The Dependability and Safety Indicators of a Train Driver-Machine System

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Contribution to the State of the Art

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Abstract: The paper aims to assess the effect of the existing actions to assist a train driver in various operational situations, as well as to numerically evaluate the effect of such assistance on the resultant indicator of an error-free driver performance. The paper calculates and analyses the probability of at least one of the independent events or actions aimed at improving the quality of driver performance and reduction of the probability of error. The model of an environment was created, in which the probability of error-free driver performance is affected by a number of factors.

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

Introduction

The driver is one a the key components in the process of train control and protection. Other noteworthy factors include the condition of the locomotive equipment and components, compliance with the rules and instructions, quality and dependability of equipment [1,2]. Such safety functions as observation of speed restrictions and correct train control are progressively being automated, yet in the majority of cases the final decision is still taken by the driver [3,4]. Today, the driver performs a host of tasks and bears great responsibility for the committed errors, therefore assisting the driver and reducing the probability of error associated with the performance of certain sets of actions is of relevance. The matter of the effect of the human factor on the railway traffic safety has been examined on many occasions. The probability of error of driver only operations is between 10^{-2} and 10^{-3}, while the probability of error-free performance is low [5], therefore the problem of ensuring stable and error-free driver performance is now of relevance. There is a number of methods of ensuring fault-free driver performance [6-8] and approaches to the evaluation of the effect of the human factor [9-11]. One of such approaches is the apportionment of the responsibility of the involved employees for incidents that caused a deterioration of the quality and efficiency of railway operations, violations of traffic safety [12]. Another approach is the evaluation of an employee's fitness for a specific professional activity for the purpose of targeted correction of professionally important qualities of employees and more efficient personnel selection [13,14]. Preventive measures aimed at reducing the probability of train control violations may be defined using a combination of methods of evaluating driver performance and prediction [6]. Another method of reducing the probability of violation is by observing the optimal ratio between periods of work and rest, granted the planned train schedule has been fulfilled [7,8]. Such approaches to the research of complex man-machine systems and human-human interactions primarily deal with the evaluation of the effect of professional and psychophysical properties of personnel on the operation of the system as a whole.

This paper examines the evaluation of the effect of the assistance to the driver's operations both by humans (traffic controller, instructing driver, etc.), and by hardware and software technical systems (train protection device, ATO systems, etc.)

The paper examines the following driver operating environment:

- in any difficult situation, the driver can immediately contact an instructing driver regarding malfunctions of the locomotive or train in order to confirm the grading of track or the methods of driving the train along a railway line;
- the physiological condition of the driver is monitored by a special device that protects against the onset of sleep and loss of attention;
- the driver receives the bulk of information on the operating situation from the onboard safety units;
- from each station, via the station duty officer, the driver receives information of the train route and emerging circumstances along the line;
- the level crossing duty officer communicates critical information to the nearest station's duty officer and the diver at the moment the train clears the station (flag), as the open line is the most hazardous facility;
- the whole travelled distance is recorded on an electronic storage device onboard the locomotive. All speed restrictions can be tracked automatically using the train protection device and visually by the driver;
- information is recorded into the electronic storage device from the speed restrictions server. Additionally, the system that tracks the locomotive location communicates real-time information to the locomotive to be displayed to the driver and for the purpose of automatic train operation. Train detection information is communicated to the traffic controller in real time. If necessary, it is also communicated to the driver via the radio channel. That is the procedure used in case infrastructure workers identify an emergency.

Adopted notations and assumptions:

1. The original sources of driver assistance shall be named "aggregators";

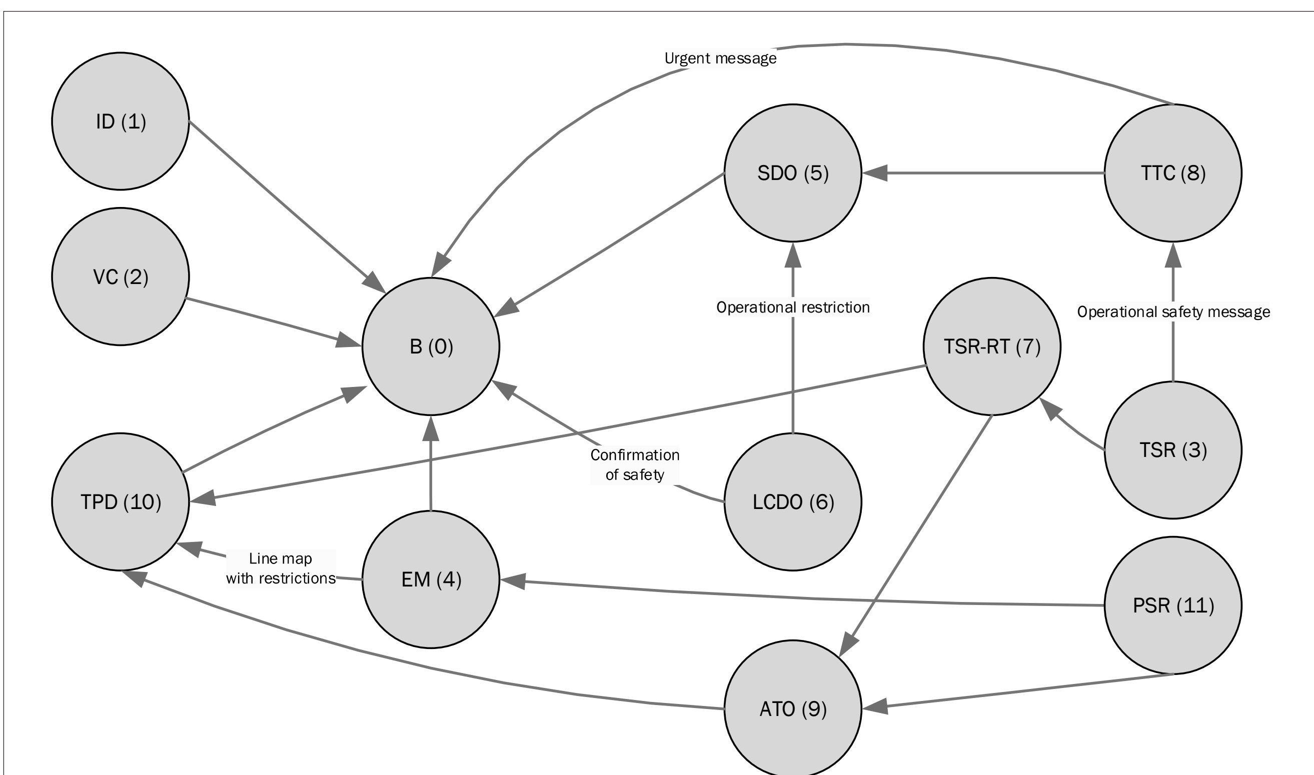

Figure 1. *Graph of interaction between a driver and the aggregators and actions aimed at improving the probability of error-free performance of train control actions*

2. The aggregators are mutually independent;
3. Each aggregator can generate one or more actions to assist the driver;
4. Each actions have a random effect of the reduction of the probability of driver error;
5. The effects of the aggregators on the probability of driver error are mutually independent;
6. The probability of error g_D is take as the quantitative measure of error;
7. Probability p_i, where i = 1,2,... m and m is the finite number of the effect of known actions aimed at reducing the probability of driver error is adopted as the quantitative measure of the effect of an action on the reduction of the probability of driver error;
8. The resultant measure of reduction of the probability of driver error is the product of the probabilities of the effect of all actions caused by the environment aggregators on the driver performance.

The diagram in Fig. 1 uses the following notations:

0, driver (D);

1, actions of the instructing driver (ID);

2. action of the driver vigilance control device (VC);

3. action of the automated system for track condition monitoring and generation of temporary speed restrictions (TSR). Temporary speed restrictions are displayed to the station duty officer and are transmitted to the train protection device (TPD) and ATO system. The ATO and TPD systems advise the driver on the optimal and safe clearance of the received restriction;

4. action of the electronic map of the line (EM);

5. action of the station duty officer (SDO);

6, action of the level crossing duty officer (LCDO);

7. action of the data of the TSR radio transmission to the locomotive (TSR-RT);

8. action of the train traffic controller (TTC);

9. action of the automatic train operation (ATO) system;

10. action of the train protection device (TPD);

11. action of the automated system for digital map generation and issuance of permanent speed restrictions (PSR). Permanent speed restrictions are loaded into the TPD and ATO databases, as well as the TSR. The TPD and ATO systems advise the driver on the optimal and safe clearance of the received restriction.

According to the diagram in Fig. 1 the finite number of known actions aimed at reducing the probability of driver error is m = 11.

In turn, the aggregators, i.e., original sources of data, are: 1, 2, 3, 6 and 11 nodes of the diagram.

The probability of error-free driver performance within the environment shown in Fig. 1 equals

$$p_D = 1 - G_D \qquad (1)$$

The probability of driver error G_D is calculated using formula:

$$G_D = g_D W \qquad (2)$$

where W is the resulting reduction of the probability of driver error as the result of designated actions within the examined environment.

In accordance with the diagram in Fig. 1

$$W = (1 - p_1)\, C_1\, (1 - p_2)\, C_2\, (1 - p_3)\, C_3\, (1 - p_6)\, C_6\, (1 - p_{11})\, C_{11}, \qquad (3)$$

where $C_1 = C_2 = 1$,

$$C_3 = (1 - p_8)\,(1 - p_8\, p_5)\,(1 - p_7\, p_{10})\,(1 - p_7\, p_9\, p_{10});\; C_6 = (1 - p_5);\; C_{11} = (1 - p_4)(1 - p_4\, p_{10})(1 - p_9\, p_{10}). \qquad (4)$$

Thus, the probability of error-free driver performance within the environment equals

$$p_D = 1 - g_D\,(1 - p_1)(1 - p_2)(1 - p_3)(1 - p_8)(1 - p_8\, p_5)(1 - p_7\, p_{10})(1 - p_7\, p_9\, p_{10})(1 - p_6)(1 - p_5)$$
$$(1 - p_{11})(1 - p_4)(1 - p_4\, p_{10})(1 - p_9\, p_{10}) \qquad (5)$$

It should be noted that in various operational situations the effect of the factors would differ. An example of evaluation of the effect will be examined in the following paper.

Let us analyse the deduced formula (5).

If none of the designated actions had an effect, then $p_i = 0$, i = 1,2,...,11 and the probability of driver error $p_D = 0$, as W = 1.

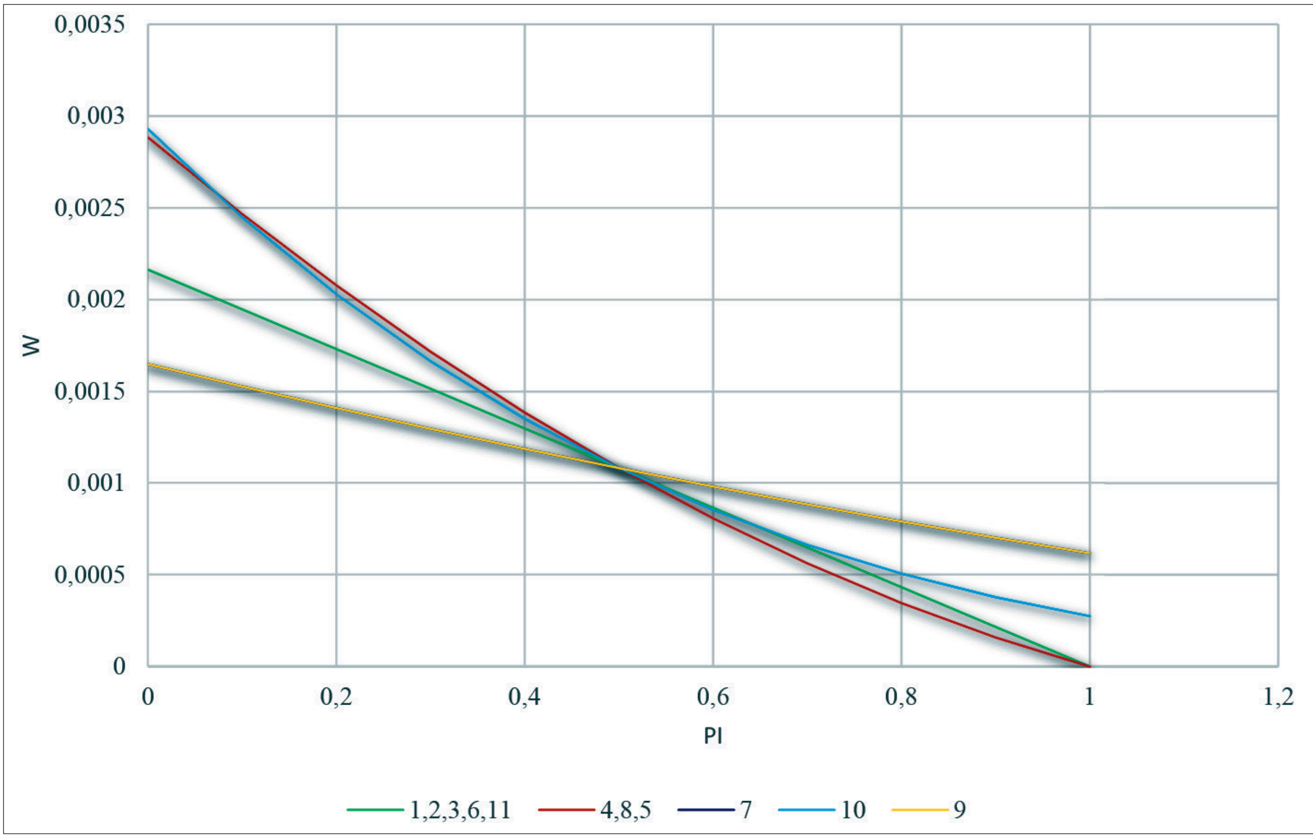

Figure 2. *Dependence W(p_i)*

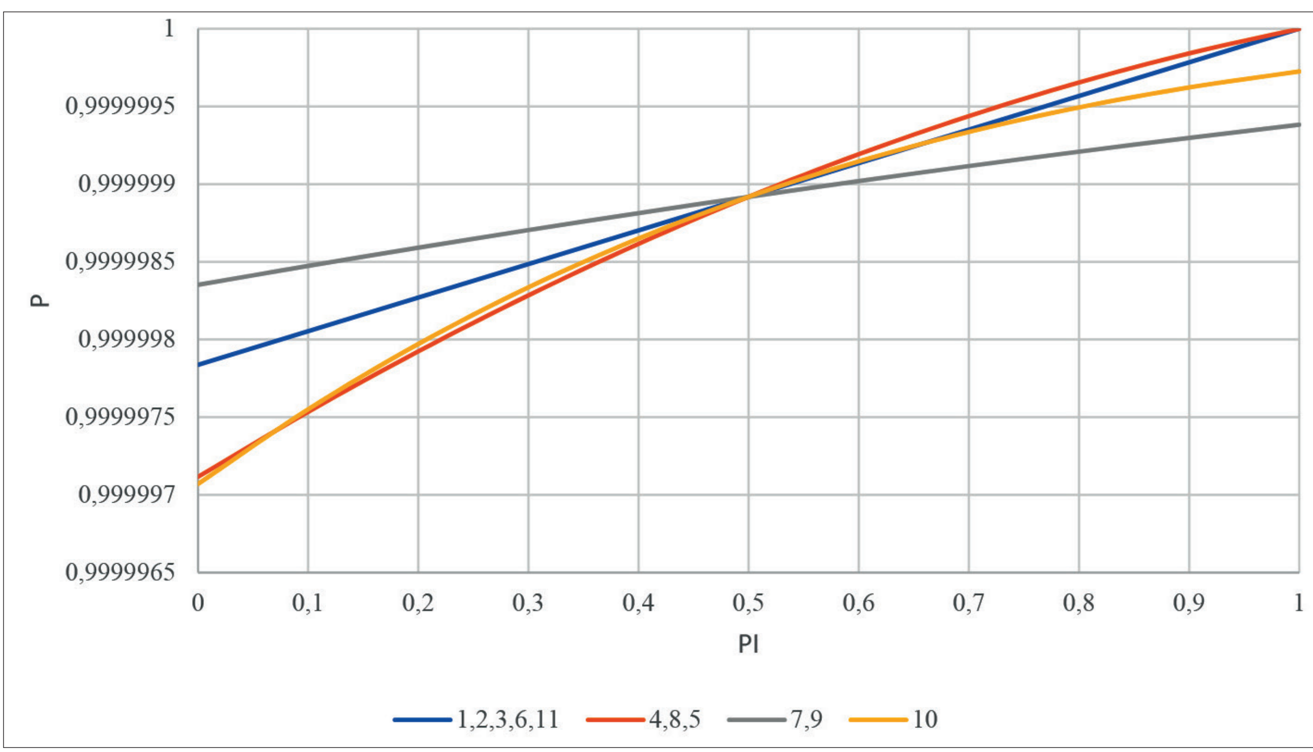

Figure 3. *Dependence and $p_D(p_i)$*

In turn, if at least one of the designated actions, in some cases in combination with others, produced a complete effect, i.e., one of the multipliers became equal to 0, then $p_D = 1$, as in that case $W = 0$.

Let us evaluate the effect of each action on the resulting probability of error. In order to identify the highest effect we will examine each probability p_i within the range between 0 and 1, while the remaining probabilities will be fixed at $p_i = 0.5$, $i = 1,2,...,11$. The probability of driver error will be adopted as $g_D = 10^{-3}$, that value being average [5]. The dependence graphs $W(p_i)$ and $p_D(p_i)$ are shown in Figures 1 and 2, respectively.

The graphs show that as the probability of successful driver assistance action increases the resulting probability grows. High values of TPD, TTC, SDO and EM have the highest effect on the final indicator. Under low probabilities the aggregators, TSR-RT and ATO have the highest effect.

Thus, if the values of error-free performance of the examined actions and aggregators are below 0.5 the highest effect is produced by the ATO and TSR-RT, while the TPD and other actions do not have a pronounced effect. However, if the probabilities are above 0.5, the situation changes dramatically. The lowest effect is produced by the ATO and TSR-RT. Between 0.5 and 0.7, the effect of the remaining factors is about the same. As the values near 1, the effect of the TPD somewhat decreases. As the probabilities of performance under normal conditions are above 0.5, it can be concluded that effort should be made to ensure the probability of correct performance of the TPD, TTC, SDO and EM, because they have a significant effect on the probability of error-free performance.

In the next article we will examine a case study involving the evaluation of the effect of each aggregator and action on the resulting probability of error-free driver performance in a specific operational situation.

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