

HUMAN ERROR MODES AND THEIR ANALYSIS IN CENTRALIZED RAILWAY TRAFFIC CONTROL

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ABSTRACT

Human behaviour and human errors are important in all transportation systems because they can lead to situations with high risk and loss of life and goods. Although in many transportation systems highly dependable technical subsystem ensure the core safety, human participation cannot be entirely avoid. In the railway transportation sector, the interlocking (control-command signalling, CCS) subsystems is responsible for the primary safety, and - mainly for operational issues - human operators play an important role during the non-safety oriented commanding; however in case of the partial or total failure of the interlocking subsystem, human operators get the tasks of maintaining the railway traffic, thus they get safety critical responsibility in such instances.

As human (operator, traffic controller or signaller) behaviour is important in the railway traffic, there is a need for a detailed analysis of the error modes and their consequences in order to be able to design such a system in which the probability of such errors is reduced to a tolerable level. In this paper we present the main error modes for human operators, summarizes the main analysis techniques and show, how TRACER method can be used for railway signallers.

INTRODUCTION

In the railway automation industry, safety is guaranteed by safety critical control and command subsystems (Control Command Signalling, CCS). These systems are operated automatically, and they are supervised by railway signallers (operators). Depending on the level of the automation of the CCS subsystems, the role of the operators can vary on a wide scale. Earlier, railway signallers and pointsmen were fully responsible for all the train and shunting movements without any automation; this required a lot of human actions, thus a lot of human contributors. Nowadays, the whole traffic of railway lines can be integrated into one operational control centre (OCC), where only a few signallers are responsible for the traffic controlling tasks of the railway line (or of a smaller section of a long railway line). In a system with high level of automation – like in the modern OCC -, the primary task of the operator is supervising and remote controlling the railway traffic (and the interlocking system ensures the safety behind the scenes); the operators' impact on the traffic and its safety increases only in a case of a system failure or an accident.

Human errors can cause more and more delays (which means cost to the railway operator), and - under extreme conditions - a human error may even become a source

of an accident. In an OCC the signallers have many diverse and complex tasks, therefore the number of potential hazards increases. In Europe, many railway infrastructure operators establish (or going to establish in the near future) OCC centres, thus the identification of potential human error modes is becoming more and more important in this field.

HUMAN ERROR IDENTIFICATION METHODS

A human error (or human behaviour) means that an action (or inaction) potentially or actually results in negative system effects [1]. As regards the transportation sector, the consequence of the human errors can be different in the various subsectors. In case of air (and water) transport the role of traffic operators is more important, than in case of guided land transport, like railways, because the operator must guarantee the safety on an ongoing basis without the help of any safety system. Therefore, the human error identification methods are much more common in the air transportation sector.

Regarding human error types, one possible grouping is published by the Health and Safety Executive in the United Kingdom – see on the Figure 1. The main types of the potential human errors are as follows [2]:

- action based slips (commission), which means, that a simple, frequently performed action goes wrong,
- memory based lapses (omission), which means, that the operator omits to perform a required action,
- rule based mistake, when a mistake occurs due to mis-application of good rule or application of a bad rule,
- knowledge based mistake, which means, that the operator has no rules or routines available to handle an usual situation,
- routine mistake, which is characterized by a lack of meaningful enforcement,
- situational mistake, when the non-compliance is dictated by situation-specific factors,
- exceptional mistake, when the operator attempts to solve a problem under highly unusual circumstances (often if something has gone wrong).

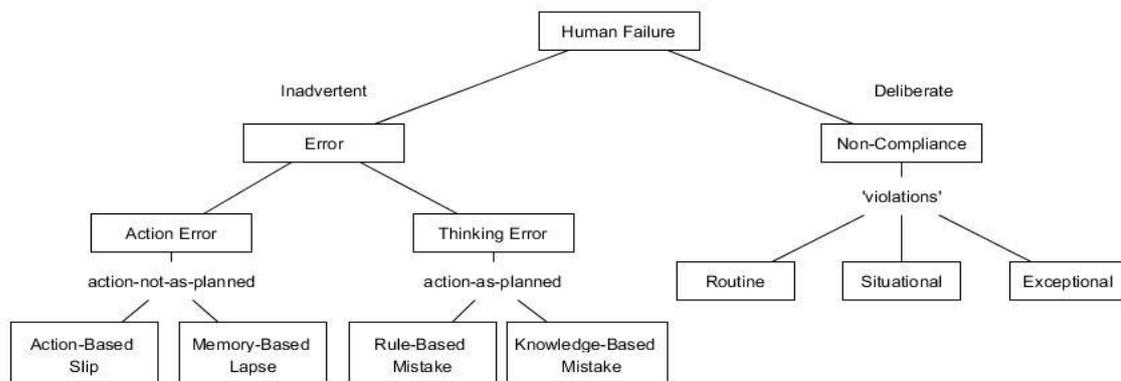


Figure 1.
One possible grouping model of human errors [2]

Another possible grouping method is presented in [3]. The major error types include the following (based on [3]):

- slips and lapses – action execution errors, generally these errors are the most predictable,
- cognitive errors - diagnostic and decision-making errors, which are related to a misunderstanding by the operators,
- maintenance errors and latent failures, which occur due to slips and lapses in maintenance and testing activities,
- errors of commission that happen when the operator does something that is incorrect and also unrequired,
- rule violations (routine and extreme),
- idiosyncratic errors, which concerned with errors due to social variables and an individual's current emotional state, when performing a task,
- software programming errors, which are important for any safety critical software applications, such as the navigational software in aviation or interlocking software in the CCS subsystems in the field of railway traffic controlling. (This category can be extended to functional safety of technical systems and to its hazardous failures due to hardware failure or incorrect development such as software errors or any similar error.)

The Potential Human Error Cause Analysis (PHECA) [4] uses a totally different classification, which combines the error causes related to the human behaviour. In the aviation industry the Technique for the Retrospective and Predictive Analysis of Cognitive Errors in Air Traffic Control (TRACER) [5] gives a detailed analysis of the error causes and their consequences in an air traffic controlling (ATC) system. This method includes the external error modes, which are the external manifestations of an error. The TRACER method examines the error modes that occur in the communication channels. In ATC systems, the verbal communication channels are the primary and the most important sources of the traffic controlling information, thus the human errors may have serious safety consequences. In a railway OCC, the CCS subsystems generally do not use verbal communication channels, therefore the examination of the communication system – based on the TRACER method – is not necessary. The errors of the communication channels represent technical failures.

The Systematic Human Error Reduction & Prediction Analysis (SHERPA) [5] is a software supported tool to document and analyse safety critical tasks in healthcare, medical device design and other industries, and it combines the FMEA and HAZOP analysis. The SHERPA method classifies the activity types and it considers the following error modes:

- action errors,
- checking errors,
- entered information errors,
- information communication errors.

The rail specific TRACER (TRACER-Rail) tool [7] [8] was developed specifically for the rail industry. The primary objective of this tool is to identify and analyse the train driver's errors (typically to understand the signal passed at danger - SPAD - situations). This tool identifies errors with a focus on the underlying psychological mechanisms. This tool has an Australian version [9] which is a modified analysis, that takes into account the local regulations and procedures.

The TRACER analysis is very detailed, thus it is suitable for the railway automatization industry: with the help of this method it may be possible to directly analyse the effects of a human error and the safety consequences too.

HUMAN ERROR MODES IN THE OPERATIONAL CONTROL CENTRES

In a railway OCC, operators are working with modern monitoring systems, and they simply remote control a vast area. The modern signalling systems provide us with all the information (status) of the signalling elements (points, signals, routes, level crossings, etc.) and ensure that all the movements of the trains are in one hand, with the aid of the modern safety communication systems. Beside the main task which is timetable based dispatching, other tasks include the supervising of shunting movements, train handling, operating the passenger information systems, supervising the catenary system, and supervising different alarm systems. These tasks are significant factors of the operator's workload.

Table 1. and Table 2. show three functions analysed by the TRACER method. The light grey cells indicate the restrictive effects, the dark grey cells indicate the serious safety consequences of a human error. The white cells mean, that the an error does not have particular consequences.

For the investigation three different cases have been selected. The first function is a frequently used function under normal operating conditions. The second function is used during a system failure, when a switch (point control) cannot be operated by normal commands and special considerations have to be taken. In this case using this function may be dangerous. The third function is a safety critical command, when the primary target is to stop a moving train (or to stop all of the moving trains) as soon as possible. The third case is different from the second in that the dangerous situation pertains to cases when the operator does not use the desired function.

The first function is the route settings ensured by the operator. In this case the signaller does not use any automation for route setting, he or she directly sets up a route between a start and an end point. In some cases, the outcome of a human error is just a restrictive effect on the railway traffic – marked in light grey colour in the tables. The restrictive effect means delays, thus it is a cost for the railway infrastructure operator and for the passengers, too. Restrictive effects have not safety consequences, but the delays may mean an increased workload, thus the sum of the restrictive effects can lead to another human error, which may have safety consequences. Based on Table 2. it seems, that none of the examined functions uses a verbal communication channel, therefore a human error is possible just in the second function, under the checking process, when the operator must ascertain the free state of a switch visually.

Table 1.
Examples of identified external error modes based on the TRACER method, part 1.

External error modes, consequences	Examined functions			
External error mode	Route settings	Switching without any occupation condition		Return of signal to stop position
		checking of the state	switching process	
Selection and quality				
Omission	restrictive effect on the railway traffic	it may have serious safety consequences	desired point does not operates, it may have a restrictive effect on the railway traffic	it may have serious safety consequences
Action too much	n. a.	n. a.	n. a.	n. a.
Action too little	n. a.	n. a.	n. a.	n. a.
Action in wrong direction	swapping the start and the endpoint of a route - in a case of the presence of the dependence of traffic direction - is not defined, but in the case of the lack of this dependence it may be a restrictive effect on the railway traffic	n. a.	n. a.	n. a.
Wrong action on right object	instead of route settings, another function is used e.g. special-purpose signal handling, thus the safety may be damaged, the train moves through not locked switches	n. a.	it means a normal switching of a point, that may not be realized because of the inherent safety functions	another function is used instead of the desired function, it may have serious safety consequences
Right action on wrong object	wrong start point is used (object confusion), it may have a restrictive effect on the railway traffic	wrong switch is checked, it may have serious safety consequences	wrong switch (object confusion) is handled by insulated operation, in a case of a shunting train - on a not locked route -it may have serious safety consequences	wrong signal (object confusion) is handled, it may have serious safety consequences
Wrong action on wrong object	wrong start point or end point is used (object confusion) with wrong action, it may be a safety critical consequence e.g. the result is a not desired train movement	n. a.	wrong switch (object confusion) is handled by normal operation, it may be a restrictive effect on the railway traffic	wrong signal (object confusion) is handled with wrong function, it may have serious safety consequences
Timing and sequence				
Action too long	the button is pushed long, it means slow working, it may have a restrictive effect on the railway traffic	the checking time is too long, it has a restrictive effect on the railway traffic	the button is pushed long, it means slow working, it may have a restrictive effect on the railway traffic	it has not safety consequences
Action too short	the route setting function is not valid, it must be repeated, it can have a restrictive effect on the railway traffic	the signaller do not a thorough job, it may have serious safety consequences	the switch will not be handled, the function must be repeated, it can have a restrictive effect on the railway traffic	the command is not working, it may have serious consequences
Action too early	another train may be delayed, it may have a restrictive effect on the railway traffic	too much time between the checking and the command, it may have serious consequences	another route settings order not will be valid, than it may be a restrictive effect on the railway traffic	this function is working on a line-clear signal, in this case a train is running on the tracks that must be stopped, then this error type is not applicable
Action too late	a train may be stopped in front of a signal, it may have a restrictive effect on the railway traffic	n. a.	a train may be stop in front of a signal, it may be a restrictive effect on the railway traffic	the command is delayed, it may have serious consequences
Action repeated	it is not possible to setting the same route more than once	the sum of the checking time may be too long, it has a restrictive effect on the railway traffic	continuous operation, it may have serious consequences	this function can be processed just one time
Mis-ordering	the route setting has a fix order, the swapping of the steps is not possible, it just means a longer route settings time, in extreme cases it may have a restrictive effect on the railway traffic	the checking is after the command, it may have serious consequences		n. a.

The operator's error may lead to serious safety consequences in two cases: the wrong action on right object, or the wrong action on wrong object. In the case of the wrong action on right object it is necessary to examine all of the possible actions, because not every possible action has safety consequences. In the case of the wrong action on wrong object, the situation is similar. On the whole, it can be concluded, that the effect of the operator's error – under the process of route settings – depends on the type of the CCS subsystems, and on the type of the wrong action (we must say that one of the primary functions of HMIs is to prevent such wrong actions).

The second function is the operation of switch without any occupation condition. In this case a switch is in – probably – in a faulty state, and the normal switching process is not working. The operator has the possibility to turn off the occupation detection system of a point, and to set it to the opposite direction. This function may have restrictive effects without safety consequences. This process can be divided into two parts. Firstly, the operator must check the free state of the switch (generally visually) and in the next step can use this command. In the first case, the omission is dangerous, because a train may pass through this switch. At this moment, the result of a switching process will be a derailment. The right action is the same, because it means an omission of the right switch. The action too long and the action repeated have restrictive effect, because the checking time increases. The action too short means, that the operator is not working thoroughly. In the case of the action too early, too much time elapses between the checking and the switching process, and a new train may approach towards the switch. The result of a switching process is a derailment. The mis-ordering means, that the checking process follows after the switching process, than it is equal with the case of the omission of the checking of the free state.

If the checking process means a visual observation, the not transmitted information and the incorrect information may have serious safety consequences. The not transmitted information is equal with the case of the omission in the group of selection and quality. The incorrect information means, that the operator determines wrongly the state of the switch, and the result may be a derailment. The visual information is not recorded. If the checking process is executed by visual technical systems, a human error is possible during the processing of the information, and in this case it is equal with the incorrect transmitted information.

During the switching process, the operator's error may be dangerous in two cases. The right action in wrong object means, that the operator is switching an incorrect point. (The condition of using of this function is the free state of the switch. In this article it is assumed, that the operator stated the free status of the switch correctly.) If there is a vehicle, that uses incorrect switch at that time, it will derail. The derailment may have serious safety consequences with injuries. A repeated action may have the same consequences, because the train driver and the shunting staff do not expect a repeated action. In this case too, a human error is not possible in the communication channel either, it means that we encounter a technical failure in every case.

The third examined function is the return of a signal to stop position. It is not an often used function, but a human error may have serious safety consequences. Based

on the Table 1, a human error may result in a dangerous situation in six different cases. Omission means, that the signaller does not use this function, and a train will not be stopped. The right action in wrong object is the same, because not the desired train will be stopped. The wrong action in right object means, that the signal will show a line clear signal instead of danger position, and the desired train will not be stopped. The wrong action in wrong object means, that the desired signal will show a line clear signal, but another train may start. In the case of the action too short, the operator does not press the desired button long enough, and a line clear signal will be shown. The action too late is equivalent to the case of the omission, because it has the same effect.

Table 2.

Examples of identified external error modes based on the TRACER method, part 2.

External error modes, consequences	Examined functions			
External error mode	Route settings	Switching without any occupation condition		Return of a signal to stop position
		checking of the state	switching process	
Communication				
Unclear information transmitted	the safety system can not process the action needed	n. a.	the safety system can not process the action needed	the safety system can not process the action needed
Unclear information recorded	not defined, because an unclear information can not be stored	n. a.	not defined, because the function can not be stored	not defined, because the function can not be stored
Information not sought/obtained	technical error, n. a.	n. a.	technical error, n. a.	technical error, n. a.
Information not transmitted	technical error, n. a.	omission, it may have serious safety consequences	technical error, n. a.	technical error, n. a.
Information not recorded	technical error, n. a.	n. a.	not defined, because the function can not be stored	not defined, because the function can not be stored
Incomplete information transmitted	the safety system can not process an incomplete action	n. a.	technical error, n. a.	technical error, n. a.
Incomplete information recorded	the safety system can not process an incomplete action	n. a.	not defined, because the function can not be stored	not defined, because the function can not be stored
Incorrect information transmitted	technical error, n. a.	it may have serious safety consequences	technical error, n. a.	technical error, n. a.
Incorrect information recorded	technical error, n. a.	n. a.	not defined, because the function can not be stored	not defined, because the function can not be stored

CONSEQUENCES AND ACTIONS AGAINST THE IDENTIFIED HAZARDOUS HUMAN ERRORS

In an OCC, an operator has different tasks, and many integrated automation functions help him to control the railway traffic. With the aim of the integrated functions the operator will use the controlling commands less often. The supervised area and the number of the trains is bigger, than in a case of a similar station. An operator supervises 10 - 12 trains at the same time consequently, than the possibility of giving incorrect commands increases. It may result in restrictive effects or may have serious safety consequences, which means derailment and injuries.

There are two potential ways are possible to reduce the consequences of human errors. The first method is to analyse the human performance and to understand the

process of the formation of an error. The second way is to build a defence against human errors by technical systems. In the railway transportation sector more and more tasks are performed by technical systems (like fully automated dispatching systems), therefore one possibility is to implement supervision systems. The possible solution is to substitute the visual checking process is to use a visual image processing system.

Table 3.
Possible solutions in case of errors with serious safety consequences

Possible solutions		Examined functions		
External error mode	Route settings	Insulated operation of a switch		Return of signal to danger position
		checking of the state	switching process	
Selection and quality				
Omission		before the switching command, it must request an reinforcement		integrated supervision systems and automated functions with alarm systems
Wrong action on right object	every different command must be a reinforced command			after the command it must to highlight and monitor the used object
Right action on wrong object		before the switching command, it must request an reinforcement	it must be a reinforced command	after the command it must to highlight and monitor the used object
Wrong action on wrong object	every different (different from the normal route settings) command must be a reinforced command			after the command it must to highlight and monitor the used object
Timing and sequence				
Action too short		before the switching command, it must request an reinforcement		it is forbidden to use a timing and it must be a simplified command
Action too early		before the switching command, it must request an reinforcement		
Action too late				= omission
Action repeated			it must to use a time window between two similar commands	
Mis-ordering		before the switching command, it must request an reinforcement		
Communication				
Information not transmitted		before the switching command, it must request an reinforcement		
Incorrect information transmitted		before the switching command, it must request an reinforcement		

The restrictive effects have no safety consequences and their long term effects can be predicted depending on the error detection time. The continuous traffic monitoring systems help to the operator to solve these problems.

In the case of the dangerous situations Table 3. presents the possible solutions in case of the dangerous situations.

SUMMARY

This paper presented a short human error – external error modes - identification analysis based on the TRACER method in the railway operational control centres. The consequences of a human error may be a restrictive effect without safety consequences or may be a hazardous situation with serious safety consequences. This analysis may be adequate to use in the modelling of the OCC's to identify the potential hazards in the early phase of the design.

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