JUSTIFICATION OF SAFE DISTANCES FOR TRACK CROSSING

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ABSTRACT

A considerable number of accidents (collisions with people) on the tracks makes it necessary to study behavior of pedestrians, their reaction, criteria of threat assessment in the zone of «areas of approaching», and of selection of a safe time for themselves within a visually controlled distance. The paper presents results of measurements and calculations of time that pedestrians need to safely cross the tracks under different conditions and in diverse situations. Practical application of obtained dependences suggests the scope of design of safety equipment and the creation of new technical devices in the zone of responsibility of railways, including the rationale for requirements for existing signaling systems at pedestrian crossings.

Keywords: rail track, area of approaching, pedestrian crossing, crossing time, safe distance, train speed.

Background. *For realization of a right of a citizen to receive rail service he should come to the place of boarding, and after leaving the coach at destination he should reach places where this person could board another mode of transport. In addition, a significant proportion of citizens cross tracks at the same level for implementation of existing communication links to social facilities (shops, markets, schools, etc.) in the zone of responsibility of the railway transport and of a nearby locality.*

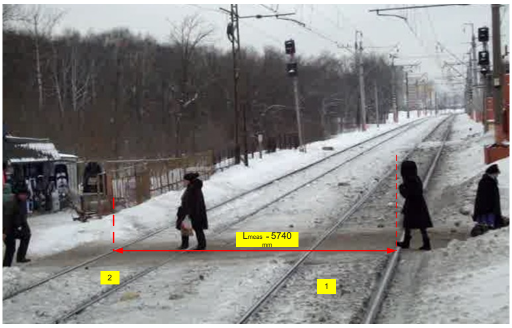
Such crossings are made by people at specially equipped walkways, as well as in non-equipped for those purposes places. According to statistical data [1], people get about 90% of injuries in the area of responsibility of railway transport in case of collision of the rolling stock. The victims usually either neglect safety rules, or are not capable to assess real level of approaching danger.

The term approaching area (or area of safe approaching to the dangerous zone) is established in the technical literature.

It is obvious that in determining conditions of safe crossing, each of pedestrians, primarily evaluates the time he will spend directly on the crossing. Comparing this time with predicted for rolling stock approach, the person is required to evaluate the safety of his forthcoming action. The paper presents the approaches to measuring and calculating safety time that pedestrians need to cross railway track in different situations that occur in the crossing zone.

Objective. *The objective of the authors is to consider safety issues in relation to crossing railway tracks by pedestrians in various weather conditions.*

Methods. *The authors use statistical analysis, comparison, mathematical apparatus, field observations. HD video format was used for the measurement. Measurements were carried out on double-track section from the moment of crossing the plane passing through the outermost rail of the first track to the exit of the plane of the same extreme path of the second track.*



Pic. 1. Measurement of time to cross tracks.

Results.

Presence of clear landmarks (rails) allows with a maximum error of not more than 100 mm to register crossing process of individuals. As shown in Pic. 1 measurement L_{meas} = 5740 mm. Such a significant base (almost 6 meters) makes it possible to minimize the influence of the absolute measurement error $\Delta = \pm(100 + 100) = \pm 200$ mm on the overall result. The relative error is no more than $\delta \le 3{,}5\%$. For example, in previous studies [3] researchers measured time of crossing the track gauge (1520 mm) and at the same absolute error relative error was about $\delta \approx 13\%$, which could not provide sufficient accuracy of the final result.

Pedestrian safety is ensured for a maximum speed of a train of less than 160 km / h while a person is at a distance not less than $L_{safe} = 2$ m from the rail closest to the pedestrian. With this in mind, the total length of the crossing through one track that ensures the safety of pedestrians, will be:

$$L_{cr} = L_{safe} + 1520 + L_{safe} + B, \qquad (1)$$

where B is human body size, determined according to [5] by formula

$$B = b1(P\,95) + \varepsilon, \qquad (2)$$

where b1(P 95) is body thickness, assumed to be 342 mm for 95^{th} percentile and 361 mm – for 99^{th} percentile;

ε is total correction for random movements of the body and clothing.

In the document GOST R EH 547-3-2009 [Russian state standard] it is recommended in determining ε to add adjustments in width in the front projection as the main for body movement of 100 mm and for heavy winter or personal protective clothing also of 100 mm.

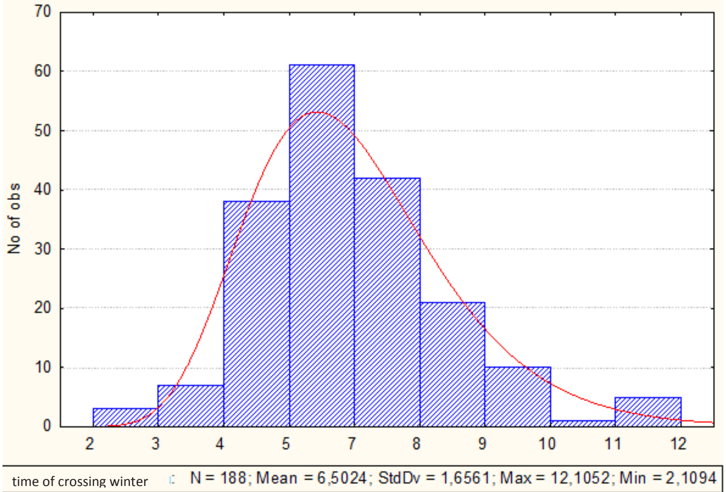
As estimated b1(P 99) we take a value of 361 mm. As a result the value L_{cr} for considered conditions will be:

$$L_{cr} = 2000 + 1520 + 2000 + 361 + 100 + 100 = 6081 \text{ mm}.$$

In view of the result time of each measurement on the section L_{meas} = 5740 mm should be adjusted by multiplying by correction coefficient $\beta = L_{cr} / L_{meas} = 1{,}059$.

Now let's consider results of the statistical processing of the measurement of time of crossing in a relatively favorable weather conditions in the winter daytime (clean walkway, without ice and snow) and in the absence of mutual influence of pedestrians on each other (Pic. 2). The latter circumstance is very significant, as it will be shown later.

To calculate the number of groups in a variational series we use the well-known Sturges formula:



Pic. 2. Statistics of time of crossing in normal weather conditions without oppressing.

$K \approx 1 + 1{,}44 \ln n = 8{,}54 \approx 9$ intervals.

We shall adhere to the rules that each of interval of changes in crossing time periods includes at least three dimensions.

Minimum recorded values of 2,0–3,0 s actually already correspond to the run, which, however, also takes place. Let's take like a theoretical law a log-normal distribution law, which density function is:

$$f(t)=\frac{1}{t\sigma\sqrt{2\pi}}e-\frac{(\ln t-\mu)^2}{2\sigma^2},\ t>0. \qquad (3)$$

Substituting the parameters obtained from a sample, we can write:

$$f(t)=\frac{1}{0{,}458\sqrt{2\pi}}e-\frac{(\ln t-1{,}782)^2}{0{,}132}.$$

The expectation of crossing time was $m_t = 6{,}50$ s, the standard deviation $\sigma_t = 1{,}66$ s:

$$m_t = e^{\mu+\frac{\sigma^2}{2}} = e^{1{,}84+\frac{0{,}257^2}{2}} = e^{1{,}87} = 6{,}50 \text{ s}$$

$$\sigma_t = (e^{\sigma^2}-1)e^{2\mu+\sigma^2} \text{ and } = \sqrt{D_t} = 1{,}66 \text{ s.}$$

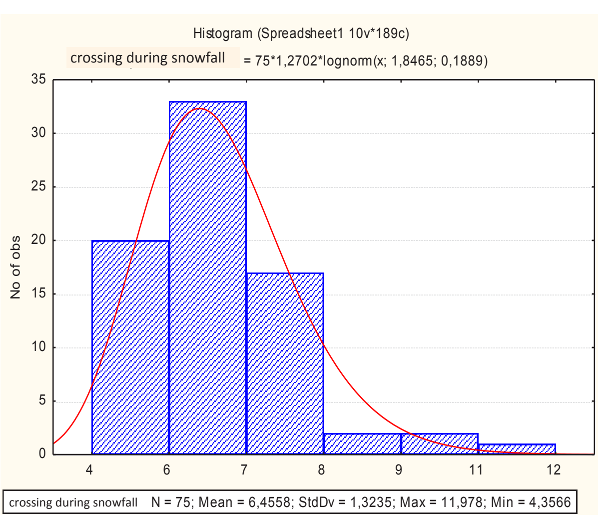
Let's consider the effect of weather conditions. Let us first analyze the data obtained under the conditions of snow, but without icing phenomena. As can be seen from the histogram in Pic. 3, this distribution has a pronounced right-hand asymmetry and can also be described by a lognormal law.

Perhaps the only difference from normal conditions is the growth of the minimum values of time for crossing tracks from 2,01 to 4,36 seconds. In case of insufficient visibility (data were recorded at the crossing of the third category) a pattern of behavior changes: pedestrians make a stop in accumulation zone and, having made themselves sure that there is no train, try to cross during minimum time.

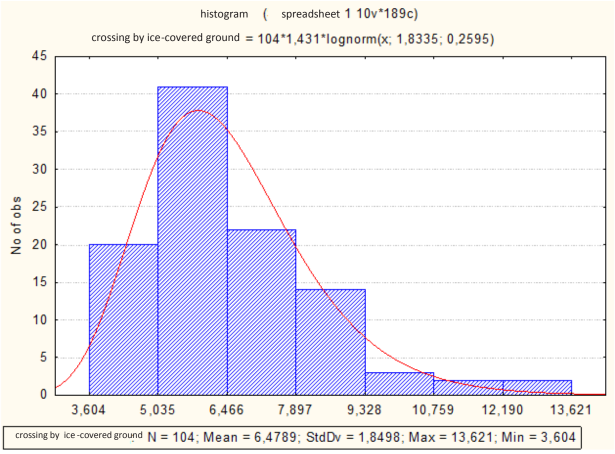
The presence of ice affects increase in the crossing time significantly stronger (Pic. 4).

Basically, this is reflected in increasing dispersion of crossing time. If for normal conditions standard deviation $\sigma_t = 1{,}66$ s, here it is already 1,85 s. In general, crossing of railway tracks by the walkway in the presence of icing phenomena can be regarded as extreme distribution of crossing time, and these data should determine the guaranteed time of crossing.

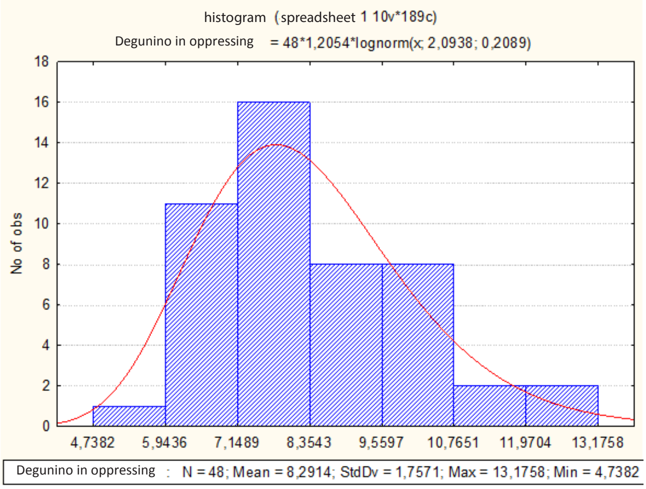
Another example of crossing at an extreme moment is the movement in oppressing conditions when the width of walkway is only enough to move in in single file in each direction. In this case, the slow pace of some of pedestrians determines the rate of motion of the entire column, and there is no opportunity to overtake him without getting off the walkway. A distinctive feature of this situation will be



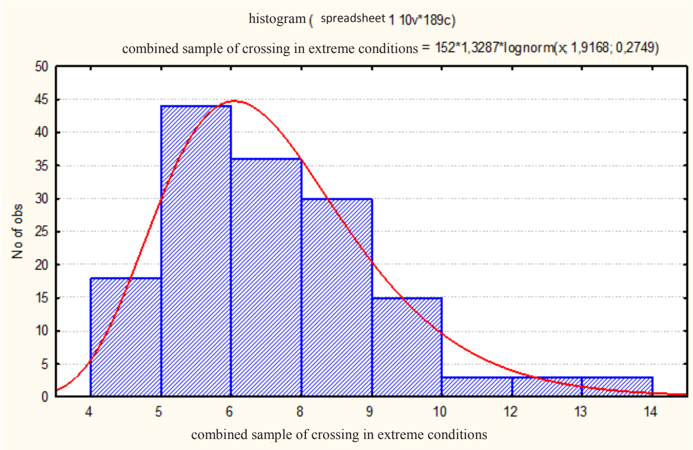
Pic. 3. Statistics of time of crossing time in a snowfall without oppresing.



Pic. 4. Statistics of crossing time in icing conditions without oppressing.



Pic. 5. Statistics of crossing time in conditions of oppressing without icing phenomena (Degunino station).



Pic. 6. Statistics of crossing time in extreme conditions: N = 152; Mean = 7,065; StdDv=2,0395;Max=14,234; Min = 3,604.

increase in the average time spent by people on the crossing – from 6,48 to 8,29 seconds. However, maximum values are the same – about 14 seconds, as seen from Pic. 5.

Checking by the consent criteria shows that both distributions belong to the same general aggregate, type of distribution of which is shown in Pic. 6.

Let's compare data obtained with the results of expert assessments. We calculate for the same conditions probability of safety provision:

$$T_{appr} = X / v_{max} \text{ and } P_{safe} = P(T_{appr} > t_{cr.cal}). \quad (4)$$

The probability of getting a random variable distributed according to a lognormal law in the region X >x, is found with the well-known formula:

$$P(T \le t) = P\left(T \le \frac{\ln t - \mu}{\sigma}\right). \quad (5)$$

However, any person before entering the danger zone, shall assure himself of safety of the crossing. Therefore, in calculations it is

Table 1

Adjusted safety assessment

Distance to approaching rolling stock, m	200	300	400	500	600	800	1000
Speed range, km / h	Probability of safety provision						
20–40 km /h	0,97429	0,99995	0,999998	1	1	1	1
40–60 km /h	hazard	0,97429	0,99959	0,99993	0,999998	1	1
60–80 km /h	hazard	hazard	0,97429	0,99884	0,999947	0,999998	1
80–100 km/h	hazard	hazard	hazard	0,97429	0,997829	0,999984	1
100–160 km/ h	hazard	hazard	hazard	hazard	hazard	0,97429	0,99884

unacceptable to take «pure crossing time», we should take into account time for detection of a dangerous object and time to make a decision. The maximum value (with a confidence level of 0,99) of extra time at the crossing will be equal to 6,0 s.

In view of the above assumptions we obtain the adjusted safety assessment, given in Table 1.

For each of these speed ranges regression equations were obtained to calculate safe approaching area for any given value of probability. In table 1 we described with category «hazard» a situation where the probability of safety is below 0,95. On the whole, demonstrated estimates correlate well with the data of expert assessments. This once again confirms the correctness of the choice of parameters of distribution of time for crossing railway tracks at a walkway.

Conclusion. *The application of obtained dependences concerns mainly justification of requirements for signaling systems at pedestrian crossings of railway tracks [9, 11]. But the experimental basis for the study has methodological value, because the simplicity of decision-making always attracts practitioners.*

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