CHARACTERISTICS OF HUMAN-OPERATOR ERRORS IN THE FIELD OF TRANSPORT AND POSSIBILITIES OF THEIR UNDERSTANDING AND PREDICTION IN A CRUCIAL SITUATION

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ABSTRACT
Undoubtedly, the human-operator is one of the most important factors to achieve a reliable and safe transportation process. However, despite safety efforts, many studies attribute human error as a causal factor in at least 70% of transport accidents. In most cases, the investigation process uncovers the details of the cause-consequence chain of an accident that has occurred, especially when causal factors are mechanical failures. Unfortunately, determining the precise reason for human error as a causal factor is much more difficult. But without a good understanding of the influence of human-operator behaviour on the performance of given transport system (or subsystem), preventive or corrective actions are impossible. The problems connected with the determination and modelling of characteristics of human-operator errors in the area of transport and possibilities for their prognosis are discussed in this article.

Key words:
Transport, Safety, Human-Operator Errors, Human-Operator Reliability

1. INTRODUCTION

That mistakes are an inevitable part of human experience is an indisputable fact in confirmation of which many examples could be given. Not accidentally, the phrase "to err is human" has a wide popularity. Used often in daily life, this expression seems to serve as an excuse for the occurrence of one or other emergency situations caused by inappropriate human behaviour. In some cases, however, the realities are much more complicated than daily life and are usually associated with the occurrence of a number of complex and highly responsible processes. Different transport modes are a

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good example of this, where the human-operator is a very important factor in ensuring a reliable and safe transport process. Statistical data shows that at least 70% of the total number of transport accidents are due to human errors, some of them with severe consequences (loss of life or harm to health of passengers, operating staff, local people, material damage, loss associated with damage to the environment, etc.). Therefore, the study and analysis of human-operator errors is a crucial issue for making correct preventive measures to improve the level of safety in transport systems. Human-operators in the field of transport have always made errors and no doubt this unwanted process will continue, but even a single accident which can be prevented is worth the effort in this area. This article discusses possibilities for modelling and prediction of errors regarding human-operator in the field of transport.

2. DEFINITION, CHARACTERISTICS AND CLASSIFICATION OF HUMAN-OPERATOR ERRORS

There are many definitions of the concept of human error, each of these scrutinizes it in the light and context of the relevant scientific field. What unites them is that the error is treated as unwanted event arising within a particular human activity and as a consequence of which the previously expected result could not be achieved. In other words, the last is considered as a criterion for the occurrence of human error. It should be noted that a similar approach to define criterion for human error occurrence (considered as its essential feature) is not entirely correct and requires special attention because in many cases the human error could be corrected by subsequent remedial actions and ultimately the desired result would be achieved. But the fact, that an error may be corrected, does not mean that it should never be considered as such an adverse event, because in other circumstances its correction may be impossible.

Another important characteristic of human error is that it appears within the process of purposeful activity performed to achieve a predefined result. Regarding this characteristic, spontaneous and unconscious errors that are not related to the main activity should not be considered when analysing the role of the human factor in the respective technological area (e.g. transport).

The significance is the third major characteristic of human-operator error. It entirely depends on the possible consequences. A kind of human error should not be particularly "special" to cause an accident with severe consequences. Even the most trivial errors, depending on the conditions under which they appear, may result in a serious outcome.

Having in mind the characteristics explained above the following general definition for human-operator error in transport can be determined: *This is human-operator inability to perform a specific action adequately and in accordance with previously established rules or the performance of unauthorized action. As a result hazards for the transport process arise, which under certain conditions may lead to the occurrence of an accident.* In other words, the human error occurs when an operator of a transport man-machine system (driver of a vehicle, traffic manager, pilot, railway signaller, etc.) *in carrying out purposeful action* clearly *does not intend to fulfil it in wrong way*, but under *certain conditions does it*, in consequence of which the desired result for reliable and safe transport process *cannot be achieved*.

A characteristic feature of human errors in transport is their broad variety of types, forms of expression and significance (outcomes). In order to establish gradation in the variety of errors, and to facilitate research, human-operator errors should be classified on the basis of a hierarchical system (human error taxonomy) developed on the basis of certain features. The choice of criteria for classification depends mainly on the research objectives and in most cases the type of error is determined by the specificity of human behaviour. In this sense and in the field of transport human-operator errors can be classified as follows:

-Type I: *Errors associated with implementation of routine tasks*. This is the main level of human behaviour that is usually associated with common tasks, the essence of which is primarily characterized by carrying out routine (in an automated fashion) tasks without conscious consideration. The implementation of all routine tasks (especially mechanical tasks) for driving a vehicle is a typical example of such a human behaviour. In most cases this is a highly reliable human activity and errors occurring either have random character or are a consequence of the influence of external factors on the previously established model of consecutive tasks. There are a number of studies regarding probability of this type of human error. For example, in [1] this probability is proposed to be between 0,005 (1 error within the implementation of 200 tasks of a given type) and 0.00005.

-Type II: *Errors associated with implementation of management and control tasks*. This human behaviour is characterized by the presence of more complex and less familiar tasks (than these of type I) that are usually carried out in accordance with predefined rules and instructions. Driving a train along a familiar route is a good example of this type of human behaviour. The theoretical education, acquired experience in driving and sufficient knowledge regarding the specifics of route (lights, speed limits, slopes, etc.) characterize this type of behaviour as a routine performance of a unique combination of consecutive mechanical manipulations and execution of operational rules. The occurrence probability of this type of human error is suggested to be an order of magnitude higher than the probability of human error **type I**, i.e.: from 0.05 to 0.0005.

-Type III: *Errors associated with decision-making process.* This behaviour is associated with a completely new situation (in some cases this is a crucial situation) for which there are no pre-established rules and written procedures (lack of knowledge) but the human-operator should choose the most adequate and appropriate decision in accordance with the specifics of the situation (cognitive process). Immediately after the choice of the new strategy and action plan the human-operator demonstrates behaviour of the above two types. Error probability is characterized by high value varying from 0.5 to 0.005. Each new operational situation (e.g. bad weather conditions, increased traffic, malfunction, road accident, etc.) that requires increased caution, will and skills for making most correct actions is a good example for such a type of human-operator behaviour.

Due to the stochastic character of many processes and events in the field of transport human behaviour is often a combination of defined above types.

3. ANALYSIS AND MODELLING OF HUMAN ERRORS

3.1. NECESSITY AND APPROACHES

The analysis of human-operator errors is an important prerequisite to ensuring reliable and effective management of complex technical or technological systems. The requirement for quantification of human reliability is determined by the need to compare the probability of error in performance of one or a set of tasks in different ways or under different influences of the operational environment (operational conditions). On its part, this allows both identification of critical tasks (potentially hazardous: characterized by high probability of human error) and the determination of measures to improve the performance reliability. The probability of error occurrence P_{error} is the most commonly used quantitative measure of human reliability, computed by the following expression:

$$P_{error} = \frac{n}{N}, \tag{1}$$

where:

N - total number of performances (opportunities for error) of a given action (task) within studied period of time;

n - number of incorrect performances (errors) of the action for the same period.

There are two basic approaches to determine probability P_{error}. The first approach is based on the recorded and analysed statistical data regarding human errors which have occurred in the performance of specific (and examined) tasks. The second approach relates to the subjective assessments of experts, obtained primarily on the basis of observations, questionnaires, etc. It must be recognized that within the first approach a variety of methods for analysis and modelling of human errors have been developed. Two of them have very wide popularity, these are: *Technique for Human Error Rate Prediction (THERP)* and *Human error assessment and reduction technique (HEART).* This paper examines the possibilities that THERP method offer for modelling human-operator errors in the area of transport.

3.2. ESSENCE AND SPECIAL FEATURES OF THERP METHODOLOGY

The development of the THERP methodology began in 1960s in the USA for use within the nuclear power industry. The underlying principles of THERP are often referred to as the THERP Handbook. [2]. The main purpose and idea of the technique are related to the presentation of a simplified approach to quantify human errors. The probabilities of human error (called basic or nominal probabilities) are classified according to the characteristics of the implemented tasks, basically as: *Probability of erroneous performance of manual control actions (tasks)* and *Probability of erroneous performance of predefined written procedures (omission of procedure steps).* The methodology also offers an approach for assessing the influence of some factors over human performance (named performance shaping factors), e.g. stress level, experience, skill level, administrative control, etc. The probability of a specific erroneous action is a function of the basic probability of human error for a generic action modified by relevant performance shaping factors.

The detailed modelling (identification, analysis and quantification) of human errors is based on the development of an event tree.

The basic human error probabilities (also performance shaping factors) are presented in extensive tables [2] and include the two mentioned above types of erroneous performances.

-*Erroneous performance of manual control actions (tasks)*

The THERP technique considers specific control errors and suggests probabilities for their assessment. For example, regarding the control error "Selection of the wrong control in a group of controls", THERP gives two alternative performance shaping factors: *densely grouped and identified by label only* and *more favourable arrangement* (not closely grouped, logically grouped, etc.).

For the first alternative, an error probability of 0.005 and an error factor of 3 are suggested. The error factor takes into account the uncertainty regarding the error probability. Thereby, both the lower and upper uncertainty bounds can be calculated. This means that the estimate of error probability lies between 0,0017 ($0{,}005 / 3 = 0{,}0017$) and 0,015 ($0{,}005 \cdot 3 = 0{,}015$).

As for the second alternative, the error factor is the same but the error probability is suggested to be 0.003. The uncertainty bounds can be determined by the same way: 0,001 ($0{,}003 / 3 = 0{,}001$) and 0,009 ($0{,}003 \cdot 3 = 0{,}009$).

Further, the taking into account of the influence of other performance shaping factors is discussed.

-*Erroneous performance of written procedures*

THERP technique provides data in respect of probability of human error related to the omission of steps within written management procedures. Depending on the number of steps that these procedures comprise they are classified into two categories: *procedures comprising less than ten steps* and *procedures comprising more than ten steps*. The presence of verification of the correct implementation of the separate steps is performance shaping factors. Here, the probabilities of erroneous performance are suggested to be as follows:

-0,001 for procedures with less than ten steps and presence of subsequent verification;

-0,003 for procedures with more than ten steps and presence of subsequent verification also for procedures with less than ten steps and absence of subsequent verification;

-0,009 for procedures with more than ten steps and absence of subsequent verification.

In all cases described above, the error factor for determination of the uncertainty boundaries is 3.

3.3. BASIC METHODOLOGICAL STAGES

THERP procedure consists of the next basic methodological stages:

♦Identification of the characteristics of the respective man-machine system whose operability may be influenced by human-operator errors and for which error probabilities are to be estimated.

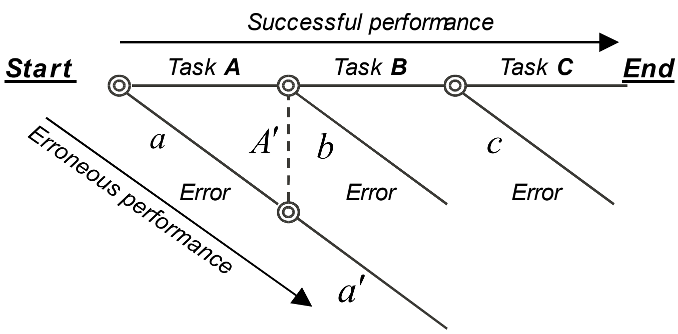

Figure 1. Human reliability (error analysis) Event Tree

♦Analysis of the human-operator's role to achieve system operability.

In this stage, a detailed study of the individual tasks that have to be implemented by the operational staff for performing an action (including analysis of interactions between humans) is conducted. The main objective here is to create an appropriate model needed to perform a quantitative analysis of human-operator reliability (next stage).

Experienced staff		
Stress level	P_m	Confidence interval
Very low	$2P_b$	$[2\theta_1 \div 2\theta_2]$
Normal	P_b	$\theta_1 \div \theta_2$
Moderately high		$[2\theta_1 \div 2\theta_2]$
► Consecutive tasks	$2P_b$	
► Dynamic tasks	$5P_b$	$[5\theta_1 \div 5\theta_2]$
Extremely high	0,25	$[0{,}03 \div 0{,}75]$
Novice staff		
Stress level	P_m	Confidence interval
Very low	$2P_b$	$[2\theta_1 \div 2\theta_2]$
Normal		$\theta_1 \div \theta_2$
► Consecutive tasks	P_b	
► Dynamic tasks	$2P_b$	$[2\theta_1 \div 2\theta_2]$
Moderately high		$[4\theta_1 \div 4\theta_2]$
► Consecutive tasks	$4P_b$	
► Dynamic tasks	$10P_b$	$[10\theta_1 \div 10\theta_2]$
Extremely high	0,25	$[0{,}03 \div 0{,}75]$

Table 1. Modification of basic error probability by stress and skill levels

Event Tree Analysis is a particularly useful tool to solve the problems related to the objectives of this stage. By using Event Tree it is possible to reveal as clearly as possible the structure of the different scenarios (sequence of events) of occurrence of human errors in completing certain tasks. Figure 1 shows an exemplary version of an Event Tree describing an action related to the consecutive implementation of three separate tasks. The symbols A, B and C denote the successful performance of these tasks, whereas symbols a, a', b and c denote the human-operator errors. A variant of recovery action is also considered (denoted by A').

♦Modelling and estimation of the probability of a specific erroneous action.

In this stage, using available data, expert judgement and model for human-operator behaviour developed in the previous stage, the human error probabilities are estimated. The quantitative analysis of Event Tree (designed for assessment of human-operator reliability) fulfilled within the THERP procedure comprises two basic steps:

-By using respective tables in [2], regarding each type of human-operator error (depending on human behaviour type– commented in section 2) the *basic (nominal) probability of operator error* is determined - P_b. The error factor K_e (correction factor), taking into account the uncertainty boundaries of P_b is also determined. The uncertainty boundaries (confidence interval) are as follows: *upper boundary* - $\theta_2 = K_e P_b$, *lower boundary* - $\theta_1 = \dfrac{P_b}{K_e}$.

-Depending on the specific characteristics of both the task and its relationship with others, the basic probability of human error is modified in a certain way. The new probability is named *modified probability* - P_m and takes into account the relevant performance shaping factors. Most important of these are: **Stress and Skill Level** and **Error Dependency.**

The way of modification by stress and skill level regarding the error probability is shown in Table 1.

THERP methodology defines five levels of error dependency. For each level of dependency between human errors occurred within the performance of two successive tasks (a is followed by b), the nominal probability P_b is to be modified as follows:

<u>Zero dependence</u>: $P_m = P_b(b/a) = P_b$,

<u>Low dependency</u>: $P_m = P_b(b/a) = \frac{(1+19P_b)}{20}$,

<u>Medium dependency</u>: $P_m = P_b(b/a) = \frac{(1+6P_b)}{7}$,

<u>High dependency</u>: $P_m = P_b(b/a) = \frac{(1+P_b)}{2}$,

<u>Complete dependency</u>: $P_m = P_b(b/a) = 1$,

where:

P_b - nominal probability of human error within implementation of task b;

$P_b(b/a)$ - conditional probability of human error in task b given that an error occurred in task a;

P_m - modified probability.

♦Estimation of the effect of human-operator errors on the system operability.

The estimation of possible hazards (accident scenarios) that may occur due to errors within the operational process of the respective man-machine system is the main objective of this stage. This objective is usually achieved through a combination of human reliability assessment and a detailed risk assessment.

♦Decision-making to improve system operability.

In this stage proposals for measures (and their evaluation) to improve the operability of the respective man-machine system by increasing human-operator reliability have to be made. Depending on the characteristics of both the system and failures that have occurred a number of solutions can be implemented, e.g. implementation of mechanical or electronic (or both types) interlocking devices, redesign of human-operator actions, individual tasks or the job as a whole, improvement of the administrative control over operators' behaviour, etc.

4. AN APPROACH FOR HUMAN ERRORS MODELLING IN THE FIELD OF RAILWAY TRANSPORT

Operational reliability and safety have always depended on the reliability of the typical for the respective transport mode man-machine systems. This fact particularly applies to the railways, where there has always been a strong link between human errors and major accidents. Therefore, a need to model human operator errors in railways (drivers, signallers, dispatchers, etc.) arises. In this sense, the THERP methodology gives a good possibility for modelling and analysis of typical errors of the human factor (as a result of which severe accidents may occur) in railways.

This section examines train driver behaviour (and error probability) in a crucial operational situation which may occur within the transport process in railways – a train approaches a level-crossing which is not protected (due to a failure of actuating equipment). Modern signalling systems are extremely reliable but such a situation is possible. According to Bulgarian operating rules, when a train approaches a level-crossing its driver is to check a caution signal (mounted at a distance of 1000 meters before the level-crossing zone). If the signal indicates that the level-crossing is protected (a single white flashing aspect signal) then the train may maintain normal movement. Otherwise (the caution signal is not lit), the train driver has to reduce the speed to 15 kph and drive through level-crossing zone with caution and readiness to stop if he sees a car.

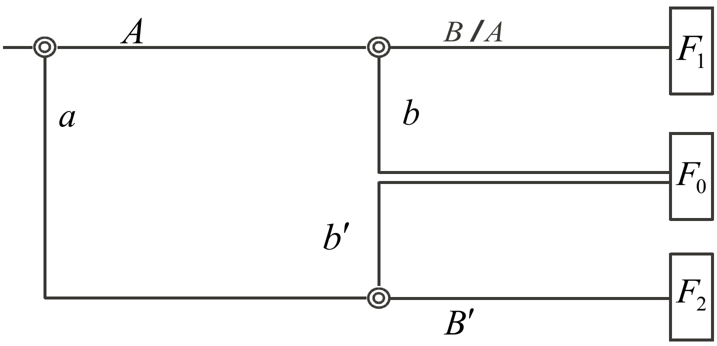

Figure 2. Human reliability Event Tree for exemplary operational situation described in section 4

The available data, operating experience and careful analysis of the events allow us to make the following classification of the main driver errors in such a case that may lead to railway accident:

-inability to locate or check the caution signal due to poor visibility;

-failure to take into consideration the reduced effectiveness of the braking system (bad weather conditions, technical failures, etc.);

-approach the level-crossing at an excessive speed;

-train driver falling asleep or losing of consciousness;

-misreading, misjudgement or disregard of the caution signal.

Figure 2 shows an exemplary tree of events designed for railway accident described above. It addresses the following events:

A-the train driver fails to observe and acknowledge the caution signal (misreads or disregards the caution signal) as a result of which he is not prepared to take adequate precautions when approaching the level-crossing zone.

a -the train driver observes and acknowledges the caution signal correctly;

B' -the train driver (although he has acknowledged the caution signal) approaches toward the level-crossing zone unprepared for precaution and with high speed;

b' -the train driver acts correctly, reduces the train speed and approaches the level-crossing with high attention;

b - the train driver acts correctly (although he fails to observe and acknowledge the caution signal) reduces the train speed and approaches the level-crossing with high attention;

B / A-train driver passes through the unprotected level-crossing without any precautions (previously, he has not observed and acknowledged the caution signal);

F_1, F_2 -negative final events (outcomes): train passes through unprotected level-crossing without adequate precaution due to driver's error;

F_0 -positive final event (outcome): train passes through unprotected level-crossing with adequate precaution (according to operating rules).

Having in mind the fact that the activities and tasks carried out by a train driver can be addressed to human behaviour **type II** (see section 2), the probabilities of errors $P(A)$ and $P(B)$ can be assumed to be 0,005. Based on the specifics of the events F_1, F_2 and F_0, the dependency between event B and event A could be assumed to be medium. Therefore, according to formulas described in section 3.3, the conditional probability $P(A / B)$ can be obtained as follows: $P(B / A) = \frac{(1+6.0,005)}{7} = 0,1471$. Following the rules for quantitative Event Tree Analysis, the probabilities regarding outcomes are: $P(F_0) = 0,9943$, $P(F_1) = 0,0007355$, $P(F_2) = 0,004975$. From this model of human error it could be concluded that in 99.43% of all cases of train approaching an unprotected level-crossing, adequate driver behaviour (with precaution) can be expected. The probability of unsafe behaviour of a train driver when driving a train toward an unprotected level-crossing is too small 0,0057.

5. CONCLUSION

After many years of operational experience and efforts for the improvement of the reliability and safety of technical equipment, transport means, transport process management and staff performance, many transport companies have reached a wrong conclusion that further improvement seems impossible to achieve. Another wrong inference is that, human errors can be prevented only by the correct design and precise performance of written procedures and rules. But theoretical and practical knowledge in the field of transport acquired through years has showed that the existence of „perfect“ predefined procedures and rules is not an effective barrier for preventing human errors - they may happen at any time and in any workplace (due to one or another causal factor).

This is why the finding of appropriate approaches for correct understanding, modelling and assessment of human-operator errors is a very considerable scientific and practical problem. On its correct solution depends on a great scale the reliability of a number of man-machine systems which play a very decisive role within overall transport process. In this connection, THERP methodology is probably most widely used technique of human reliability analysis. As the present article shows, this technique could successfully be used to solve a very important practical problem related to the reliability and safety of the transport service – human factor reliability.

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