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# The Application of Common Safety Method to Evaluate Migration to Autonomous Railway Operation - Discussion

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## Abstract

A major difficulty in traditional finite element analysis is the effort to integrate complex three-dimensional solids and structures. The inherent reason for the difficulty is that highly distorted elements should be avoided. This condition is difficult to satisfy because the traditional elements must abut each other, that is, they cannot overlap. To overcome this restriction, we have developed ’overlapping elements’. These elements perform well even when highly distorted, and hence can be used much more easily in meshing a complex domain. However, they use additional nodal degrees of freedom, which add to the computational effort of solution. To reduce the overall solution cost, including the meshing, we focus on the AMORE scheme in which traditional undistorted elements are used to discretize most of the analysis domain and overlapping elements are used for the rest of the domain. The premise is that, in this way, the meshing effort is much reduced and the computational effort is also less than in a traditional finite element analysis. In this way, the use of AMORE leads to an overall efficient modern finite element analysis.

**Keywords:** common safety method, autonomous railway, safety, automated train operation, discussion paper, Europe rail.

# 1 Introduction

Although significant progress has been made in the field of automatization of the car driving process and multiple producers are now boasting of an automation level of 3 or even 4, autonomous train operation remains limited to the subway and special railways. The transition from standard railway operations to autonomous train systems represents a significant advancement in the transportation sector that promises to enhance safety, efficiency, and reliability. This shift is driven by the convergence of various technological innovations, including advances in artificial intelligence (AI), machine learning, and sensor technologies. Automated Train Protection (ATP), Autonomous Train Operations (ATO), and Perception systems (PER) leverage these technologies to enable trains to operate without direct human intervention, thus minimizing human error, optimizing scheduling, and improving energy efficiency.

The concept of autonomous trains is not entirely new; it has been explored for several decades, particularly in urban rail transit systems. However, recent technological developments have accelerated the potential for broader implementation across different rail systems, including freight and long-distance passenger services. The primary motivation behind this transition is the need to address the growing demand for higher capacity, better punctuality, and improved safety in rail operations. According to a report by the International Association of Public Transport (UITP), the adoption of autonomous systems can reduce operational costs by up to 30% while simultaneously increasing network capacity by 20% [3].

Several pilot projects and fully operational autonomous rail systems already exist globally. For example, the Santiago Metro in Chile and the Copenhagen Metro have successfully implemented ATO in their operations, demonstrating significant improvements in service reliability and efficiency [2]. Nevertheless, all of these, safety wise rely significantly on separated tracks from built-in environment (metro tunnels, overground monorail in Japan, and fences alongside rails in overground lightrail and metro or others). In addition, the European Union's Shift2Rail initiative is heavily investing in research and development to foster the integration of autonomous technologies within the rail sector [6].

Despite promising prospects, migration from standard railway to autonomous train operations poses several challenges. These include the need for substantial investments in infrastructure, regulatory adjustments, public acceptance, and safety analysis of new operational concept. Safety remains a paramount concern, necessitating rigorous testing and validation of autonomous systems to ensure that they meet the stringent safety standards of traditional rail operations. In addition, the transition period can involve complex integration of new technologies with existing systems, requiring robust cybersecurity measures to protect against potential threats. The safety of the whole railway system with regard to automation of its operation and processes is the topic of this paper. In the following chapters, expectations regarding architectural, systematic, operational and functional changes resulting from automation and digitization of the railway will be presented, and the capability of the CSM method will be discussed as a potential tool to analyze the influence of these systems on overall system performance.

## 2 Upcoming changes in functionality and responsibility of train operation

The automation of railway systems promises numerous benefits, including increased safety, improved efficiency, increased capacity, and reduced operational costs. This section explores these expected benefits in detail and outlines key performance indicators (KPIs) that can be used to measure the success of rail automation initiatives. These were already estimated in previous studies, as well as stated as expectations in projects such as Shift2Rail [6] and its continuation Europe's Rail [7]. In the newest undertaking of Europe's Rail Consortium, and impressive budget of over 160m of Euro is allocated to develop digitalized up to autonomous railway.

Automation minimizes the risk of accidents caused by human error, a significant factor in railway accidents. Automated systems maintain consistent operational standards, adhering strictly to safety protocols, and reducing variability. In addition, real-time monitoring and diagnostic systems can detect and address potential issues before they escalate to critical problems, significantly improving overall safety. According to a study by UITP, automation in metro systems has been shown to reduce safety incidents by up to 50% [3]. In terms of efficiency, autonomous train operations can optimize scheduling to reduce waiting times and improve service frequency. These systems employ regenerative braking and optimal speed profiles to reduce energy consumption, leading to notable energy efficiency. In addition, automated operations can minimize station dwell time, further enhancing network efficiency. Hansen [2] highlights that autonomous train systems can reduce energy consumption by approximately 15-20%.

However, in order to achieve these benefits, significant changes in the current railway architecture are needed. Considering these, we can identify progressive grades of automation (GoA). These steps increasing automation of train movement are specified in the international standard EN 62267 [4] and EN 62290-1:2014 [5].

Figure 1 presents a simplified distinction of the main functionalities of operating train. As can be seen, the least distinctive change is occurring during the shift from GoA 3 to 4. The change here is "only" in the presence and responsibilities of the train attendant who is responsible for closing/opening the door and permitting the departure from station. In this regard, this change is purely operational and therefore may be omitted in the safety analysis performed in this document. In general, in addition to conventional command control and signalling (CCS) systems like interlocking, signalling, and European Train Control System (ETCS) 3 main components need to be added in order to provide automatization of train movement. The first such component is Automation Driving Module (ADM) also known as Automated Train Operation (ATO). In the latest TSI [1] it is defined as ATO over ETCS, and in this context train-

**Grades of automation**
as in EN 62267:2010, EN62290-1:2014

| Basic functions of train operation | | On-sight train operation | Non-automated train operation | Semi automated train operation | Driverless train operation | Unattended train operation |
|---|---|---|---|---|---|---|
| | | TOS | NTO | STO | DTO | UTO |
| | | GOA0 | GOA1 | GOA2 | GOA3 | GOA4 |
| Ensuring safe movement of trains | Ensure safe route | X (points command/ control in system) | S | S | S | S |
| | Ensure safe separation of trains | X | S | S | S | S |
| | Ensure safe speed | X | X (partly supervised by system) | S | S | S |
| Driving | Control acceleration and braking | X | X | S | S | S |
| Supervising guideway | Prevent collision with obstacles | X | X | X | S | S |
| | Prevent collision with persons on tracks | X | X | X | S | S |
| Supervising passenger transfer | Control passengers doors | X | X | X | X or S | S |
| | Prevent person injuries between cars or between platform and train | X | X | X | X or S | S |
| | Ensure safe starting conditions | X | X | X | X or S | S |
| Operating a train | Set in/set off operation | X | X | X | X | S |
| | Supervise the status of the train | X | X | X | X | S |
| Ensuring detection and management of emergency situations | Perform train diagnostic, detect fire/smoke and detect derailment, handle emergency situations (call/evacuation, supervision) | X | X | X | X | S and/or staff in OCC |

X = responsibility of operations staff (may be realised by technical system)
S = realised by technical system

Figure 1: Grades of Automation as specified in the International Standard EN 62267:2010 and EN 62290-1:2014, In colors we define responsibilities of newly developed systems; red - Automation functions module; Blue - perception; Green - Automation Driving Module

borne ATO technologies refer to functions required in GoA2 up to GoA4 (STO/UTO) systems and provide traction and braking control to obtain punctuality according to Journey Profile and optimization of energy consumption as well. Specifically, their (ATO) functionalities are related to processing profile of set track segments, stop the train at requested places and times, and optimize energy consumption.

# 3 Common Safety Methodology for risk valuation and assessment in accordance with Commission Implementing Regulation (EU) No 402/2013

When introducing changes to the trans-European railway system or one of its subsystems, the Infrastructure Manager is obliged to ensure that the introduced changes do not at least impair its safety level. Similarly, manufacturers who offer structures or devices intended for railway traffic by making changes to the types of devices and structures already approved for use are also responsible for ensuring compliance with the type so as not to affect the safety of these products. In both cases, a helpful tool enabling the fulfillment of these obligations by both Manufacturers of structures and equipment and Infrastructure Managers is the implementing regulation of the European Commission on the common safety assessment method, commonly known as the " four hundred and two ", and hereinafter also referred to as the "regulation".

According to the evaluation methodology included in the *regulation 402* In the first step, the entity introducing the changes should determine whether they affect the safety of the system, subsystem, device or structure. Decisions in this regard are made on the basis of the so-called professional judgment, which is not defined in the regulation itself, but is referred to many times in its content. Therefore, it seems crucial to properly define the "professional judgment" by the entity introducing changes.

In terms of determining the impact of the change on safety, there are two possible answers: yes or no, where in the case of the second answer, the process ends with determining the lack of impact of the change on safety. If, based on professional judgment, the entity introducing the change determines its impact on safety, then in the next step it should also be decided based on professional judgment whether the proposed change is a significant change. When deciding on the importance of a change, it should be related to the following six criteria: effects of failure, innovation, complexity of the change, monitoring, reversibility, and additionality. Fortunately, words come to our aid in correctly understanding these criteria. 2 of Article 4 of the Regulation, where we will find helpful definitions of each of these criteria. After considering the change introduced in accordance with the above-mentioned criteria, it is time to decide whether, in their light, the change should be considered significant. As in the first step of the procedure, two decisions are possible: the change is significant or the change is insignificant. In the second case, when the change is insignificant, the person making the change keeps appropriate documentation justifying such a decision, and this ends the process.

If the change is significant, the person introducing the change is obliged to carry out the risk management process, which is specified in Annex I to the regulation. Due to the complexity of this process, the authors will not describe it in detail, but it should be noted that if it is necessary to apply a risk management process, its implementation alone is not sufficient to successfully complete the change implementation process. If, after carrying out the risk management process, changes are made, the process must be assessed by an inspection body, which will confirm or question whether the process was carried out correctly in a report. Only a report confirming the correctness of the risk management process allows for correct and safe changes to be introduced in the trans-European railway system, its subsystem, or a single structure or device. The complexity of the risk management and assessment process is presented in Figure 1 taken from the appendix of the regulation.

# 4 Conclusions

The shift to autonomous train operations presents challenges and opportunities. The Common Safety Method (CSM) for risk evaluation offers a structured approach to maintaining safety standards. Provides a framework for identifying, evaluating, and mitigating risks associated with new railway technologies, including changes in a whole system. The CSM, according to the European Commission Regulation (EU) No 402/2013, standardizes risk assessment, helping regulatory approvals.

Integrating technologies such as automated train protection (ATP) and autonomous train operations (ATO) is complex. The CSM manages this with a step-by-step process, identifying critical points and potential failures, including their consequences. Despite substantial initial investments, long-term benefits include reduced operational costs and increased efficiency. The CSM ensures these benefits without compromising safety.

The CSM fosters continuous monitoring and improvement and promptly addresses new risks. This fosters a culture of safety and innovation, ensuring that new risks are promptly addressed and best practices are updated. This proactive approach is crucial for the evolving nature of autonomous technologies. Successful implementations, such as the Santiago and Copenhagen metros, demonstrate automation benefits, highlighting it as a clear way forward in railway technologies.

In conclusion, applying the Common Safety Method to railway automation is not only feasible but also highly advantageous. It ensures a safe, efficient, and regulatory-compliant transition to autonomous operations. By managing risks, facilitating integration, and promoting continuous improvement, CSM is essential to modernize rail systems and realize the potential of autonomous train operations. Therefore, future academic investigation of the topic is needed to identify reach and widely understood impact of individual automatization systems, which take over responsibility for the functions provided by train drivers nowadays on the exploitation of railway system.

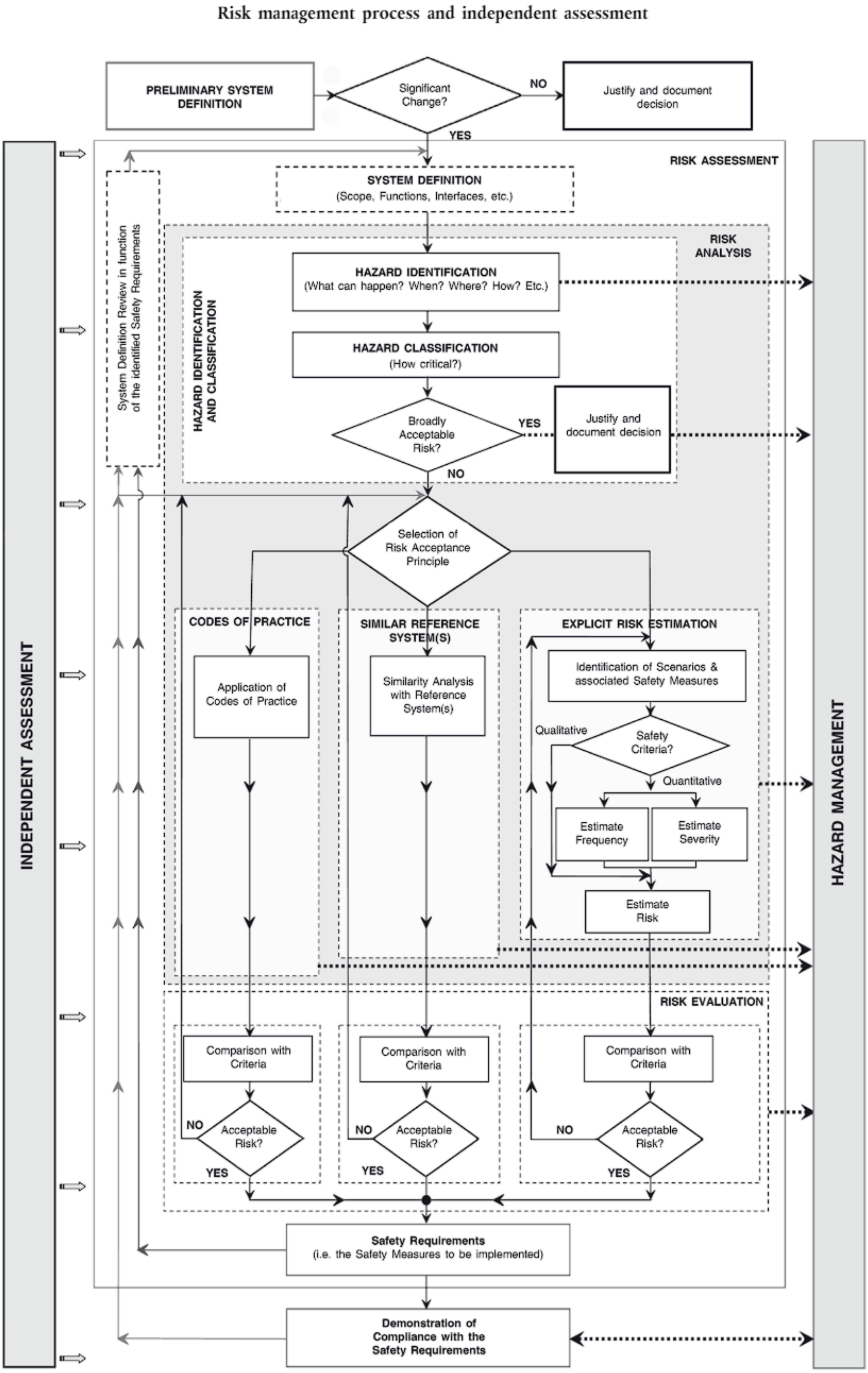


Figure 2: Process of risk management and independent assessment

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