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Auxiliary strobe lights improve train visibility

Anne Silla[1*], Esko Lehtonen[1], Ari Virtanen[1], Johannes Mesimäki[1], Katrin Bialinska[2], Jan Grippenkoven[2], Annika Dressler[2]

1. Technical Research Centre of Finland VTT Ltd, Finland

2. German Aerospace Centre (DLR), Germany

anne.silla@vtt.fi

Abstract

The inattentiveness of road users during their approach towards passive railway crossings represents a major threat for level crossing safety. This paper presents an auxiliary strobe light system installed in train in addition to the already existing headlights to increase the salience of the train and hence to cope with this inattentive behaviour. The system was installed on a real railway vehicle as well as in the virtual environment of a driving simulator with the objective to assess its technical feasibility and to test its effects on users. A proof of concept of the auxiliary strobe light system was successfully implemented on a railway vehicle and tested under realistic conditions. The participants of the study judged the system as highly useful to enhance the detection of the train at the level crossing as well as to improve the overall safety.

Keywords: TRAIN VISIBILITY, LIGHTS, LEVEL CROSSING

Introduction

The level crossing is one of the most critical areas in railway traffic, because the safety strongly depends on the attention and the behaviour of road users. At level crossings, road users generally have to give the right of way to trains. Especially at passive level crossings without any infrastructural safety systems (e.g. like barriers), road users are not actively informed about an approaching train. They are responsible to first detect the level crossing (e.g. based on the warning signs) and subsequently attentively check the left and right directions for approaching trains, and decide if the passage is safe. However, research in this field concordantly underlines that the majority of drivers tend not to check actively whether a train is approaching at passive level crossings (Åberg, 1988; Grippenkoven & Dietsch, 2015; Wigglesworth, 1978).

As a consequence, the use of stationary peripheral lights in the vicinity of passive level crossings have shown to be an effective measure to attract the visual attention of drivers to left and right peripheral regions to enhance the probability to detect a train (Grippenkoven, Thomas & Lemmer, 2016). A comparable positive effect might be expected from the use of additional lighting devices on train locomotives. While a regular locomotive can be identified by three headlights that are arranged in a typical triangular shape, an addition of auxiliary strobe lights might further enhance an earlydetectability of the train and reduce the probability that a road user misses it accidentally.

Several studies have examined the effect of similar lighting measures on train conspicuity in the past. A study by the U.S Department of Transportation (1995) studied train detectability, arrival time estimation and accident reduction potential for three additional experimental light installations on a train, and compared their safety potential to a headlight only configuration. The light systems included in the study were (1) strobe lights mounted on the front of the train on both sides, (2) ditch lights illuminating the sides of the track which headlights do not illuminate, and (3) crossing lights, which are essentially a flashing variant of ditch lights (Carroll et. al. 1995). Crossing lights featured a statistically significant increase in train detection distance in comparison to the two other systems and use of a headlight only, whereas the ditch light featured a statistically significant increase compared to use of a headlight only. The strobe light's improvement was bordering on statistical significance (Carroll et al. 1995). In contrast, other studies suggest that strobe lights draw attention far more effective than headlights only (Hopkins & Newfell 1975, Devoe & Abernethy 1975). However, due to the research methods there remain doubts connected to the results of Carroll et al. (1995) that limit their generalizability. The participants in the study knew that a train would be approaching as the target stimulus they had to detect, therefore they were prepared. Furthermore, participants did not approach the passive level crossing dynamically, but were positioned in a stationary chair some distance in front of the level crossing, what made the task rather artificial.

Cairney et al. (2002) evaluated the effectiveness of headlights and a ditch light, as well as a strobe light combined with crossing lights and headlights. The crossing lights were found to be so bright that they essentially masked the strobe lights and rendered them useless during nighttime testing. During daytime testing, none of the lights were found to be effective in bright sunny conditions. The report concludes that neither of the lighting systems offered a superior alternative to standard headlights, but Cairney (2003) suggests that these results are probably not so much due to the systems themselves, but instead due to unsuitable research design and limited time available for testing.

Since the effect of additional lighting devices on railway cars on road users approaching a level crossing have not been quantified to a satisfactory degree, it appears worthwhile to spend further effort into this specific safety measure. Improved headlights could be an effective as well as a cheap solution that might lead to a significant improvement of safety at passive level crossings. Hence, the objectives of this study were to investigate the technical feasibility of the auxiliary strobe lights on the locomotive under realistic conditions and to analyse the effects the system has on the behaviour of road users.

First, the technical layout was designed, implemented and tested under real world conditions. In a first study, user preferences regarding the strobe light patterns of this setup were tested with an online survey using videotaped material of the equipped train approaching a level crossing with different blinking patterns. In a second study, the effect of a locomotive equipped with strobe lights on the actual driving behaviour of motorized road users was analysed in a driving simulator study.

Study 1 – Evaluation of the Auxiliary Strobe light installed on a train

In the first study, a strobe light system for a train was designed and implemented. Its technical feasibility was tested on field. The different blinking patterns were evaluated by experts, using videos filmed from the road user perspective.

Technical layout and implementation of the auxiliary strobe light system

The developed automatic warning light system contains three high intensity LED lights and a control unit. LED lights are high beam accessories and accepted by road traffic authorities in Europe. These lights were installed on a train according to the prevailing regulations in addition to the regular headlights of the locomotive. The technical principle of the developed automatic warning light system is shown in Figure 1. The warning system is automatically activated at a set distance in front of the level crossing and deactivated after the level crossing has been passed. A level crossing database containing the geoposition of each level crossing as well as warning trigger point distances can be used to trigger the auxiliary strobe lights based on the geoposition of the locomotive. In this database settings can be defined for light intensity limits as well as the timing for the strobe light patterns applied at each level crossing. Thus, for every level crossing it can be tuned individually for best performance and minimal disturbance. Additionally, the intensity of the warning light can be adjusted automatically to take account of ambient light conditions at different times of the day.

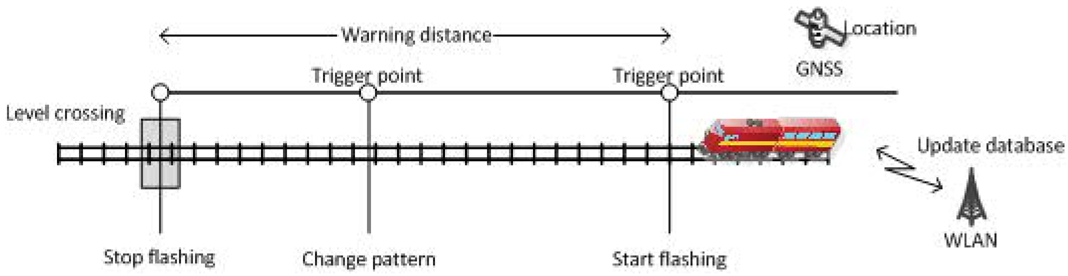

Figure 1 – Warning system principle.

Method

The train that was equipped as described in the previous section crossed a level crossing several times both in daytime conditions (12 pm–1:30 pm) and during darkness (at 11 pm–1:30 am). It elicited the strobe light patterns in three different configurations that are described in Table 1. Each video that had to be rated used the same stationary camera perspective that resembled the perspective of a pedestrian looking down the rails on the right-hand side of the level crossing. The video recordings were done for all different light configurations, and for the reference condition without active strobe light, both during daytime and during darkness. The reference configuration had standard train headlights: three continuous white lights, two on the bottom and one on the top.

Table 1 − Four configurations tested.

Configuration/Number of blinks	Description
0	Reference system without strobe light
1	Single blink every 1 s
2	Double blink every 2 s
3	Triple blink every 3 s

The evaluation of the videos was carried out with a web-based questionnaire by rail and road transport experts connected to the SAFER-LC project. Three alternative light configurations were compared to the standardly used reference configuration, both in the daytime and in the nighttime conditions. The questionnaire focused on the expert evaluation of the alternative configurations regarding safety, comfort and suitability for day and nighttime conditions, as well as on their visibility and glare. Benefits and drawbacks were also asked, and which configuration the experts preferred. Additionally, the experts were asked to report the time when they would not anymore start crossing the track (the crossing margin). This was done to investigate whether the blinking configurations might elicit the illusion of faster movement of the train or were estimated to make the train appear more threatening.

In the questionnaire, eight videos were rated: four in the daytime conditions demonstrating containing the reference system and the three alternative configurations, and similarly four in the nighttime conditions. The duration of videos was 66–68 s for the daytime videos, and 111–130 s for the nighttime videos. The nighttime videos were longer because we wanted the train to become visible in the beginning of the video, and in the nighttime this occurred earlier. The questionnaire started with the presentation and evaluation of all four daytime videos, followed by the four nighttime videos. The reference configuration without blinks (0) was always presented first. It was followed by configuration with two blinks (2), configuration with one blink (1), and finally configuration with three blinks (3). With the reference configuration, the participants were asked to watch the video and report when they would not anymore start crossing the railway lines. For all the alternative configurations, the participants reported similarly the time when they would not start crossing any longer. Furthermore, they were asked if they perceive benefits or drawbacks relating to the different alternative configurations compared to the reference configuration. If they did, they were asked to describe those. For each alternative configuration they were also asked to rate the alternative configuration on safety, comfort, suitability for day/nighttime conditions, visibility, and glare, using a five point Likert scale, where 1 = worse than the reference system, 3 = equivalent to the reference system, and 5 = better than the reference system. After going through all the four day/nighttime videos, the participants also reported which one they preferred and why.

Answering was voluntary and anonymous. In total, responses of 18 participants were received and analysed.

Results

A proof of concept of the auxiliary strobe light system was successfully implemented on a railway vehicle, and the lights functioned as planned under realistic conditions. Overall, in the daytime all of the alternative configurations were evaluated to be better than the reference configuration. The preference was clearest on the questionnaire dimensions safety, suitability, and visibility. In the nighttime, the responses followed the similar pattern, but the responses were slightly less favorable for the alternative configuration.

The majority of the respondents saw benefits in the three presented alternative configurations with the auxiliary strobe light, both for the daytime and nighttime conditions. Less than one fifth of the respondents saw drawbacks with the alternative configurations in the daytime videos, and one third in the nighttime videos compared to the regular headlights (Table 2). Majority of the comments regarding the benefits concerned increased visibility and detectability. Some responses mentioned that it was easier to judge the approach speed or that the train seemed faster with flashes. Drawbacks mentioned were disturbance and potential misinterpretations caused by blinking lights.

Table 2 − Benefits and drawbacks reported for alternative configuration vs. reference system.

Timing	Configuration	Benefits (%)	Drawbacks (%)
Day	1 blink	67	17
	2 blinks	78	17
	3 blinks	72	17
Night	1 blink	56	33
	2 blinks	72	28
	3 blinks	56	33

With the daytime videos, majority of the respondents preferred the alternative configuration 3 with three blinks (Figure 2, left). In the nighttime videos, none of the configurations were clearly preferred over each other (Figure 2, right).

The participants were asked to report the moment when they would not anymore cross the track. These crossing margins were shorter in all daytime videos (*Mdn* = 16 s, *M* = 25 s, *SD* = 18 s) compared to the nighttime videos (*Mdn* = 71 s, *M* = 68 s, *SD* = 34 s). The difference can be partly explained by the fact that the nighttime videos were longer than the daytime videos, but it may also indicate that in the nighttime, the responders wanted to play it safe. The differences between the configurations were small compared to the variability.

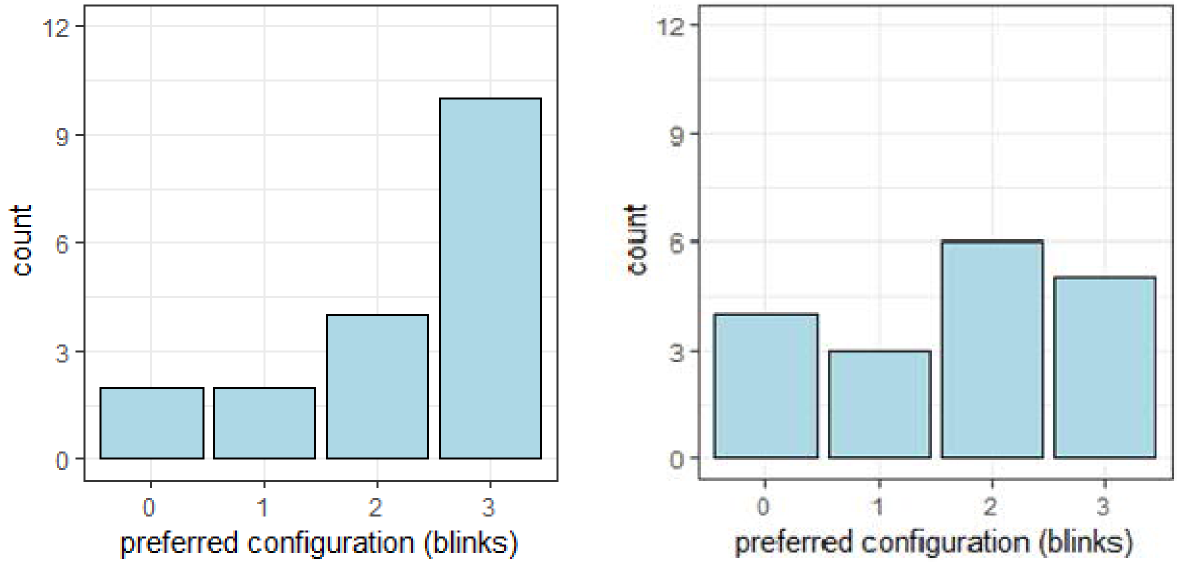

Figure 2 − Preferred configuration in the daytime (left) and nighttime (right) conditions.

Study 2 – Driving simulator study on the effect of auxiliary strobe lights on car drivers

Methods

Three performance indicators were selected to judge the effectiveness of the auxiliary strobe lights in the driving simulator study. As a first indicator participants were asked to give a *subjective judgement* on the measure based on six point Likert scales. Furthermore, the effect of the auxiliary light on the behaviour was checked based on the variation in the *speed choice of drivers* on their approach towards the passive level crossing. Finally, the impact of the auxiliary blinking lights on the attention of drivers was analysed using *eye-tracking data* to determine at what stage of their approaches towards the level crossing the participants first checked for an approaching train. The number of data sets that were analysed varied for each of these indicators:

- The total sample of participants of the driving simulator study consisted of n = 36 German participants (16 females and 20 males). The average age of these participants was 33.8 years (*SD* = 13.3, *max.* = 65, *min.* = 18).
- Out of those 36 participants, eye-tracking data of 30 participants could be processed. The eye-tracking data of the remaining six participants could not be used due to technical issues with the eye tracking device. Out of those 30 participants, 13 were female and 17 were male. The average age in this subset of the sample was 32.6 years (*SD* = 13.8, *max.* = 65, *min.* = 18).

The simulator study followed a between subjects experimental design with two different train light conditions. Each participant crossed two relevant passive level crossings. In both train light conditions participants crossed the first passive level crossing after a driving time of approximately seven minutes. At this first passive level crossing, no train was approaching. It served as a baseline. The second level had to be crossed at the end of the virtual driving after approximately 45 minutes. At the second level crossing half of the participants were confronted with an approaching train equipped with regular headlights. At the same level crossing the other half of the participants encountered an approaching train equipped with auxiliary strobe lights.

To distract the participants from the level crossing focus, a cover story was used. The participants were told that the focus of the experiment was on the use on mobile phones during driving. The real purpose of the study was revealed to participant immediately after the study.

The study of the effect of auxiliary strobe lights was conducted in a high fidelity driving simulator within the premises of DLR in Germany. The driving course consisted of both, village parts and rural roads between them. The virtual environment was surpassed under simulated daylight conditions. The passive level crossings were always approached on a straight road of 500 metres with a clear view on the railway tracks. The speed limit on this road was set to 50 km / h. To record the eye-tracking data a four-camera contact free remote eye tracker provided by the company Smart Eye was used.

Results

Subjective Judgement

Immediately after finishing the virtual driving course, participants had to reply to an online questionnaire to give their subjective estimation on the effectiveness of the train with the auxiliary strobe lights installed on the locomotive. In this questionnaire the auxiliary strobe light system was explained and illustrated with an image of the blinking train. Due to this illustration a judgement could be given by the participants that encountered the locomotive with the auxiliary strobe lights as well as the participants that saw the regular locomotive approaching.

First, participants had to rate the general usefulness of this system to prevent collisions between cars and trains with a value ranging from 1 (“totally useless”) to 6 (“extremely useful”). On this scale, the auxiliary strobe lights received an average rating of 4.63 (SD = 1.51). With the second scale, participants were invited to judge the extent to which the auxiliary strobe lights are capable to foster the detection of the level crossing ahead. The scale ranged from 1 (“not at all”) to 6 (“extremely”). Regarding the level crossing detection, participants judged the system on average with a 3.53 (SD = 1.62). Third, participants had to rate to which extent the auxiliary lights support the detection of an approaching train with a score from 1 (“not at all”) to 6 (“extremely”). On this scale, the strobe light received the highest average rating of 5.05 with the smallest standard deviation (SD = 1.24).

Driving Behaviour

To assess the effect of the auxiliary strobe light on the driving behaviour of the participants in the simulator study, the driving speed of their approach towards the level crossing in the baseline condition (no train approaching) was compared to the speed choice in the experimental condition (auxiliary strobe light or regular headlight). In both conditions, the approaching train was triggered when the participants passed a distance of 391 m upon the street leading to the level crossing. For each participant, the difference in velocity was calculated between baseline and experimental condition. The mean values of the resulting velocity difference profiles are depicted in Figure 3, starting 500 m in front of the level crossing and finishing 300 m behind it.

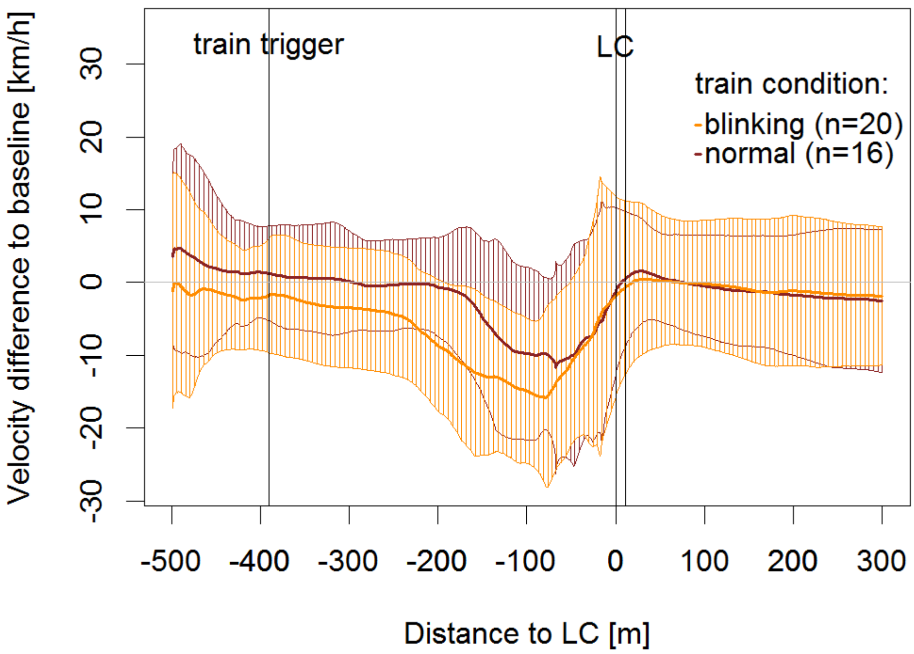

Figure 3 – Speed profiles of participants in two train light conditions.

The mean values are differentiated by the train light conditions (auxiliary strobe light vs. regular headlight). The error bands represent the mean speed difference between baseline and the experimental conditions +/- 1 SD. A drop of the slope can be perceived for both curves, meaning that participants decreased their speed upon their approach towards the level crossing in both conditions. However, there are differences in the profiles between the two conditions. The drop in the slope of the speed differences appears on average around 240 m in front of the level crossing in the auxiliary strobe light condition, while it occurs around 70 m closer to the level crossing and thus later upon approach in the regular train light condition. Furthermore, the 20 participants that encountered the train with the auxiliary strobe lights reduced their speed an average stronger, compared to the 16 participants in the regular train headlight condition. Five independent samples t-tests were calculated for selected distances of 400 m, 300 m, 200 m, 100 m and 0 m ahead of the level crossing, to compare the mean values of speed reduction between the regular headlight condition and the auxiliary strobe light condition. The results are presented in Table 3. Due to five pairwise tests the level of significance was reduced to $\alpha = .01$, using a Bonferroni correction. Only the t-test comparing the amount of speed reduction between the train lighting conditions at a distance of 200 m reached statistical significance, $t(37.737) = -3.18$, $p = .003$. While the participants in the regular headlight condition had barely reduced their speed at this distance (M = -0.64 km / h), the participants that encountered the train with the auxiliary strobe lights had already reduced their speed by -8.61 km/h on average compared to the baseline. This suggests that the train with the auxiliary strobe lights was perceived earlier by participants, resulting in an earlier adaptation of driving behaviour.

Table 3 – Results of independent samples t – tests for five distances ahead of level crossing.

		Mean speed difference (km/h) between train and no-train condition (SD)				
		train with regular headlight	**train with auxiliary strobe light**	t	df	p
Distance ahead of the level crossing	400 m	+ 1.43 (*6.30*)	- 2.12 (*7.20*)	- 1.662	37.807	.10
	300 m	+ 0.16 (*6.95*)	- 3.47 (*8.25*)	- 1.5129	37.955	.14
	200 m	- 0.64 (*6.78*)	- 8.61 (*9.07*)	- 3.1779	37.737	.003*
	100 m	- 9.77 (*11.88*)	- 14.86 (*9.98*)	- 1.4464	33.297	.16
	0 m	- 1.27 (*11.50*)	- 1.94 (*13.81*)	- 0.1662	37.98	.87

Eye-Tracking Data

The speed reduction data suggest that the train with the auxiliary strobe lights was perceived earlier by participants. This assumption was tested further using the eye-tracking data. The data was analysed for the moment in which the approaching train received the first fixation by each participant. The moment of the first fixation reveals how early the train could be detected by the participants. As a natural metric for statistical comparison, the detection *distance* ahead of the level crossing was determined. The detection distance indicates the distance at the moment in which the first fixation on the train was observed by each participant. Detection distance data of 30 participants was analysed. Within these datasets, 14 participants were in the regular headlight condition, while 16 participants were in the auxiliary strobe light condition. All participants were able to detect the train and let it pass before they safely crossed the level crossing. While the participants in the auxiliary strobe light condition detected the upcoming train on average at a distance of 252.65 m (SD = 23.66 m) to the level crossing, the participants in the regular headlight condition detected the train later at an average distance of 214.08 m (SD = 24.48 m). The difference in detection distance between the train light conditions was highly significant, $t(25.504) = 4.3385$, $p < .001$. This result converges with the results of the driving data. Participants in the auxiliary strobe light condition detected the train earlier and started to reduce their speed earlier, resulting in the significant speed difference at the distance of 200 m. The participants in the regular train light condition that detected the train later, at a distance of 214 m on average, had not yet reduced their speed to a noteworthy degree at the 200 m point of speed comparison.

Overall conclusions

In the expert judgements on video data, the videos with the auxiliary strobe lights were evaluated better than the regular headlights. Specifically, auxiliary strobe lights were estimated to improve visibility and detectability of train as well as safety of level crossings. Potential drawbacks mentioned were that flashing lights may be disturbing or could cause glare. Concerns on misinterpreting the flashing lights were also raised.

In daytime conditions, the experts clearly preferred the warnings lights with three consecutive blinks followed by 3 s break. In the nighttime condition, none of the configurations were clearly preferred. The results suggest that the flashing lights caused more glare or were more disturbing during darkness. Also, in the nighttime the train can be easily detectable even without flashing lights. The visual quality of the nighttime videos were not as good as in the daytime, which may have influenced the ratings.

The investigation of crossing margins did not suggest that the flashing lights would make the train appear more threatening or faster. Based on the visual inspection of the videos, the majority of the responses were given when the train movement started to be visible. It can be that the time when the participants would not anymore start crossing the tracks is based on the visual looming of the train rather than on the lights configurations.

Based on the expert judgements, the auxiliary strobe lights appear to be a promising way to increase the detectability of approaching trains, especially under daytime conditions. During darkness, the flashing lights might be disturbing or misleading. However, during darkness they might be even more salient and still support an early detection of an approaching train. Potential drawbacks of the flashing lights, and ways to address them, e.g. by focusing the lights and adapting them to the lighting conditions, should be investigated further. While flashing lights may improve an early detection of approaching trains, the results do not suggest any influence on the last safe crossing time judgements.

The subjective ratings of the participants in the driving simulator study are in line with the subjective ratings of the video survey. Participants recognised the safety potential of the auxiliary strobe lights mounted at the locomotive and estimated that this system supports an early detection of approaching train. This qualitative judgement is supported by the quantitative data that were assessed in the experiment. Specifically, the participants in the simulator study detected the train that was equipped with auxiliary strobe lights earlier than the train with the regular headlights. Due to the earlier detection, the approach speed of the vehicle was reduced earlier as well. Generally, an earlier detection of a train is positive, since it leaves more time to adopt the own driving behaviour and to cross safely. In the simulator study each participant was able to cross safely. However, this might be due to the rather artificial conditions of a 500 m road that is leading in a 90° angle towards a passive level crossing with a sight triangle free of obstacles. This can be perceived a slight shortcoming of the study, since there hardly exist passive level crossings with such a layout in reality. Still, the train was detected in the visual periphery almost 40 m earlier, when the auxiliary strobe lights were used. This distance can be decisive at a level crossing with a sight conditions worse than the ones in the simulator study. The distance of 40 m corresponds to the overall stopping distance that is expected to result from the combination of a driver’s reaction time and the braking distance of a car travelling with 50 km/h.

The technical feasibility as well as the positive expert ratings and the promising results from the simulator study suggest that it might be worthwhile to test auxiliary strobe lights in a larger scale real world experiment. Especially in railway lines with a high number of passive level crossings, this system can be expected to increase safety by supporting a timely detection for the road users whose inattentiveness is known to lead to a noteworthy number of severe accidents.

Acknowledgements

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