RISKS ANALYSIS FOR ASSESSING SAFETY IN RAILWAY TUNNEL THROUGH BEHAVIOR- BASED SAFETY STRATEGY

Fabio De Felice[(a)], Antonella Petrillo[(b)]

[(a)] Department of Civil and Mechanical Engineering - University of Cassino, Italy
[(b)] Department of Civil and Mechanical Engineering - University of Cassino, Italy

[(a)]defelice@unicas.it, [(b)]a.petrillo@unicas.it

ABSTRACT
In most situations, human and machines are linked in one system. Accidents and malfunctions occur in most systems; and, therefore, there are procedures for reporting them. Recently, the emphasis has been on developing techniques for predicting human reliability. Present effort is focused on developing a more academic methodology which applies to practical human-machine systems. However it is desirable to treat the concept of human error with caution and to avoid an approach in which the operator appears to be held solely responsible. The aim of our work is to propose a methodological approach based on the consideration that errors are the combination of conditions in the human-machine system. It is on the total system that attention should be centered.

Keywords: risk analysis, railways, BBS, safety

1. INTRODUCTION

After serious accidents, which happened in tunnels in the last few years, most countries have established new measures in order to evaluate the safety of existing tunnels and to establish new safety measures. In view of the recent events of the year 2001 (terrorism act on the 11th of September and the Gotthard fire on the 24th of October) particular attention should be turned on related safety aspects (Vuilleumier et al., 2002). So, in the late eighties and early nineties of the last century, European national governments as well the EU Commission decided to introduce competitive elements into the European railway industries (Jamasb et al., 2003).

Railways have unique characteristics that result in potential risks: heavy vehicles run at considerable speed over fixed rails while braking capacity is small due to minimal friction between metal wheels and rails. These characteristics generally prevent that trains can be brought to a standstill within the distance that can safely be observed by the driver and neither is a driver able to steer away to avoid conflicts. Therefore, railway networks are equipped with *safety systems* for excluding risks of derailments (by e.g. a broken rail, open movable bridge, unlocked switch), collisions between trains, collisions between trains and road vehicles on level-crossings, and accidents with maintenance workers (Meer, 2000). The main interface between the safety system and the trains are the trackside signals which can be partitioned into automatic and controlled signals. Train separation on open tracks is guarded by automatic block systems in conjunction with automatic train protection. Block signals protect block sections and operate completely automatically based on train detection and interlinked signals. Block systems are complemented by train protection systems to further avoid human errors or failure (of the train driver). Signals also protect routes through station layouts to avoid head-on, end-on, and flank collisions. These signals are controlled by dispatchers and the interlocking system. Safety and signaling systems rely on train detection systems for track occupancy and track-free detection.

In addition, tunnels are unique environments with their own specific characteristics: underground spaces, unknown to users, no natural light, etc. which affect different aspects of Human Behaviour (Worm, 2006, De Felice *et al,* 2012) such as pre-evacuation times (e.g. people may show vehicle attachment), occupant–occupant and occupant–fire interactions (Frantzich and Nilsson, 2004), herding behaviour and exit selection.

In this context, several Computational Modelling software packages have been used in recent years as a tool for analyzing occupant safety conditions in case of emergency.

Based on a real case study, the new safety measures are presented in this paper. It is clear that there are many strategies for managing safety (De Felice, Petrillo and Silvestri, 2012). We will focus on one of the many effective strategies: behavior- based safety (Grindle et al. 2000).

2. THE SCENARIO AND TUNNEL RISK ASSESSMENT METHODS

In the literature two main categories of risk assessment methods can be distinguished (Molag and Trijssenaar-Buhre, 2006):

1. Deterministic safety assessment: The consequences for loss of life of tunnel users and tunnel structure are analyzed and assessed for possible accidents that can occur in a tunnel.

2. Probabilistic safety assessment: The consequences for loss of life of tunnel users and tunnel structure and the frequency per year that these consequences will occur are analyzed.

Consequences and the frequency of the consequences are multiplied and presented in risk for the individual tunnel user, a societal risk and a risk for tunnel damage.

Figure 1 shows the different stages in a probabilistic and deterministic safety assessment.

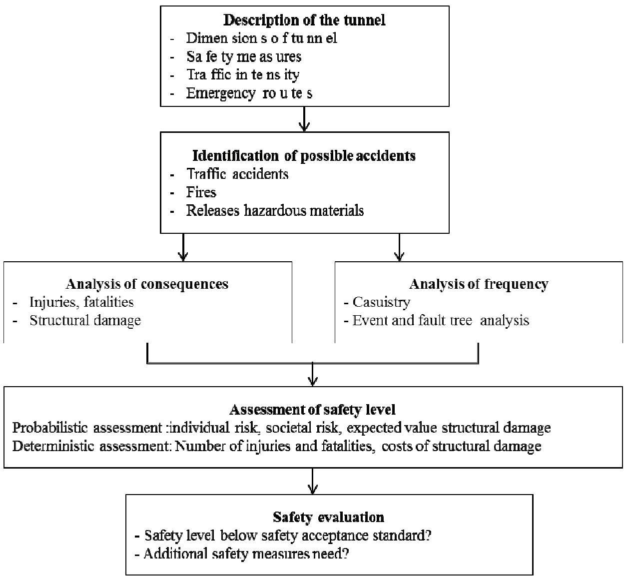

Figure 1: Main steps in a tunnel risk assessment

The tunnels studied put into practice the maximum number of measures for obtaining the highest security objectives. Nevertheless, the risk factor will never be reduced to zero even though we must do everything in our power to reduce the risks to the greatest extent possible (See Figure 2, 3 and 4 Appendix A).

Here below are described activities involved in the project:

1. Definition of risk and reliability of the railway tunnel system with particular reference to a railway tunnel "type";
2. Study of the reliability existing
3. Development and verification of the model for particular systems;
4. Testing and validation of new model for all system installed in the railway tunnel.

Characteristics of tunnel considered are:

- Length (km) = 4,476
- N ° Track = 2
- N ° Windows Intermediate = 1
- N ° Niches Equipped = 175
- N ° Rods = 1
- N ° Exchanges = 0
- N ° Turnouts Hydraulic = 0
- N ° Turnouts Electromechanical = 0
- N ° Fixed Signals 5
- N ° LED Signals = 0
- N ° Track circuits at low frequency = 6

In Figure 5 (Appendix A) is shown Level of Risk.

In Table 1 are shown the data traffic expected by 2021:

Table 1: Data traffic expected by 2021

	Long-distance	Regional	Goods	Hazardous substances
Daily	28	26	13	3
by day	*24*	*26*	*6*	*1*
by night	*4*	*0*	*7*	*2*

Analysis of the hazards related generic rail system, the following potential hazards are considered relevant:

- Derailment;
- Collision;
- Fire.

In Appendix B (Table 2) the main derailment causes are shown.

In Table 3 are shown values of MTTR (Mean Time To Repair) and MDT that is the Mean Down Time, represents the average time of unavailability, obtained by the sum of MTTR and logistical and administrative delay time (if available).

Table 3: Values of MTTR and MDT

Sub system	MTTR (h)	MDT (h)
Telecommunication systems	2.00	4.00
Railway signaling system	1.12	3.12
Lighting and power system	0.51	2.51
Electrical traction system	2.17	4.17
Ventilation and smoke control system	1.55	3.55
Sprinkler	1.33	3.33
Security systems	1.79	3.79
Integrated supervision system	0.53	2.53
Global system	**0.68**	**2.68**

Equation 1 shows the calculation of the values of MTTR of subsystems:

$$MTTR_{subsystem} = \frac{\sum_{i}^{N} \lambda_i * MTTR_i}{\sum_{i} \lambda_i} \quad (1)$$

where λ_i represents failure rates

In Table 4 are shown *Mean Time Between Critical Failures* for Lighting and power system:

Table 4: Values of MTBCF

Equipment	MTBCF (h)	Reliability requirement MTBF	Requirement fulfilled
MV/LV Transformer	**175000**	> 130000 h	**YES**
Switchboard	**25700***	> 60000 h	**NO ***
Electric SCADA Front-End and LFM	**79800**	> 60000 h	**YES**
Electric Treats	**77000**	> 60000 h	**YES**
Junction boxes and buttons Emergency	**60000**	> 60000 h	**YES**

2.1. Human factors in system effectiveness

As human beings become involved in system, their abilities and limitations are manifested in their performance of mission tasks (Kou *et. al,* 2001). Since humans are essential to the operation of such system, it is important to measure the effect of human performance on the system reliability.

There is evidence that the human component is responsible for 20-90% of the failures in many systems depending upon degree of human involvement in the system (Lee *et al.,* 1988 a and b). Human factors specialists usually provide only qualitative analysis of human factors in human machine systems. A better approach to study human factors in system effectiveness is to combine the human and hardware performance measures into a meaningful index taking into account the interaction of human and hardware components of the system. Comparison between human and hardware reliability is provided in Table 5 (Appendix B).

Many methods have been proposed in the literature to analyze the human factors. The method that is most widely used and, that we used, for studying human factors is Behavior based safety method.

3. BEHAVIOUR BASED SAFETY APPROACH

Behavior-based safety approaches have become a popular way of managing the people side of safety. The approach was originally developed in the USA. It revolves around what motivates and reinforces people's behavior. Basically it was recognized that the rewards for behaving unsafely often outweigh the rewards for safe behavior (Cook and McSween, 2000).

Behavior-based safety programs attempt to address the balance of rewards for behavior by increasing rewards for safe behavior and decreasing rewards for at-risk behavior. Behavioral safety has four general components:

1. Identification of change targets through a careful analysis and assessment of the data.
2. Development of a measurement system. The most successful behavioral safety processes involve all employees and management in data collection.
3. Development of a feedback, reinforcement and problem solving process. Normally, a good measurement system will include verbal and graphic feedback (posted by group data, not individual), positive reinforcement for safe behavior or situations, positive reinforcement for conducting observations, and problem solving for at-risk behavior or situations.
4. Continuous improvement of the process. Behavior-based safety processes require a great deal of time, effort, and expertise but as discussed above, the payoffs can be considerable.

Traditional behavior-based safety programs attempt to achieve this objective by (Dekker, 2002):

1. educating people in the workplace about safe and unsafe behavior;
2. using peers and supervisors to observe worker activities;
3. isolating target behaviors;
4. providing various forms of feedback to individuals and groups in order to positively change safety-related attitudes and behaviors.

This feedback usually comes in the form of praise and recognition from peers and/or supervisors. The fundamental concern about traditional behavior-based safety programs is that to some extent, they assume that we always have a choice as to whether to behave safely or unsafely. For example, there is an underlying assumption that if haul truck drivers speed or drive recklessly, it is because they choose to do so. Behavior-based safety programs suggest that if an individual was rewarded for safe behavior then safer driving would occur.

3.1. Behavioral Safety Measures

In this paragraph we would like to propose a sample of guideline to improve risk and safety management in railway tunnels. In fact, a systematic Behavioral Safety process fulfils safety conditions. The intention is to focus worker's attention and action on their safety behavior to avoid injury. Interventions are aimed entirely upon the observable interactions between safety behavior and the working environment (Mearns et l., 2003; Cooper, 2009).

The most common sequence of steps to apply BBS involves (Sulzer-Azaroff *et al.,* 2000):

- Determining the controllable factors involved in injuries (e.g., processes, environmental conditions, worker and manager behavior).
- Defining these behaviors, processes, and conditions precisely enough to measure them.
- Implementing procedures to reliably measure the behaviors, processes, and conditions to

determine their current status and setting reasonable goals for their improvement.
- Providing feedback.
- Reinforcing progress.

In table 6 is shown a sample for Site Preparation and Assessment.

Table 6: Site Preparation and Assessment

Pre visit – Preparation activities	
1. Organization review	Site coordinator
Organization chart	
Number of employees	
Interview planning and scheduling	
….	
2. Document (injury/incident)	BBS internal consultant
Incident report (for past 3-5 years)	
Precaution worksheet analysis	
…..	
Visit Activity	
3. Interviews	BBS internal consultant
Manager	
Employees in group	
…..	
4. Perception surveys	BBS internal consultant
Results	
…	
5. Safety program review	BBS internal consultant
System review	
Conditions review	
Behavior review	
6. Steering team development	
7. Management briefing	BBS internal consultant

In Figure 6 (Appendix A) is shown Behavior Based Safety Process adopted.

To begin, we held a 'lessons learnt' review exercise of different Behavioral Safety processes operated by some of the different contractors. From this a process was developed that would build on the positives and address the areas of opportunity identified (one of the major findings was a lack of managerial support built in to the process).

This resulted in a planned sebuential roll-out of the Behavioral Safety process across all the contractors, with planned milestones for achievement for each individual contractor. One hour briefings were held with the management of all the contractors.

Broadly, the time-frame of the Behavioral Safety rollout and execution activities were (see Table 7):

Table 7: BBS time frame

Description	
Trained Project coordinators	Five days
Developed Behavioral Checklists	4 weeks.
Conducted Managerial Alignment Sessions to obtain commitment	6 weeks (at 2 hour sessions)
Trained employees	1 year
Established Baseline performance	1st four weeks of observations
Set work crew improvement targets	Determined by Baseline Scores
Gave feedback	Daily (verbal) / Weekly(written) / monthly Managerial Summaries.
Developed Publicity Infrastructure	Developed Behavioral Safety Site Induction package / Posters/ Newsletters, etc.
Reviewed Process and adapted according to the construction program	Changed checklists to suit and Construction program trained new observers.

A comprehensive training document outlining roles & responsibilities, implementation activities and a planned implementation schedule was developed and provided to the main contractor and all sub-contractors to help facilitate self-sufficiency in the training of project administrators and observers. The number of the various checklists returned and corrective actions completed (in 1 year) were as follows:

- Safety Behavior Observations = 450;
- Senior Managers Leadership Checklists = 145,
- Middle Managers Leadership Checklists = 250;
- Corrective Actions Completed = 170.

4. CONCLUSIONS

We can conclude this work with following observations and considerations. Important for the selection of a tunnel safety assessment method is the level of detail in the available input for the method. Once the tunnel has been taken in operation an assessment of the safety performance is necessary periodically. In a periodic safety evaluation the following methods or tools could be used:

- Checklists;
- Casuistry: for existing tunnels during operation all serious accidents should be evaluated.

- Inspections;
- Audits.

This study provides a guidelines regarding the impact that management Safety Leadership exerts on employee safety behavior.

We can summarize our work considering “technical” results and “management” results.

As regards the first point results are:

1. Identification of value of Total and Individual Risk Level for the railway tunnel “type”.
2. Definition of MTBCF and MTTR.
3. Definition of Mean Time Between Critical Failures for Lighting and power system.

As regards the second point we proposed an approach based on BBS in order to improve risk analysis and safety in railway tunnel.

We can note that:

1. The behavior model is not complicated, its’ application in a company does not require a new organization chart or structure.
2. The behavior model and a BBS process can be integrated with existing structures, organizations, procedures, safety and health programs.
3. The BBS programs often improve safety, in the short term, because nothing else was being done before.

Behavior-based safety training and implementation helps improve organizational safety culture. By increasing the quality and frequency of safety feedback in the organization, barriers between employees both within and across organizational levels are reduced. Improving safety communication (both correcting and rewarding feedback) through BBS leads to a more open, positive, and trusting safety culture as well as improved safety performance.

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APPENDIX A

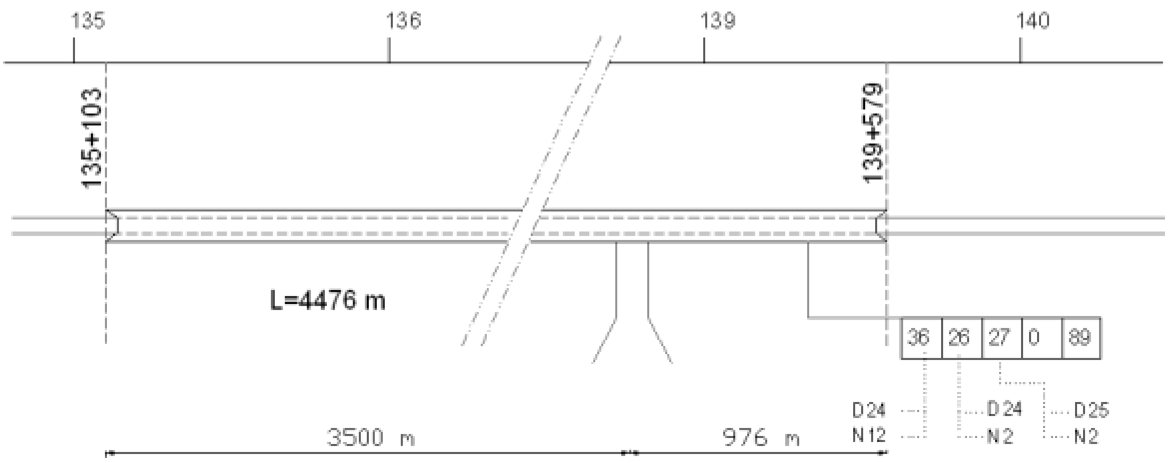

Figure 2: Diagram of the tunnel

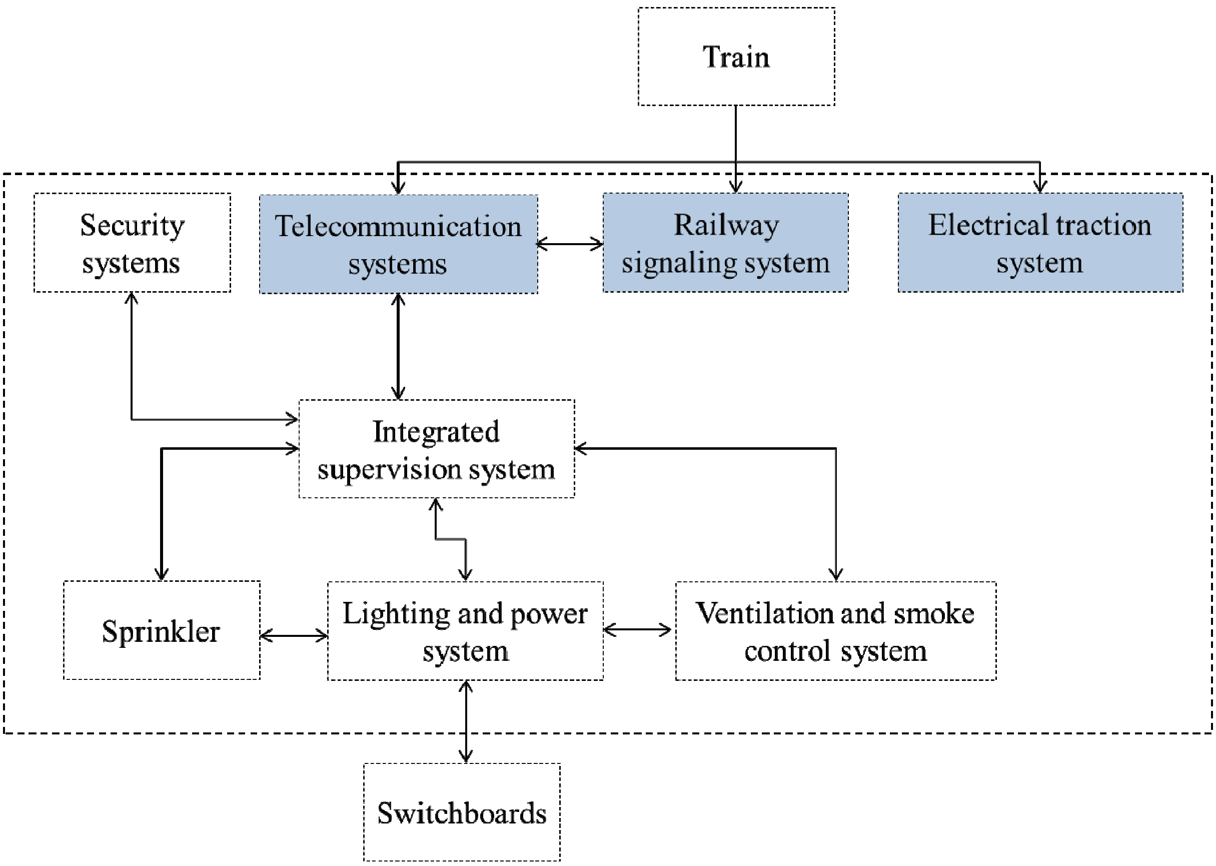

Figure 3: Systems installed

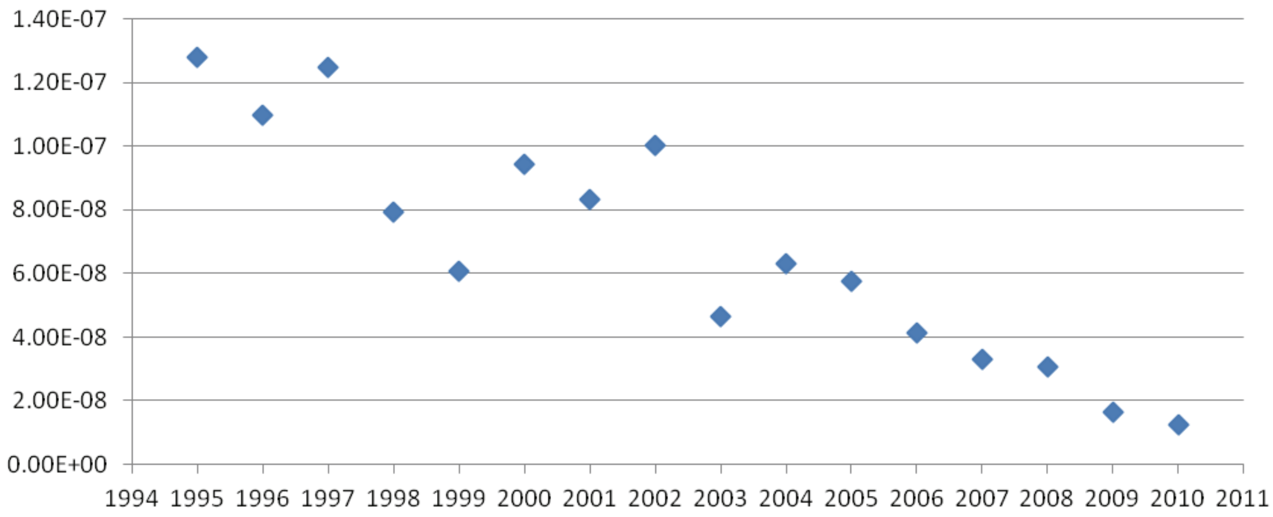

Figure 4: Accidents in circulation

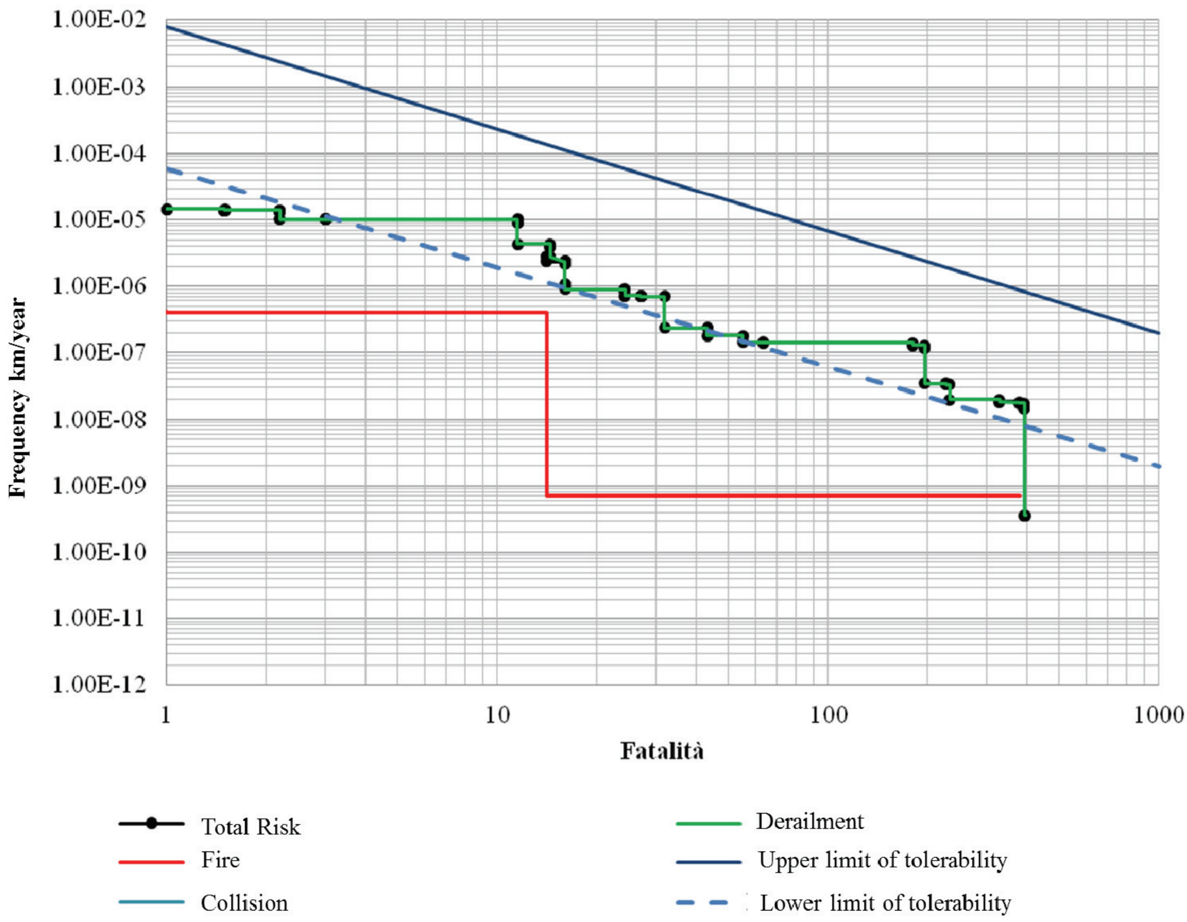

Figure 5: Level of Risk

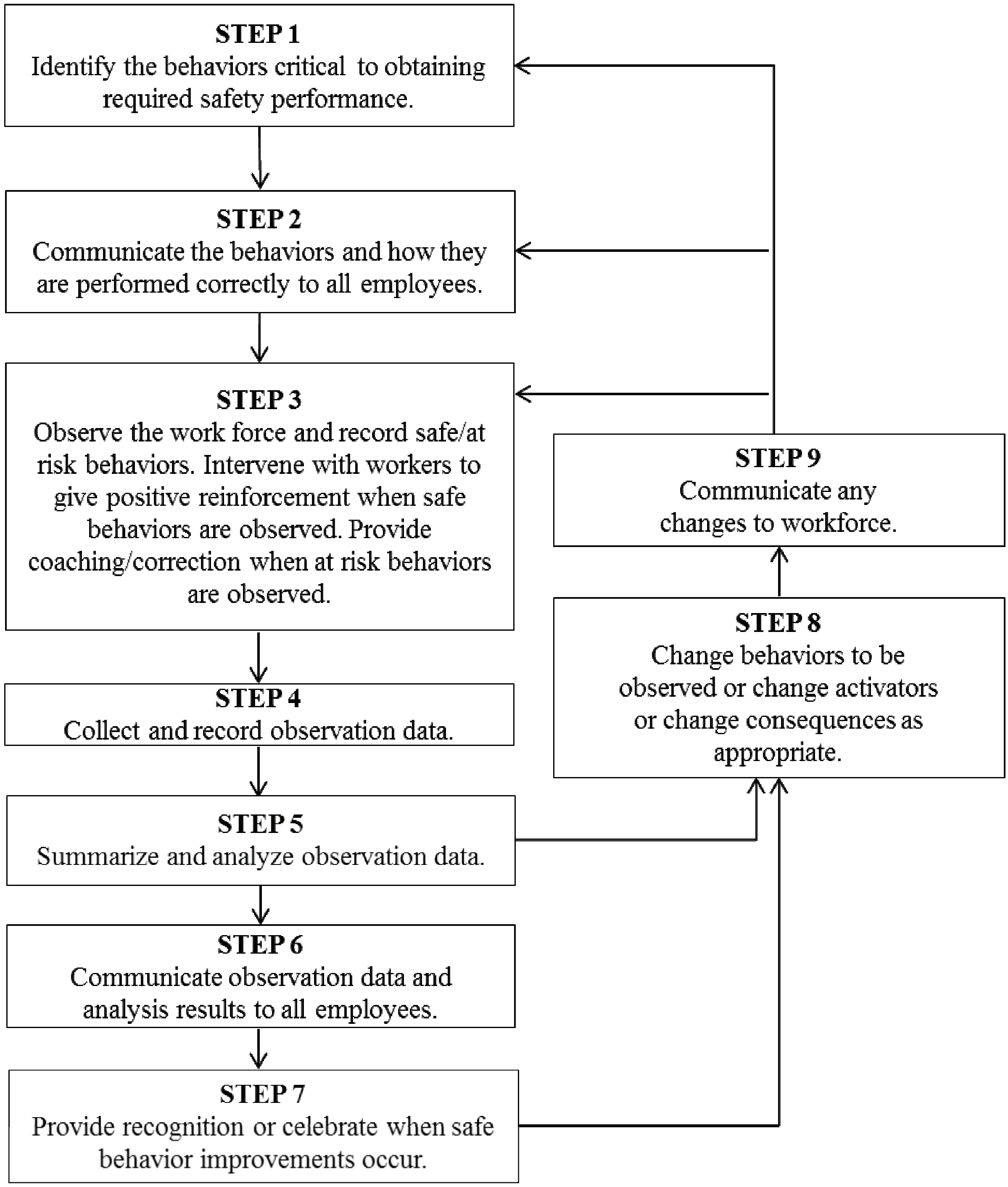

Figure 6: Behavior Based Safety Process

APPENDIX B

Table 2: Derailment causes

Derailment causes				
Type of train:	*Passenger train*	*Goods trains*	*Not Specified*	
Human Error				***49.0%***
Failure or incorrect compliance with the regulations	10	13	3	16.6%
Failure or incorrect compliance with the requirements movement/ techniques	2	3	0	3.2%
Irregular movements of maneuver	7	30	2	24.8%
Failure of the stop signal	1	3	0	2.5%
Incorrect preparation of itinerary/routing	1	0	0	0.6%
Exceeding speed limit	2	0	0	1.3%
Staff not attentive	0	0	0	0.0%
Technical Errors				***34.4%***
Infrastructure				***17.2%***
Irregularities in the infrastructure (track / catch / portals)	6	1	2	5.7%
The track geometry irregularities (bumps / slineamento / rail route) or headquarters / infrastructure	9	9	0	11.5%
Train, locomotives, passenger coaches, etc				***17.2%***
Defective or worn mechanical / electrical	3	10	0	8.3%
Containers / containers / tanks circulating iron with defects in the structures or components	0	2	0	1.3%
Hotbox	1	0	0	0.6%
Load non-compliant (displaced / excessive weight / sore broken)	0	5	0	3.2%
Loss of components	2	3	0	3.2%
Breaking the coupling means	0	1	0	0.6%
Causes external to the rail system				***9.6%***
Landslide / boulders / trees bulky	1	0	0	0.6%
Abnormalities for external event	6	4	0	6.4%
Vandalism	1	0	1	1.3%
Abnormalities on the teams / work sites	1	0	1	1.3%
Other causes				***0.6%***
Obstacles	1	0	0	0.6%
Not determined causes				***6.4%***
	0	9	1	6.4%

Table 5: A comparison between hardware and human reliability

Category	Hardware	Human reliability	
		Discrete task	Continuous task
System definition	A set of component which perform their intended functions	A task which consists of several human behavioral units	Continuous control task such as vigilance, tracking, and stabilizing
System configuration	Functional relationship of components	Relationships of behavior units for given task (task taxonomy)	Not necessary to define function relationships between the task units
System failure analysis	Fault tree analysis	Human error categorization: derivation of a mutually exclusive and exhaustive set of human errors for a given task	Binary error logic for continuous system response
Nature of failure	Mostly binary failure logic Multi dimensionality of failure Common cause failure	Sometimes hard to apply binary error logic to human action Multi dimensionality of error Common cause error Error correction	Same as discrete task
Cause of failure	Most hardware failures are explained by the laws of physics and chemistry	No well codified laws which are generally accepted as explanations of human errors	Some as discrete task
System reliability evaluation	With probabilistic treatments of failure logic and statistical independence assumption between components, mathematical models are derived In case of network reliability and phases mission reliability, which require statistical dependency between components, it is hard to evaluate exact system reliability	Very difficult because of problems in depicting the functional relationships between human behavioral units	With probabilistic treatments of binary error logic for system response, stochastic model are derived
Data	The data base for most types of machines is relatively large and robust compared to human reliability	No trustworthy and useful data base exists for human behavior units Largely depends on the judgment of experts	Some as discrete task