Evaluation of the Effect of Operational Scenarios on a Train Driver Performance

Igor Shubinsky, Efim Rozenberg, Natalia Boyarinova

Research and Design Institute for Information Technology, Signalling and Telecommunications on Railway Transport (NIIAS), Moscow, Russia, n.boyarinova@vniias.ru

Contribution to the State of the Art

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Abstract: This paper aims to numerically evaluate the effect of existing actions to assist a train driver in various operational situations, as well as select the indicators of error-free operation ending on the form of activity and other factors. The effect of each individual examined factor on the resulting indicator was evaluated, operational situations were examined taking into account the proportion of times when the action has a positive effect. A few practical cases were examined, whereas the method can be used.

Keywords: safety of a man-machine system, increasing the probability of error-free transportation process performance, driver's operational environment.

In the previous paper we made an attempt to assess the effect of the existing actions to assist a train driver in various operational situations. Now let us analyse the effect of each aggregator and action on the resulting probability of error-free driver operation in a specific operational situation.

The probability of error-free human operation is affected by a number of factors. The most significant ones include the psychological and physiological factors of stress, types of situation and activity, time allowed for decision-making [1]. The probabilities of human error when performing various types of activities under various psychophysiological conditions differ.

Thus, [2] cites the following ranges of human error frequency depending on the type of activity:

Activity	Error frequency. Mean value range
Reaction to a signalling device	0.00005 – 0.001
Reading signals off of a digital screen	0.0005 – 0.005
Reading analogue instruments	0.001 – 0.01
Writing down more than three numbers	0.0005 – 0.005
Selection of the adjusting device on a functionally divided panel	0.0005 – 0.005
Switching a multiple-position switch	0.0001 – 0.1
Reading instruments with limiting markers	0.0005 – 0.005
Performance of a set sequence of actions	0.003 – 0.03

In [3], the following indicators of error-free human performance as part of various types of activities are given:

Activity	Coefficient of error-free operation
Reading manuals	(0.9901)
Reading electronic instruments	(0.9928)
Switching a multiple-position switch	(0.9940)
Reading a pressure gauge	(0.9952)
Setting switches into the "0" position	(0.9959)
Checking the time	(0.9966)

The probability of error depending on the type of activity associated with an exchange of information given in [4]:

Activity	Error coefficient
Speech acquisition	
Loudness and tone	
Significantly above the level of noise	$5*10^{-4}$
Insignificantly above the level of noise	$1*10^{-3}$
Practically equal to the level of noise	$5*10^{-3}$
Ambiguity	
Ambiguity allowed	$5*10^{-3}$
Definitely ambiguous	$5*10^{-3}$

Repeat	
No repeat	$9*10^{-4}$
Repeat	$3*10^{-4}$

[1] cites the following statistical data regarding the probabilities of human error:

Name of operation	Error probability
Perception of a verbal message (1 – 3 words)	0.0002
Issuance of a verbal message (1 – 3 words)	0.0002
Reading (1 – 3 words)	0.0010
Taking notes (1 – 3 words)	0.0003
Perception of alarm light, sign	0.0035
Perception of plates	0.0014
Perception of indicating meters	0.0072
Perception of digital device indications	0.0012
Pushing a button	0.0025
Pressing the required key	0.0050
Switch actuation	0.0020
Setting a selection switch into the required position	0.0044
Connecting cables	0.0032
Disconnecting a bullet connector	0.0009
Setting controller handle parameter	0.0094
Same for handwheel	0.0100
Same for lever	0.0150
Selecting out of several different switches	0.0001
Intense work with quickly changing situations	0.2 – 0.3

The probability of error significantly differs depending on the time allocated for decision-making and activity performance. In [1], the following indicators are given:

Time allocated for decision-making and activity performance	Probability of erroneous action of qualified personnel
Very short (less than 5 min)	0.1
Short (5 to 60 min)	10^{-3}
Long (more than 1 h)	$3*10^{-4}$

[5] cites the following frequencies of operator error when put under stress and depending on the time allocated for decision-making

Time to react	Probability of error
The action must be taken within the first 60 seconds upon the beginning of the stressful situation	~1.0
The action must be taken within the first 5 minutes upon the beginning of the stressful situation	$9*10^{-1}$
The action must be taken within the first 30 minutes upon the beginning of the stressful situation	10^{-1}
The action must be taken within several hours upon the beginning of the stressful situation	10^{-2}

The above results show that, depending on the type of action, presence of stress and availability of time for decision-making, the probability of human error may differ by 4 orders of magnitude. Having analysed the above statistical data, we can conclude that the presence of stress increases the probability of error by an order of magnitude, while the reduction of the time allocated for decision-making decreases this indicator by another order of magnitude.

In order to identify the probability of error in the course of interaction with

- an instructing driver (ID) p_1,
- a level crossing duty officer (LCDO) p_6,
- a line-level train traffic controller (TTC) p_8,
- a station duty officer (SDO) p_5,

let us use statistics on the frequency of human errors in the types of activity associated with the exchange of information, as the interaction occurs through verbal communication and issuance of commands and recommendations as to proceed along specific lines. Let us evaluate the effect of the factors by the lower bound, i.e., in the worst conditions out of those considered, namely the perception of speech under multitasking and high level of interference. Let us adopt $1 - p_1 = 1 - p_5 = 1 - p_6 = 1 - p_8 = 5 * 10^{-3}$ as the probability of error.

While evaluating the effect of a database error on the driver performance it must be taken into consideration that in most cases databases are populated by specialised personnel, and a population error is two orders of magnitude higher than the error of the system's electronic components in the process of data storage and communication that is about 10^{-5}, therefore the probability of error of temporary restrictions p_3 and permanent restrictions p_{11} will be taken equal to the probability of error of writing with the number of signs greater than 10 [6] $1 - p_3 = 1 - p_{11} = 4*10^{-4}$.

In order to identify the probability of error-free operation of electronic devices, including the vigilance control (VC) p_2, TSR radio transmission to the locomotive (TSR-RT) p_7, and automatic train operation (ATO) p_9, let us use the data on the dependability of single-channel SIL0 devices. The probability of failure per hour of such devices is 10^{-5}, therefore $1 - p_2 = 1 - p_7 = 1 - p_9 = 10^{-5}$. The safety integrity level of the train protection device and electronic map is SIL4, therefore $1 - p_4 = 1 - p_{10} = 10^{-9}$.

In order to identify the base probability of driver error let us take into consideration the time to react and presence of stress. In the examined operational situation the decision-making time is limited to several dozen minutes, as the situation is an emergency, it is assumed that the driver is stressed, therefore the base indicator of probability of driver error is taken to be equal to $g_D = 5*10^{-2}$.

Obviously, depending on the operational situation the set of auxiliary actions varies. Simultaneous assistance of all system components appears to be unlikely. In order to evaluate the effect, let us introduce an additional coefficient that takes into account the proportion of time when an action or an aggregator has a positive effect.

Then, formula (1) will become as follows

$$p_D = 1 - g_D (1 - p_1 k_1)(1 - p_2 k_2)(1 - p_3 k_3)(1 - p_8 k_8)(1 - p_8 k_8 p_5 k_5)(1 - p_7 k_7 p_{10} k_{10})(1 - p_7 k_7 p_9 k_9 p_{10} k_{10})(1 - p_6 k_6)(1 - p_5 k_5)(1 - p_{11} k_{11})(1 - p_4 k_4)(1 - p_4 k_4 p_{10} k_{10})(1 - p_9 k_9 p_{10} k_{10}) \quad (1),$$

where k_1 is the coefficient that takes into account the proportion of time when an action or aggregator may have a positive effect on the driver.

Let us examine the following operational situation:

The train protection device (TPD) has failed and the driver is to perform "removal of the train from the open line" subject to the time restrictions of the driver's list of warnings (DU-61) and assistance of the instructing driver who has knowledge of the presence of permanent restrictions [7].

Let us calculate the probability of error G_D when moving on a section other than a level crossing:

$g_D = 5*10^{-2}$

$p_1 = p_5 = p_6 = p_8 = 5*10^{-3}$

$p_3 = p_{11} = 4*10^{-4}$

$p_2 = p_7 = p_9 = 10^{-5}$

$p_4 = p_{10} = 10^{-9}$

$k_1 = 1$, as in this operational situation the instructing driver completely monitors the operation and assists the driver;

$k_2 = 0$, as when the TPD fails, in this operational situation the instructing driver performs the function of vigilance control;

$k_3 = 1$, as the driver uses temporary speed restrictions from DU-61 and ATO;

$k_6 = 0$, as according to the conditions the driver does not move over a level crossing;

$k_8 = k_5 = 0$, as the operational situation is out of the competence of TTC and SDO;

$k_9 = 0$, as the automatic train operation does not enforce the allowed speed;

$k_{10} = k_4 = 0$, as according to the conditions the TPD and electronic map of the line (EM) have failed;

$k_{11} = 0$, as the electronic devices have no access to the database.

Thus, the probability of driver error when the train moves other than over a level crossing can be calculated as follows:

$$g_D = 0{,}05(1 - 0{,}995*1)(1 - 0)(1 - 0{,}9996*0)(1 - 0)(1 - 0)(1 - p_7\, 0)(1 - p_7\, 00)(1 - 0{,}995*1)(1 - 0)(1 - 0)(1 - 0)(1 - 00)(1 - 00) = 1{,}25*10^{-6}.$$

When the train moves over a level crossing the probability of driver error is

$$g_D = 0{,}01(1 - 0{,}995*0)(1 - 0)(1 - 0{,}9996*1)(1 - 0)(1 - 0)(1 - p_7\, 0)(1 - p_7\, 00)(1 - 0{,}995)0{,}5(1 - 0)(1 - 0)(1 - 0)(1 - 00)(1 - 00) = 1*10^{-7}.$$

Practical results:

1. The creation of a driver operational environment containing certain auxiliary actions and sources of additional information on a railway line and the restrictions in force allow reducing the probability of error and significantly improving the probability of error-free driver performance.
2. The TPD, TTC, SDO and EM have the highest effect on the indicator of fault-free operation. Of significant importance are the sources of data, including ID, VC, LCDO and database information on the temporary and permanent restrictions.
3. The effect of various actions and information depends on the operational situation.

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About the authors

Igor Shubinsky is the Deputy Head of Integrated Research and Development Unit of JSC NIIAS, Doctor of Engineering, Distinguished Professor, expert of the Scientific Council for Information Security under the Security Council of the Russian Federation. His research interests include methods of analysis and synthesis of functional dependability and functional safety of complex systems, adaptive fault-tolerance of information systems, management of technical assets based on their dependability and safety status and risk assessment. He has authored 37 monographs and textbooks, over 400 papers and over 40 patented inventions.

Efim Rozenberg is the First Deputy Director General of JSC NIIAS, Doctor of Engineering, Distinguished Professor. He is a recipient of the award of the Government of the Russian Federation in the field of science and technology. He was awarded the title of Honored Designer of the Russian Federation, Best Innovator of JSC Russian Railways. Professor Rozenberg leads research and development in train control and protection including signalling, train separation, automatic train operation, traffic safety, communication, cybersecurity. He is an author of about 300 research papers and about 400 patented inventions.

Natalia Boyarinova is a Senior researcher of Centre for Safety and Algorithmic Support of JSC NIIAS. In 2013, she graduated with honors from the Moscow State Transport University. Her areas of research interests are functional safety, risks in railways, autonomous systems, automatic control, methods for safety verification. She was awarded an honorary certificate for high professional competence, dedication and outstanding performance. She has authored 2 scientific papers and 1 patented inventions.

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