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MARKING OF ESCAPE ROUTES IN MINING EXCAVATIONS – RESULTS OF PILOT TEST

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Purpose: The publication cancers one of problems related with safety in mining industry - the marking of escape routes in mining excavations. A review of literature on the subject and applicable legal regulations and standards, and authors' study on the subject covering use of color-lighted signs created by them are presented.
Design/methodology/approach: Literature studies were conducted: 1) to identify methods and findings in researches on marking of escape routes, described in scientific publications; 2) to define the requirements set out in legal acts and standards. The field study of the marking of escape routes was carried out in a training mine gallery in which there are conditions reflecting the real ones in underground mining excavations. The observations and questionnaire research were conducted during a training of a group of 20 professional mine rescuers. The following variables were set for the experiment: distance (5, 10 and 15 m), color (white, green, blue, red), shape (square, arrow).
Findings: The article presents the results of pilot test in the field of the marking of escape routes in mine excavations. Different colors and shapes of the signs, and different distances of observation were taken into account. White color was found best to assure signs detectability but least appropriate if shape identification is required. Red and green colors were indicated as recommended if the shape identification is the evaluation criterion.
Research limitations/implications: The research was dedicated to the underground mining industry, but can be adapted to other working sites where the evacuation takes place in similar conditions (lack of visibility and smoke).
Practical implications: The research revealed among others that: 1) Polish regulations do not imply detailed rules as regards signage of escape routes in underground coal mines, which gives floor for development of new concepts and designs, 2) it is possible to propose color-lighted signs for effective marking escape routes in underground coal mines.
Originality/value: The publication contains the original results of pilot test in the field of the marking of escape routes in mining excavations, and they can be addressed to persons managing mining plants and managers of mining supervision authorities.

Keywords: safety, evacuation, escape routes, underground mining, mine rescue.

Category of the paper: research paper, general preview.

1. Introduction

Depending on a hazard that occurred at a workplace, evacuation might be necessary. Proper marking of escape routes with signs indicating the way and exits is crucial for effective evacuation and thus saving people's health and lives. Design (features) of signs used and their placement are among factors that affect wayfinding during evacuation. Visibility of signs has to be assured in all foreseen conditions, including poor light, lack of light, presence of smoke.

Signs dedicated for marking of escape routes are classified as 'safety signs', and the later ones are covered by regulations, standards and guidelines at national, European and international level.

Standardization of safety signs is a subject of: ISO 7010:2019 (introduced in European Union as EN ISO 7010:2020, in Poland as PN-EN ISO 7010:2020) in which safety signs for the purposes of accident prevention and fire protection are prescribed; ISO 3864-1:2011 and ISO 3864-3:2012 in which relevant design principles (applicable also for developing new safety signs) are established. The assumption followed by the standards developers was that when there is risk to people, both under ordinary circumstances (e.g. carrying out work in conditions typical for a given workplace) and during emergency situations (e.g. occurrence of fire), providing safety information that relies as little as possible on the use of words, contributes to people's safety due to quick understanding of the information conveyed (PN-EN ISO 7010:2020, Introduction). In these standards, the following definition of 'safety sign' (established in ISO 17724:2003) is applied: a sign giving a general safety message, obtained by a combination of a color and geometric shape and which, by the addition of a graphical symbol, gives a particular safety message.

In standard ISO 16069:2017, rules regarding location of safety signs are established. E.g., following the rules, low evacuation signs are placed on the floor or slightly above the floor, while high evacuation signs are placed at the ceiling height or no less than 1,8 m from the floor level.

Obligation of employers to provide safety signs where hazards cannot be avoided or adequately reduced by preventive measures or procedures used in the organisation of work is established by a directive on the minimum requirements for the provision of safety and/or health signs at work (Council Directive 92/58/EEC). In Poland, obligation to use safety signs is stated in a regulation on general occupational health and safety regulations (Rozporządzenie Ministra Pracy i Polityki Socjalnej z dnia 26 września 1997 r. …). According to §6 of this regulation, places in the workplace where there are hazards to workers should be marked with visible colors or safety signs in accordance with the requirements set out in Annex 1 of this regulation and in the Polish Standards. Examples of the requirements established in the Annex are:

- safety signs (classified into groups: prohibition, warning, mandatory, escape and information signs) should be used as permanent signs (§4),
- escape routes, properly market with signs, have to be provided covering all rooms of the building where workers may be present, allowing workers to escape quickly to an open space (§9),
- safety signs should be placed: 1) taking into account the line of sight, 2) directly at the place where a hazard exists or in the immediate vicinity, 3) at the entrance to area where a hazard exists (§9),
- the place where safety signs are located should be well lit, easily accessible and visible. If the signs are located in a place with insufficient daylight, the place should be illuminated by electric light or signs made of or covered with a material having the ability to emit light after the removal of the light source should be used (§9).

As regards escape routes, according to standard PN-N-01256-5:1998, they can be marked: 1) only with photoluminescent evacuation signs, 2) only with illuminated evacuation sings or 3) with use of both types of signs. Photoluminescent signs are suitable for areas with a regular source of light, as the light will 'charge' the signs. Illuminated signs are recommended in areas where escape routes at which there is no daylight or artificial light for extended periods (therefore charging of photoluminescent material wouldn't be secured). In the same standard also other rules to follow during placement of safety sings on escape routes are provided. The signs should preferably be placed at a height of 150 cm from the ground. If the signs are above the escape route, they should be placed at a height of at least 200 cm, perpendicular to the direction of movement of the people being informed about the direction to the exit of the escape route. If this requirement is not met, signs of an extra size should be placed. Signs placed low should not be more than 40 cm from the floor. Additional marking - allowed by the standard - that can be introduced on the escape route, are yellow-black stripes made of phosphorescent material. Black and yellow striped tape, as well as underlays of phosphorescent material can, among others, facilitate the identification of doors in rooms and on escape routes, provide information on the direction of evacuation or mark obstacles on the road (constrictions, depressions, pillars).

Each evacuation action is individual. There might be a variety of combinations as regards conditions and situations, human reactions, behaviours and abilities (psychical and cognitive) (Chan et al., 2012; Duarte et al., 2014; McClintock et al., 2001; Wang et al., 2021; Zijlstra et al., 2016, Grodzicka et al., 2022). This makes proper marking of escape routes more challenging than it might seem, and thus the issue has become a subject of many researches.

The publication presents an experiment concerning the marking of escape routes in underground excavations along with the implications from the research. The experimental research was preceded by literature studies on the marking of escape routes. Specially designed mining excavations (lack of visibility, smoke conditions) were used for the research – a training mine gallery located in the Central Mining Rescue Station S.A. in Bytom (CSRG). Literature

studies were conducted to identify the methods applied in studies regarding evacuation route markings and their findings, described in scientific publications, the requirements contained in applicable legal acts and recommended technical standards.

2. Signage of escape routes – overview of researches on the subject

Researches on signage of escape routes include among others: experiments in real conditions or sites imitating them, e.g. (Fujii et al., 2020; Galea et al., 2017; Jiang, F et al., 2020; Kim et al., 2022; Ronchi et al., 2018); experiments with use of VR, e.g. (Chen et al., 2020; Guilei, 2020; Huang et al., 2021; Kubota et al., 2021); collecting data with use of eye-tracking solutions, e.g. (Chen et al., 2020; Guilei, 2020; Huang et al., 2021; Ding et al., 2022); collecting data with use of a questionnaire, e.g. (Chan et al., 2012; Galea et al., 2017; Galea et al., 2014; Xie et al., 2012; Ronchi et al., 2016); application of mathematical models, e.g. (Huang et al., 2021; Liu et al., 2011; Yuan et al., 2018; Yuki et al., 2005; Wan et al., 2021; Zhang et al., 2017). As regards the sites for which the studies are carried out, these include among others: buildings – corridors, e.g. (Jiang et al., 2022; Kim et al., 2022; Huang et al., 2021; Ding et al., 2022; Wong, Lo, 2007; Olander et al., 2017); tunnels, e.g. (Ronchi et al., 2018; Xie et al., 2012; Higgins et al., 2015; Fridolf et al., 2013); public spaces, e.g. (Galea et al., 2017; Chen et al., 2020; Wan et al., 2021; Zhang et al., 2017; Jeon et al., 2019; Zeng, 2011). Findings of the studies – among others - establish what signs (type, design) should be used; in what way the signs should be installed (located); how the way in which escape routes are marked affects evacuees' actions, behaviours and evacuation speed (Guilei, 2020; Huang et al., 2021; Kubota et al., 2021; Xie et al., 2012; Yuan et al., 2018; Wong, Lo, 2007; Jeon et al., 2019; Bae et al., 2021; Filippidis et al., 2006; Fu, Liu, 2020; Fu et al., 2019). As regards the signs, there were mainly two types used in the studies: showing emergency exit and showing in which direction to go to the emergency exit. Modified versions of the standardized signs, were used in some of the studies. Smoky conditions are taken into account in studies described e.g. in the following papers (Fujii et al., 2020; Kim et al., 2022; Ronchi et al., 2018; Yuan et al., 2018; Yuki et al., 2005; Fridolf et al., 2013; Jeon et al., 2019). Further, some of the papers on the subject are discussed in a more detailed way.

According to (Guilei, 2020), the best way for placement of exit signs to maintain their quick discovery and identification is at the height of 1 m on the front of the observer's line of sight. In (Bae et al., 2021), height of vertical installation of a sign ranging from 30 cm to 270 cm (with interval of 30 cm) and its observation carried out at 10 m distance was a subject of a study regarding signage at a T-type indoor intersection, and the signs considered were arrows indicating direction: left and right. Decision-making time (DMT) was the criterion of comparison. It was found that the highest DMT was for low installation location, and to obtain

good results the sings should be installed higher than 120 cm on the same horizontal side as the arrow direction, and more than 210 cm in the middle of the wall in any other case. Research presented in (Huang et al., 2021) revealed that hanging sings had lower perception rate but at the same time also lower average perception time than wall signs. As it is stated in (Filippidis et al., 2006), the horizontal observation angle should not exceed 85^0 , otherwise the sign will be practically invisible.

Authors of (Jiang et al., 2022) focused on design of evacuation signs. They carried out experiments - in reality and with use of MR (Mixed Reality) - covering emergency evacuation at a corridor (T-junction type) to find out: 1) what kind of signs are best in terms of attracting attention of evacuees and 2) what are relations between design of evacuation signs and evacuee's decisions regarding escape activities. Each type of experiment (i.e. in real and in virtual world) consisted of 5 sub-experiments – separate for 5 types of evacuation signs that were used. The signs had different features (background-foreground): black-green, green-white (3 variants: with and without flashing, and with a red X-mark – to indicate that escape in given direction is prohibited), red-white. Evacuation signs with a black background, green foreground and flashing lights were found as most effective in terms of providing guidance to evacuees. A reverse use of the same colors, i.e. green background and black foreground of sign was proposed in (Chen et al., 2020). The other combinations of colors for safety signs examined in this study were (background-foreground): red-white, yellow-black, and blue-white. The experiment was carried out with use of VR and eye-tracking.

Typically, evacuation signs inform in which direction and through which exit to go. The message conveyed is positive ('do it this way'). In papers (Olander et al., 2017; Olander, 2015) the focus is on emergency exit signs aimed at dissuading evacuees from using a particular exit door. The data were collected with use of a questionnaire. It was found that a good way to obtain an effective dissuasive sign is to negate its positive counterpart. In the research, adding a red LED X-mark across the whole sign was applied. Also adding red flashing lights next to the sign (in immediate proximity) was found as effective solution to increase its effectiveness. Affecting the considered urgency by the red color was provided as the explanation. In the study mentioned earlier – in the paper (Jiang et al., 2022), two dissuasive signs were also used. They obtained relatively low scores. As the cause, it was indicated that – as opposed to the dissuasive signs used in the experiment - generally people encounter the standard evacuation signs (in buildings and other places) and that transmits into natural understanding and acceptance of their meaning. Implementation of a negative sign was also one of elements covered by a study presented in (Galea et al., 2017). The findings proved that it is possible to design a dissuasive sign that in a clear way indicates that an exit route can no more be used. Four designs of negated signs were proposed, out of which one was found clearly understood by 92% of respondents (sample 311 persons). The following percentages were obtained for the other three sign designs - respectively – 83% (sample 312 persons), 63% (sample 311) persons, 78% (sample 295 persons).

Positive effect of adding of flashing lights to a sign was also supported by studies presented in (Ding et at., 2022; Ronchi et al., 2016; Nilsson, 2009; Yasufuku et al., 2017; Nilsson et al., 2005). Adding dynamics to a sign by incorporating flashing components was also a subject of research in (Galea et al., 2017; Jiang et al., 2022; Ding et al., 2022; Galea et al., 2014; Fridolf et al., 2016). For the application of flashing in signage system, its positive impact on evacuation was demonstrated. As regards color to be used, green – being commonly associated with guidelines, actions etc. that contribute to safety – is suggested. An experiment on participants' associations regarding colors, in context of emergencies presented in (Nilsson et al., 2005) covered several colors: green, red, orange, yellow, white and blue. The findings confirmed considering green as related with safety, and red – as related with danger. For the other colors it was concluded that in case of white and blue no distinctive associations were identified, while for orange and yellow association with warning was indicated. Adding of a lighting installation to a signage system to reduce or overcome problem of low or lack of visibility of signs was also a subject of research presented in (Cosma et al., 2016). In the studies, LED stripes, giving green light were used and located along the evacuation routes in smoke conditions in railway tunnels. Experiments (carried out with use of VR) confirmed that such solution has positive impact on way-finding.

A critical review of studies carried out on relations between visibility of emergency signs and walking speed in smoke-affected areas is presented in (Fujii et al., 2020). In the research, mostly Japanese researchers' publications are covered, including those dating back to 1970s, e.g. (Jin, 1970). In the same paper the authors present their own experiment within which measurements of walking speed under different conditions in an experimental corridor (resembling building corridors) were carried out. The conditions were varied by combinations of the following parameters: 1) presence of a lit emergency exit sign (installed or not), 2) smoke density (four levels), and 3) lighting (ceiling lights switched on or off). Ten men and ten women, aged 21-25 years, with no mobility or vision limitations participated in the experiment. The used exit sign complies with ISO 7010:2019. In total 130 tries (realizations of the procedure established for the experiment) were carried out. A thorough analysis of the data collected and conclusions are presented in the paper. E.g. the study revealed that: 1) for smoke density of 1,5 l/m in an illuminated corridor, the walking speed was higher when the lit emergency exit sign was installed, 2) for each smoke density the walking speeds in a corridor with the installed sign were lower under conditions of no illumination. The study confirmed that the higher smoke density, and the higher distance from the sign, the lower its visibility is, which is more distinctive under no illumination.

Authors of (Yuki et al., 2005) raised that when evacuation is carried out because of fire, not only lighting and obscuration by smokes affect visibility of emergency signs, but also another phenomena - adhesion of smoke both to the signs (their surface) and to the sources of light. They also proposed a calculation model of target luminance in fire-smoke taking into

account smoke adhesion and argued that its application should contribute to better designs and planning as regards exit signs addressed for evacuation in case of fire.

General conclusion related to the studies discussed above is that there is no ‘best solution’ as regards signage of evacuation routes. Each of the researches was carried out in an individual way in terms of a combination of: objectives and criteria, methods, locations and evacuation's circumstances. In addition to individual circumstances at the area for which signage system is to be developed, while selection of signs and their location on the evacuation routes, it has to be taken into account that each sign is a part of the whole es-cape system that has to be effective, which was raised by authors of (Fu et al., 2020). Another conclusion is that a number of researchers proved that implementation of own ideas as regards design of signs and their installation may bring good results as regards evacuation.

In underground coal mines, fire may be caused by a number of causes, including shortcomings in safety culture (Stańczak, Kaniak, 2021). During evacuation from fire-affected areas – similarly as in case of surface sites (e.g. buildings), tunnels (e.g. road tunnels, subway tunnels) – lighting conditions (including darkness) and smoke that affect visibility of signs are also present. However, it should be underlined that in a coal mine, the marking of evacuation routes is addressed to a very specific group of evacuees, i.e. coal miners and mine rescuers. There is little publicized as regards marking of evacuation routes particularly in underground coal mines.

3. Marking of evacuation routes in underground coal mines

The two main methods used to aid evacuees in coal mines are: signage and lifelines.

Coal mines signage evacuation routes in a variety of ways. Typically, metal boards with textual and/or graphical (e.g. an arrow) information are used. As Meij (Meij, 2020) raises, use of signs is a cheap way to effectively inform on evacuation routes in good visibility conditions. In smoke, their visibility deteriorates, which is even worse if the signs are not properly cleaned from dust, smoke etc.

A lifeline (Figure 1) is a line on which there are mounted spatial objects that are a tac-tile signal – e.g. cones, spheres, and cylinders that can be felt with the hands and recognized in darkness. These objects and their configurations have concrete meaning as regards giving instructions that direct/guide evacuees (Meij, 2020; Onifade et al., 2022; Badura et al., 2017; Badura, Musioł, 2015; Gaab, 2019).

Figure 1. A lifeline installed in a coal mine roadway.
Source: CAB Lifeline.

A condition for effective use of lifelines is locating them ('reaching them') by evacuees, which might be difficult to meet when visibility is low e.g. because of smoke, or in darkness (Gaab, 2019; Martell et al., 2020). An experiment (in a dark, smoked laboratory chamber) to find out whether use of self-illuminating lifeline can be a solution to this problem was presented in (Martell et al., 2020). In addition to a traditional lifeline, three color variants of self-illuminating lifeline were used: red, green and blue, and tested in terms of: 1) visibility, 2) color recognition. Based on the study, the red color was rejected – the red-lighted lifeline was detected only in 6,66% of trials. Blue color was found the best in terms of visibility (100% of cases), but the color identification was relatively poor (6,67% of the cases). The green-lighted lifeline was detected in 90% of cases, and the color was recognized in 36,67% of the cases. The traditional rope was missed (not found in the smoky conditions) in all the cases.

4. Marking of evacuation routes in underground coal mines – legal background

Lifelines are mandatory in coal mines in the USA, which is laid down by §75.380 of federal regulation (Code of Federal Regulations. Title 30…), while there is no mention on them in European directive (Council Directive 92/104/EEC). According to the federal regulation, there are five types of tactile signals on lifelines: directional cones (indicating the direction to go outside), a coil to indicate a refuge chamber, two sets of double cones to indicate a self-contained, self-rescuer (SCSR) cache, two directional cones in a row to indicate a branch line, and a ball to indicate a personnel door. The fireproof cord of a lifeline has to be also marked with reflective material every 25 ft (7,62 m). Lifelines are not a subject of regulation in the European Union.

In the USA, signage of escape routes is also a subject of the federal regulation (Code of Federal Regulations. Title 30…) provisions of which (§ 57.11051, § 75.380) indicate in that easy to notice and read signs must indicate escape ways in a clear way. In the European Union, according to Council Directive 92/104/EEC (point 9.7), the sings used to indicate emergency routes and exits have to comply with Council Directive 92/58/EEC. Provisions of the later directive state in particular that a safety color of signs providing this kind of information

(i.e. escape routes and exits) is green. To inform about danger and prohibited actions, red should be used.

In Poland, a regulation (Rozporządzenie Ministra Energii z dnia 23 listopada 2016…) provides general requirements for familiarizing employees with information on hazards, the designation and marking of escape routes, the organization of rescue and first aid. § 475 states that escape routes should be determined by the mine operations manager and properly marked and equipped with a system allowing identification of the direction of withdrawal in case of lack of visibility. None of the provisions states that requirements established by Polish Standards should be followed when marking escape routes.

5. Method

A study on the applicability of lit signs for marking of evacuation routes where dark-ness and smoke are present was carried out. The research included an experiment within which participants observed sample lit signs in conditions imitating smoked coal mine gallery and expressed their opinions on their visibility related with the color and shape. The observation was carried out at 3 distances from the sign: 5 m, 10 m, 15 m. The opinions were collected with use of a questionnaire. In the questionnaire, a 5-point Likert scale was used. By assigning a score, respondents expressed how strongly they agree with the statement, that the given sign in the particular color is highly visible. Also talks regarding the perceived visibility of the signs in terms of shape identification took place, however these did not have a form of a structured interview.

The experiment was carried out in a training gallery of the Central Mine Rescue Station (CSRG) in Bytom (Figure 2). The site was equipped with a smoke generator Antari FT-100 Fogger, dedicated for fire training.

Figure 2. A training gallery in which the experiment was carried out.

The research sample included mine rescuers employed in specialist fire-fighting unit at the Central Mine Rescue Station. They are involved in rescue actions, also in heavy smoke, in coal mines. Nowadays there are 24 mine rescuers in the unit and 20 of them participated in the experiment.

All the rescuers taking part in the tests had valid health examinations and work permits. No one in the group had a visual impairment.

In the experiment, 8 signs were used. They were made of a LED tape (1 cm wide) formed to the desired shape – a square or an arrow, attached to a rectangular board in white color. The tape was equipped with a remote controller that enables changing colors. In the experiment the following colors were used: white, green, red, blue. Additionally a stand with a bright, yellow rectangle was prepared, further called ‘reference stand’. During the experiment it was used as a reference to show that the site of experiment was actually filled with smoke. The sizes of the signs and the reference stand are shown in Figure 3. The unit used is mm.

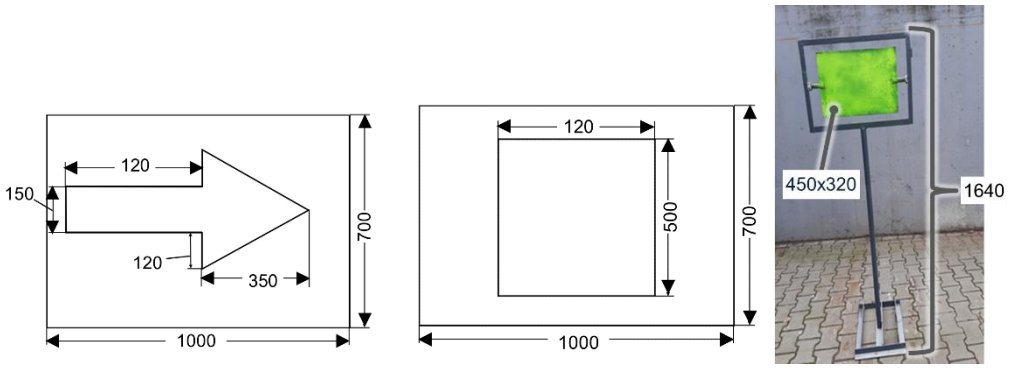

Figure 3. Measures of signs and reference stand.

The distances from the observation point were measured and marked (Figure 4).

Figure 4. Marking distances of observation.

A graphical characteristics of the site where the experiment took place is presented in Figure 5. The board with a lit sign was placed directly on the tape conveyor that has height of 1 m.

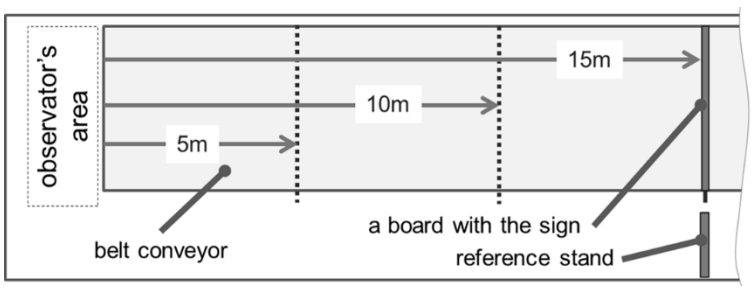

Figure 5. Site at which the experiment was carried out – graphical description.

There were two stages of the experiment – one for the square shaped sign and one for the arrow shaped sign. Each stage was carried out according to the following procedure:

1. arrangement of the ‘reference stand’ and of a sign, at 5 m distance from the point of observation (Figure 6); once the arrangement was ready, the LED tape on the sign was switched on to make sure that it works properly and then it was switched off;

Figure 6. Arrangement of a sign and the reference table (view for the blue color variant).

2. entering by a rescuer to the research site and taking place in the observation point;
3. filling the gallery with smoke;
4. switching the light off;
5. switching on the LED tape of the sign and changing its color (with use of a remote controller); all the colors considered are subsequently selected, and each color is switch on and observed during 5 seconds;
6. switching the light on and gathering opinions on the visibility of the sign in each color, at the current distance.

The procedure was repeated for each distance separately.

6. Research results

In Figures 7-9, photos taken during each observation of the square shaped sign are presented, and similarly for the arrow shaped sign – in the Figures 10-12. It should be underlined that the image captured by a camera and the image captured by human eye are not identical. Opinions expressed by the rescuers regarded the visual observation of the lit signs.

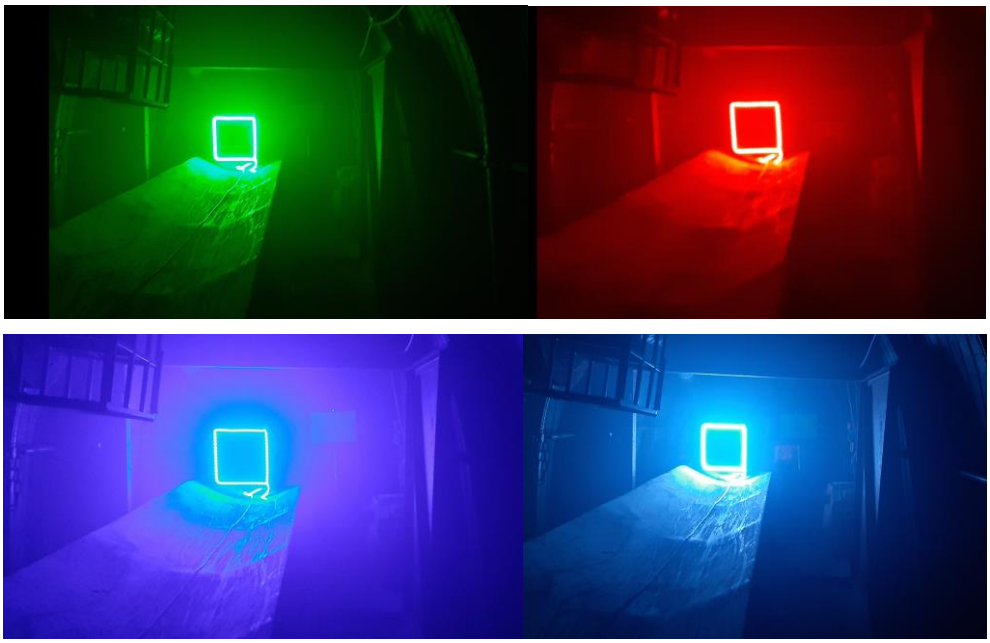

Figure 7. Observation of the square shaped sign, a the distance of 5 m.

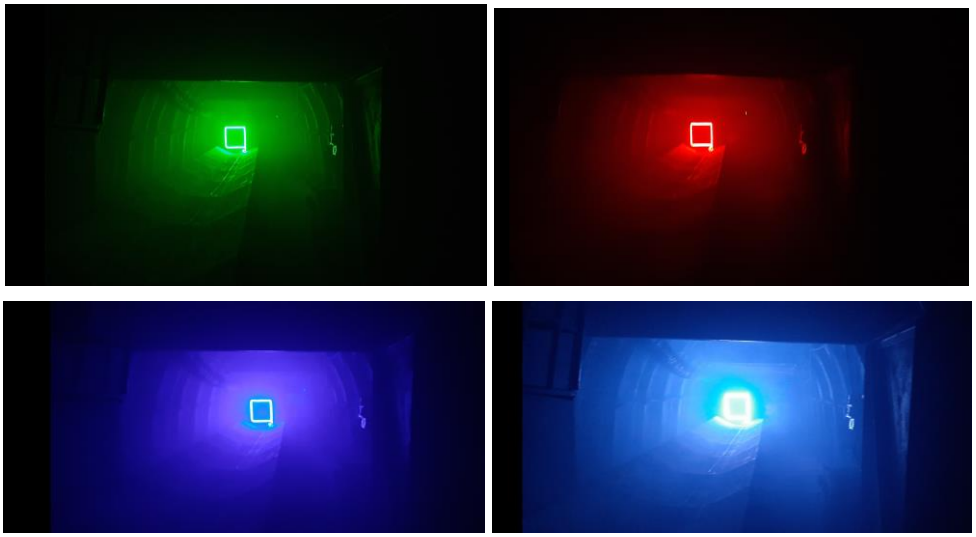

Figure 8. Observation of the square shaped sign, a the distance of 10 m.

Figure 9. Observation of a square shaped sign, a the distance of 15 m.

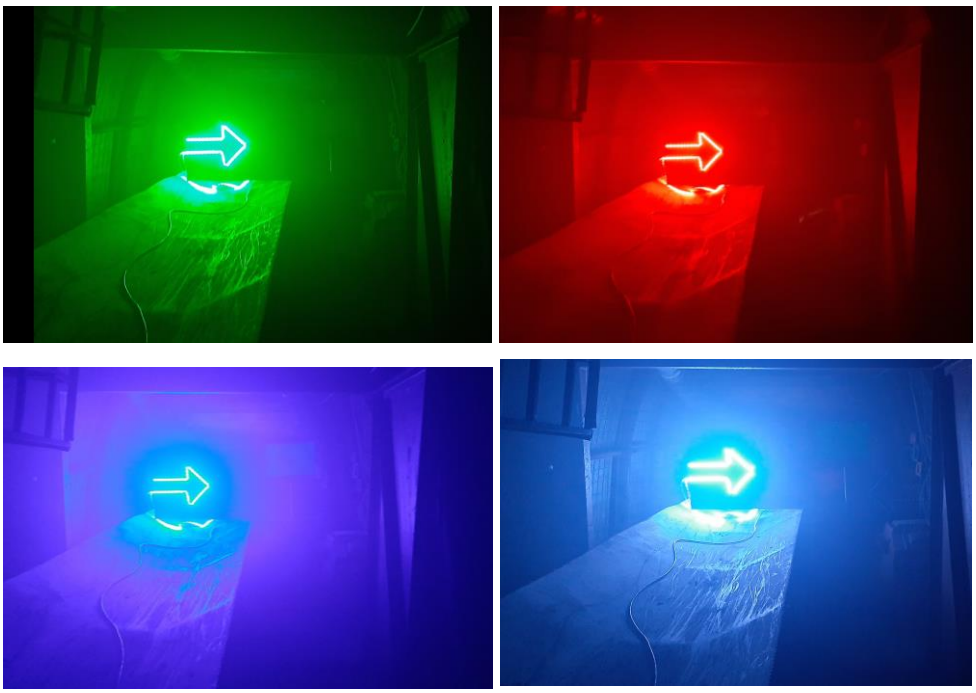

Figure 10. Observation of the arrow shaped sign, a the distance of 5 m.

Figure 11. Observation of the arrow shaped sign, a the distance of 10 m.

Figure 12. Observation of the arrow shaped sign, a the distance of 15 m.

The answers regarding visibility of the square shaped sign are summarized in the Table 1.

Table 1.
Answers obtained for the square shaped sign, taking into account color and distance

DISTANCE	COLOR	SHAPE: SQUARE				
		Answers*				
		1	**2**	**3**	**4**	**5**
5 m	green	0	0	0	0	20
	red	0	0	0	2	18
	blue	0	0	2	4	14
	white	0	0	0	0	20
10 m	green	0	0	2	6	12
	red	0	2	4	4	10
	blue	4	6	4	4	2
	white	0	0	0	0	20
15 m	green	2	6	6	4	2
	red	4	8	6	2	0
	blue	6	10	2	2	0
	white	0	0	0	2	18

*1 – definitely no, 2 – rather no, 3 – no opinion, 4 – rather yes, 5 – definitely yes.

For the rescuers standing at the distance of 5 m from the ‘square’, the sign was highly visible, regardless of its color. However, in case of the blue color, there were answers (10%) indicating no opinion. At the distance of 10 m, the answers were more differentiated. The best visibility was found for the white color – all the respondents assigned the highest score. The visibility of the blue color was considered as worst. Only 30% of rescuers positively assessed visibility of this color, but only 10% assigned the highest score. 50% of respondents did not consider the sign as properly visible, and 20% had no opinion on the subject. The visibility of the red color was rated positively by 70% of the respondents, no opinion was declared by 20% of respondents and there was a negative opinion given by 10% of respondents. For the green color, visibility was positively assessed by 90% of the respondents. At the distance of 15 m, the visibility was positively assessed only for the white-lighted square. The worst visibility was indicated for the blue color - 80% of the respondents expressed a negative opinion. In case of the red color, the majority of the respondents (60%) also negatively assessed its visibility, and 30% of the respondents declared no opinion on the subject. The green color was not definitely classified as properly or insufficiently visible - there were 30% of positive answers, 40% of negative answers.

The rescuers also expressed the following general opinions and impressions:

- at each of the distances considered, the square shape is visible in all colors, however its sharpness is not the same,
- red color darkens the gallery,
- white is the most visible color and it additionally illuminates the excavation.

Answers regarding visibility of the arrow shaped sign are summarized in the Table 2.

Table 2.
Answers obtained for the arrow shaped sign, taking into account color and distance

DISTANCE COLOR		SHAPE: SQUARE answers*				
		1	2	3	4	5
5 m	green	0	0	0	0	20
	red	0	0	0	2	18
	blue	0	0	2	4	14
	white	0	0	0	0	20
10 m	green	0	0	2	6	12
	red	0	2	4	4	10
	blue	4	6	4	4	2
	white	0	0	0	0	20
15 m	green	2	4	6	6	2
	red	4	6	8	2	0
	blue	6	8	4	2	0
	white	0	0	0	1	19

*1 – definitely no, 2 – rather no, 3 – no opinion, 4 – rather yes, 5 – definitely yes.

For the distance of 5 m, the rescuers gave the same answers as for the ‘square’ sign. At the distance of 10 m, the visibility of the blue color was negatively assessed by 50% of the respondents and positively assessed by 30% of them. The visibility of the red color was evaluated positively by 70% of the respondents, and negatively – by 10% of the respondents. Both in case of the red and blue color, 20% of the respondents declared having no opinion. The green color was found properly visible by 90% of the respondents.

At the distance of 15 m, the blue color was the least visible – 70% of the respondents gave a negative opinion, and only 10% found its visibility as proper (however no highest score was indicated). Visibility of the red color was negatively assessed by 50% of the respondents and positively by 10% of them. In case of the green color, the numbers of negative and positive opinions were equal – 40% of the respondents. The visibility of the white color obtained the highest scores – no negative or ‘no opinion’ answers were given.

For both shapes, i.e. square and arrow, the rescuers also expressed the following general opinions and impressions:

- at each of the distances considered, the shape is visible in all colors, however its sharpness is not the same,
- red color darkens the gallery,
- white is the most visible color and it additionally illuminates the excavation (the conveyor and possible obstacles in the way were visible).

What should be also underlined, the high visibility of the white color was found by the rescuers as unexpected and surprising.

7. Discussion of the results

Obligations of an employer regarding the rules of conduct to cope with hazards to health and life in the working environment are defined by law and standards, at national and higher (e.g. European, international) levels.

In Poland, these obligations are established both by general law - created by the Labor Code Act (Ustawa z dnia 26 czerwca 1974 r. …) and executive acts, and by the industry law, like e.g. the Geological Law and Mining (Ustawa z dnia 9 czerwca 2011 r. …) and executive acts - in the mining industry. Among these obligations, there is the use of safety signs. Detailed regulations regarding safety signs are defined in formal standards.

In the applicable standards, safety signs are classified. The type of a safety sign depends on its purpose. According to the PN-EN ISO 7010:2020 standard, there are: signs indicating evacuation route, location of safety equipment or safety facility, safety action (E); fire equipment signs (F); mandatory action signs (M); prohibition signs (P); warning signs (W). A similar classification of signs is contained in the series of standards PN-N-01256: signs for fire protection; technical fire protection means sings; evacuation signs; information signs; warning signs; prohibition signs; mandatory signs. Within each class, safety signs have a consistent design.

Based on the analysis of the requirements defined in the PN-N-01255:1992 standard and the PN-N-01256 series of standards, conclusions regarding the relation between the purpose of a safety sign and its design – geometric shape and safety color used can be drawn. The geometric shapes are divided into the following groups: circle – to indicate prohibition, obligation, triangle – for warning, rectangle and square – to provide information with description. Safety colors used are as follows: green (safety – in context of evacuation, first aid etc.), yellow (warning of danger), blue (obligation), red (prohibition, stopping, fire protection).

Based on the analysis of the requirements set out in the PN-EN ISO 7010:2020 standard, it can be concluded that safety signs for evacuation (evacuation signs) have a square shape, a green background and a white graphic symbol (e.g. emergency exit, direction arrow, evacuation assembly point, escape ladder, evacuation chair).

The review of Polish regulations revealed that they do not imply detailed rules as regards marking of escape routes in mining excavations, which gives floor for development of new concepts and designs for it.

As the literature research shows, there are two basic directions of solving the problem of evacuation in the mining industry, in underground working environment (lack of visibility, smoke conditions): marking (safety signs and colors) and rescue equipment (safety lines) used in mining excavations, e.g. (Badura, Musioł, 2015; Badura, Grodzicka, Musioł, 2017; Gaab, 2019; May, 2020; Martell et al., 2020; Onifade et al., 2022). As regards the escape routes

signage, the researches described in the scientific publications show among others that it is possible to propose color-lighted signs for effective marking escape routes.

Based on the comparative analysis of safety colors and safety signs according to the current international standard PN-EN ISO 7010:2020 and detailed national standards PN-N-01255:1992 and PN-N-01256 series, two following two basic variables and values for them were considered during design of signs to be used in the experiment carried out in the training mine gallery in CSRG: shapes of figures (rectangle, square, circle, triangle, arrow), colors of figures (green, red, blue, white, yellow). Findings from scientific publications review and technical capabilities (training gallery equipment, type of LED tape) were also taken into account while designing the signs as well as when defining the procedure for carrying out the experiment. Finally, the following variables were adopted for the practical study on the marking of escape routes in mining excavations: shape of the tested figure (square, arrow), color of the tested figure (green, red, blue, white), observation distance (5 m, 10 m, 15 m).

Summarizing the respondents' feedback from observation of the colors, the following was found:

- At 5 m, the visibility of all colors was comparable and high (positive rating by at least 90% respondents).
- At 10 m, the visibility decreased for blue color (positive opinion of 30% of respondents) and for red color (positive opinion of 70% of respondents), remained high for green color (90%) and remained unchanged for white color.
- At 15 m, visibility of blue color and red color decreased to low level - positive opinion expressed by 10% of respondents, acceptance of green color also decreased, however positive opinion was expressed by 40% of respondents for arrow shape and 30% - for square shape, and visibility of white color remained high (acceptance by 100% of respondents, for both shapes).

Therefore, the higher the distance was, the more differentiated perception of visibility of green, red and blue colors was – it decreased. A the same time, the visibility of the white color was high, at all the distances.

Taking into account ability to see a lit sign in smoky conditions in a mine gallery, use of white color is the best choice, while use of blue – the worst. However, for white color, an effect of blurred shape was observed, which was particularly distinctive at 10 m and 15 m distances. The phenomena of perceived decrease in sharpness of the sign was more intensive for the arrow (that is a more sophisticated shape than a square).

Application of both lit signs in white and in red or green seems a good solution for marking evacuation routes in a mine gallery. White lit signs should be used to mark main points on the escape route. Being visible from a long distance in a smoke, they enable to identify in which direction to move. Meaning of such signs is defined mainly by their color, and their shape should be very simple. In case of lit signs, the shape of which has to be unambiguously and correctly identified to understand their meaning, like e.g. an arrow showing a direction, red or green color should be applied.

8. Summary

When an evacuation takes place, easiness of wayfinding affects evacuees' safety. Escape routes have to be marked in a way that guarantees their identification in conditions that affect visibility, like blackout or smoke. Related obligations, rules and recommendations are formally set out in applicable regulations and standards. Following them does not guarantee most effective evacuation, due to a variety of circumstances in which the evacuation takes place. Literature research shows that finding best solutions as regards marking of escape way is a subject of a number of studies covering among others: own de-sign of signs; placement of signs; application of flashing lights and illumination. Many of the studies presented in the papers prove that it is possible to develop own ideas - also as alternative to the solutions that comply with regulations and standards - that bring good results.

As regards marking of escape ways in underground coal mines, there are separate regulations, which was shown for the USA, European Union, and – at national level – for Poland. In Poland, provisions of the regulation that set out rules for marking of escape routes do not imply use of safety signs defined in the Polish Standards, which opens window for implementation of a variety of solutions meeting one mandatory requirement – providing effective aid to evacuees in any possible conditions, including lack of visibility.

Authors of this paper carried out an experiment focused on perceived visibility of lit signs in different colors (white, green, blue, red), in smoky conditions, in a mine rescue training gallery. Observation was carried out at three distances from a sign. Two shapes of different complexity were used: a square and an arrow. The shapes were formed with use of a LED tape, on a white board. The rescuers taking part in the experiment found white-lighted signs most visible and blue-lighted signs least visible, in case of both shapes. However, red or green color was indicated to apply if identification of the shape would be the criterion of assessment. Usability of the research results does not limit to underground coal mines.

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