through them. When located orthogonally to the curtain, the view of what lies behind is not affected. When looking at the structure from an angle, however, the individual elements move together in a subject's field of vision and do not allow light through past a certain angle (Figure 15).

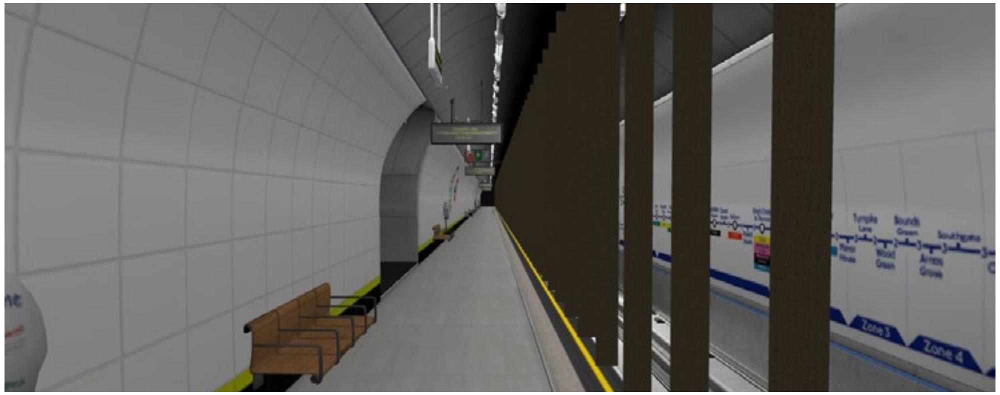


Figure 15: Curtains obstruction suspended from the ceiling,

8. method

The experiment was split up into six different scenarios that aimed at quantitatively assessing the stationary interventions. The impression of train origin direction during the illusion interventions (audio and light) were tested using a Two Alternative Forced Choice (2AFC) approach, which is a common method to measure subjective responses. The subject had to indicate with a mouse click, before the train became visible, which direction they thought it would come from (left or right). Upon seeing the train, the subject needed to press the Space button and the response time was recorded. After the audio and light scenarios were completed, the subject was asked to move to the location on the platform from which they would see an approaching train from a known direction (left) the earliest. After another control measurement, the two visual interventions were tested while the player remained static. The routine is summarised in Table 2 and a video asset of the experiment routine is available in Appendix C.

Due to the large amount of environmental information available in the VR environment, the experiment had to be carefully parametrised in order to retain scientific validity. Table 3 shows constants and initial conditions, which determined how the scenarios 'played out' in the experiment. The train's speed was constant throughout the experiment.

Table 2: Sequence of scenarios in the experiment routine

Scenario	*Type*	*Measured Quantity*
S1	Control	Directional Response / Response Time
S2	Audio Illusion	Directional Response / Response Time
S3	Audio Illusion + Light Illusion	Directional Response / Response Time
S4	Control (Custom Platform Location)	Response Time
S5	Block Obstruction	Response Time
S6	Curtain Obstruction	Response Time

Figure 16 shows a cutout of the top-down view of the experiment environment. The player was initially located at the origin, unable to move along the platform during the first three scenarios. The subject could then move to another fixed position for scenario S4 to S6.

Table 3: Experiment Parameters

Parameter	*Symbol*	*Unit*	*Value*
Platform Length	L	m	121.5
Start Time	t_0	s	0
End Time	t_1	s	25
Train Start Distance To Player	d_0	m	500
Train End Distance to Player	d_1	m	0
Train Speed	v_T	m / s	-20
Countdown Time	-	s	3
Number of Scenarios	-	-	6
Directions	-	-	[1, -1, 1, 1, 1, 1]
Train Volume	V_T	-	0.4
Loudspeaker Base Volume	V_{L0}	-	0.2
Loudspeaker End Volume	V_{L1}	-	0.8
Trigger Distance	$d_{TRIGGER}$	m	150
Light Illusion Start Range	l_0	m	30
Light Illusion End Range	l_1	m	140
Light Illusion Activation Time	t_l	s	10

Figure 16: Top-down cutout of the experiment environment. The scene is symmetric across the blue, dotted line. The red circle indicates the origin, where the player is placed intially. The player may move to any position along the green line (and its reflection) after completing S3. Moving to the left corresponds to moving in the positive direction.

9. results

The experiment was performed on 20 subjects over the course of two weeks. The ratio of male to female was 1.22. The raw data can be retrieved from Appendix B: Raw Data.

9.1 outliers

The participants were instructed to indicate that they had seen the train only when the locomotive became visible. Nonetheless, five participants indicated their time response before the train became visible in S3. In all of these cases, the subjects actually had indicated the false direction, but pressed the interrupt key whilst looking at the light illusion. They explained that they expected the train to come out, having seen the reflection of its headlights. The illusion consequently worked, but the time measurements were excluded from analysis, since they did not represent the actual response time.

9.2 descriptive statistics

Table 4 and Figure 16 show the descriptive statistics and boxplots of the responses times of the six groups, respectively. The big standard deviation in S3 can be attributed to the all-or-none nature of the illusion. Subjects either 'fell' for the illusion, or localised the train on the correct side as with the control scenario. Figure 17 shows the directional responses for S1, S2 and S3. Figure 18 shows the distribution of response times for all scenarios. Finally, Figure 19 and Figure 20 show the distribution of chosen platform location in S4 and the response times as a function of the chosen platform location (S4, S5, S6), respectively.

Table 4: Descriptive Statistics

		S1	*S2*	*S3*	*S4*	*S5*	*S6*
Time Response (s)	*Mean*	20.62	21.43	21.73	18.63	24.38	25.85
	Std. Dev.	1.29	1.65	3.76	1.65	1.32	1.21
Direction Response	*Count Correct*	20	3	1	-	-	-
	Count Wrong	0	17	19	-	-	-
	Percent Correct	1.00	0.15	0.05	-	-	-
	Percent Wrong	0.00	0.85	0.95	-	-	-

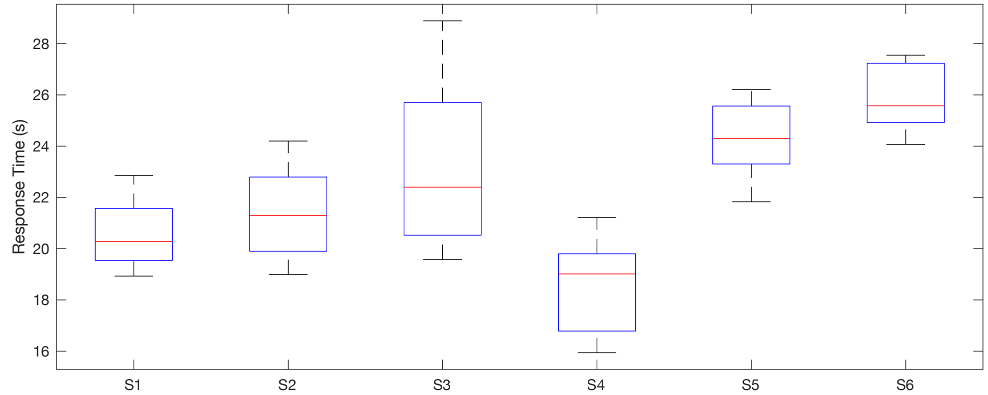


Figure 16: Response time boxplots for all scenarios

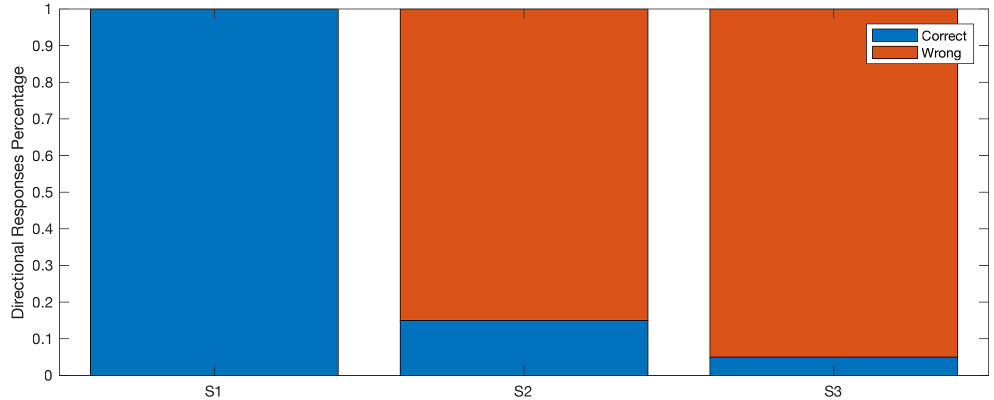


Figure 17: Percentage directional responses for S1, S2, S3

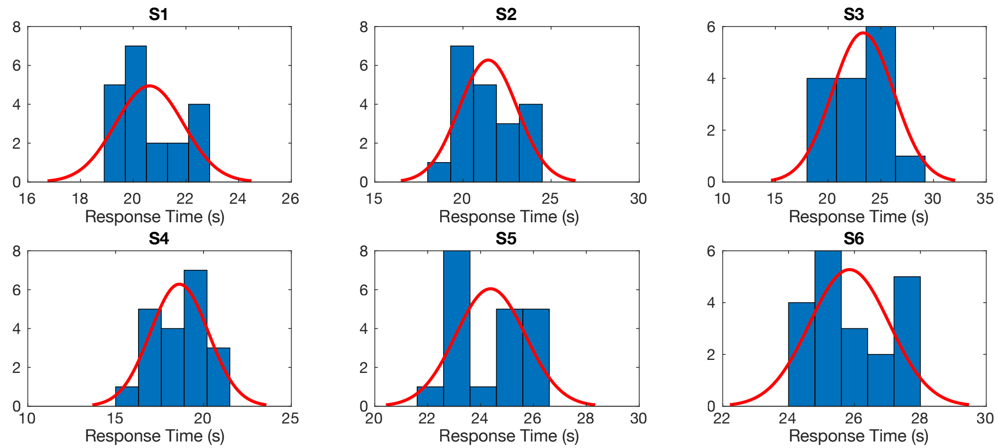


Figure 18: Response time histograms for all scenarios

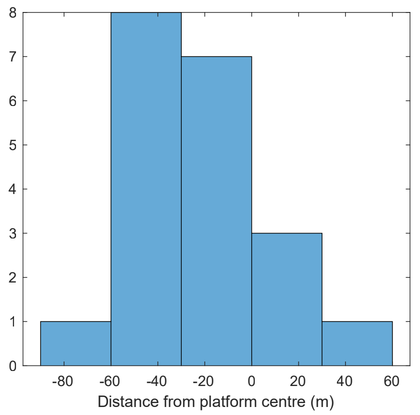


Figure 19: Histogram of chosen platform location during S4

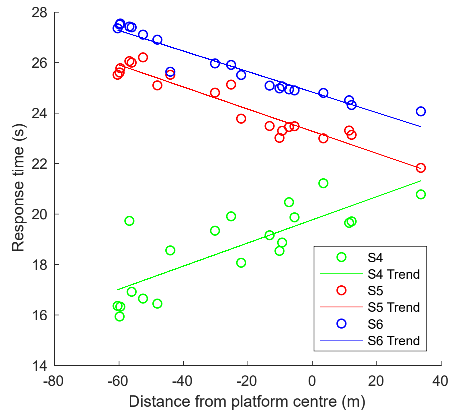


Figure 20: Chosen platform location vs. respones times (S4, S5, S6)

9.3 inferential statistics

Based on Figure 18, S1, S2 and S3 were deemed to be normally distributed. S1 shows a degree of non-normality, which was attributed to the fact that it was the first measurement and, as such, variability was expected to be larger. This is supported by the fact that S4 (also a control scenario) was normally distributed. Since S1, S2 and S3 were dependent, a repeated measures ANOVA was run. Repeated measures ANOVA showed that the difference between the groups is significant ($F(2,28)=4.54$, $p=0.020$). Multiple dependent samples t-tests were carried out post-hoc, showing no significant differences between S1 vs. S2 ($t(19) = -1.75$, $p=0.095$) and S2 vs. S3 ($t(14) = -1.75$, $p=0.100$). Significant differences were found for S1 vs. S3 ($t(14) = -2.47$, $p=0.027$).

A non-parametric method was chosen for S4, S5 and S6, since the latter two showed a non-normal distribution. Inferential statistics was performed independent of platform location. Since the measures were dependent, a Friedman test was carried out. It showed that the difference between the groups is significant ($x^2(2)=40$, $p<0.001$). A post-hoc Dunn test was carried out, showing that significant differences exist for S4 vs. S5 and S5 vs. S6 ($p=0.005$ in both cases), as well as S4 vs. S6 ($p<0.001$).

10. discussion

10.1 illusion approaches

directional audio is highly effective to alter the impression of train origin

Figure 17 shows that, compared to the control scenario, almost all subjects got the direction wrong in S2 and S3. This serves as strong evidence that the application of directional audio inverts the primary localisation of the train. In underground systems, where the trains usually stop at every station, speed and braking distance are much lower towards the false end of the tunnel. An incorrect impression of where the train is coming from could therefore make a suicidal individual move towards that end of the platform. This could, in turn, raise the chances of survival, although this is subject to further research.

audio-visual illusions can significantly delay the localisation of the train

The mean response times are 0.81s (S2) and 1.11s (S3) longer than in the control scenario. At the chosen train speed of 20 m/s (72 km/h), even a one second delay corresponds to 20 metres of distance covered by the train. Many suicides already fail, because individuals hit the side of the train rather than the track area. Any additional distance the train has done could therefore increase the likelihood that the suicide attempt fails or is not committed in the first place (as the individual realises it is impossible to jump in time).

During the experiment, it was observed that the nature of the results in S3 could be divided into several categories;

1. The subject saw the train light before seeing the illusion (illusion failed)
2. The subject saw the illusion, but checked the other side after not seeing a train coming out (illusion partially worked)
3. The subject saw the illusion and didn't see the train until it passed from the other side (illusion worked)

This is illustrated by the high standard deviation compared to the other groups. In the cases where the illusion worked, the delay was usually several seconds. When it didn't work, the difference to the control scenario was either none or very small. The significant difference in response time for S1 vs. S3 lays evidence that audio-visual illusions can alter response times. The fact that some subjects did not see the illusion in the first place, however, implies that the illusions might need more sensory cues to draw sufficient attention.

10.2 obstruction approaches

Expectedly, the obstructions had a more pronounced impact on response times. The results were highly dependent on the chosen location along the platform, giving rise to the non-normal distribution shown in Figure 18. The significant differences to the control scenario provides strong evidence that visual obstructions can delay the localisation of approaching trains.

Figure 19 shows that subjects tended to choose locations further down the plaform (with respect to the known train origin direction). The obstructions had a pronounced impact on response times in the sectors furthest away from the approaching train, as shown in Figure 20. The effect is much less pronounced in the sectors closer to the train.

10.3 limitations of the experiment

The developed VR environment was very realistic and contained a large amount of environmental data. Constraining the experiment parameters was a big challenge, which was crucial to retain comparability. The limitations of the experiment included the following:

- The subject could not choose their location during S1, S2 and S3
- The subject could not move during a scenario
- The train speed was constant
- The different scenarios were not tested on independent groups
- A general perception was that there was a degree of variability as to the reaction times of the subjects when the train became visible

10.4 implications and next steps

The results imply that all the proposed interventions could have some benefit. While the audio intervention alone effectively changes the impression of train origin direction, the added light illusion significantly increased the response time. These are two low-cost, low-maintenance and stationary interventions that do not obstruct the platform in any way. Following this concept design and pilot study, a more thorough experiment should follow. It should mainly aim to rectify the issues mentioned in the previous section and undergo more rigorous statistical analysis. Should these illusion interventions be deemed feasible, a longer-term implementation at a suicide hotspot would follow to evaluate the impact on actual suicide rates. It is also imperative to mention that one major issue remains unsolved: If an individual hits the side of the train, they might still fall into the gap and injure themselves heavily. This would need to be addressed by geometry changes to locomotives or platforms.

The obstructions proved very suitable and created the most notable differences in response time. They could serve as a low-cost measure to increase the barrier to commit suicide in a station, whilst providing an interesting canvas for ads or other interactions. There is potential to extend these blocks with optical barriers, help signs etc.

An analytic solution to when the train is visible as a function of the platform position should be elaborated. Furthermore, any additional experiments should take into account that a subject is able to move. It should also be noted that without an audio illusion, the subject could still localise the train through sound. Future studies, in the same manner, would be followed by longer-term implementations at suicide hotspots to evaluate the impact on actual suicide rates.

10.5 limitations and potential of the method

The objective of this project was to output quantified approaches to reduce suicides on the railway. VR was chosen as a quick and low-cost method to test these concepts on real subjects. The key limitation of this method was the uncertainty of whether these insights are transferable to real train stations.

Major difficulties with the method included the current state of the technology and the transfer of a real issue into the virtual sphere. The former was related mainly to the quality of rendering the interventions, while the latter revolved around recreating a physical scene realistically in the virtual world. VR enables a huge step out of the 'laboratory' environment into a more realistic use case, but there are no predefined, physical laws within it. As a result, constructing and constraining the experiment parameters was a big challenge. The closer the virtual representation of an environment becomes to reality, the larger becomes the reliability of results achieved within it.

Due to its low cost and unique capabilities, VR will undoubtedly become a ubiquitous tool in research, education and other sectors. However, considering the recent emergence of the technology, frameworks tailored to specific industries are not yet commercially available. Further to the implications of the experiment, this project also presents the backbones of such a framework in the context of railway safety. The cost of testing physical interventions is massively reduced, since neither the physical space nor the real intervention is required to quantify its potential. As such, one of the major achievements of this project is the framework on which the interventions were tested.

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appendix A: code

Please find the Unity project, the code base and the data processing scripts here. Due to licensing restrictions, some of the CAD models cannot be made public.

appendix B: raw data

Please find the raw data here. The processed raw data for subsequent analysis in MATLAB can be retrieved from the sheet 'CSV Export'.

appendix C: experiment procedure

Please find a video asset of the experiment procedure here. The spatialised audio only works on suitable headphone systems.