



COSYS Department ESTAS laboratory newsletter

November 2024

COSYS Department

Components & Systems

Évaluation des
Systèmes de
Transports
Automatisés et de leur
Sécurité

estas.univ-gustave-eiffel.fr

In this edition

Editorial by the director

State of the art for the formal verification of Artificial Intelligence

SORTEDMobility: Self-organization applied to railway traffic management

News & events

New projects

End of projects

Joining

Scientific events

Awards

New PhDs

Editorial by the director

In this issue, we give an overview of our ongoing work as part of the CERTIFER GAPAVE 'Railway Safety' chair, focusing on the contribution of formal methods to the evaluation of AI based modules. We are also proud to share the results of the European SORTEDMobility project, which explores self-organising solutions for rail traffic and opens up new prospects for sustainable mobility. Two new projects, TravelWise (European) and RITMEA (regional), involving the Estas laboratory and which have just started, will also be presented, in addition to the SORTEDMobility project (European) which has just ended.

This quarter, our laboratory has been enriched by new talent, with a new researcher (CR) joining the rail traffic management team. Still in the News section, various other items are mentioned. These include scientific events in which the laboratory staff have taken part, recent PhD thesis and HDR defences, the start of a new PhD thesis, and a list of new publications. Finally, recent prizes awarded to two of the laboratory's researchers are listed.

We hope you enjoy reading our information letter. Please do not hesitate to contact the referees indicated for further details.

[Mohamed Ghazel](#), Director of ESTAS

State of the art for the formal verification of Artificial Intelligence (AI)

Formal methods are nowadays strongly recommended by railway standards for safety-related applications, in particular in CENELEC 50128. However, the desire in recent projects on autonomous trains to introduce artificial intelligence-based functions creates new problems for the train's safety evaluation due to the highly opaque internal behavior of AI functions. Within the CERTIFER GAPAVE Chair on "Safety of

HDR defense

PhD defenses

Publications

railway systems", we are thus working on reviewing the state of the art in terms of formal methods to verify and guarantee the safety of AI modules. Our work is primarily focused on AI modules modelled by neural networks and for perception tasks (object detection and classification), our objective is to identify the strength and weaknesses of these formal methods in view of their potential use within railway applications.



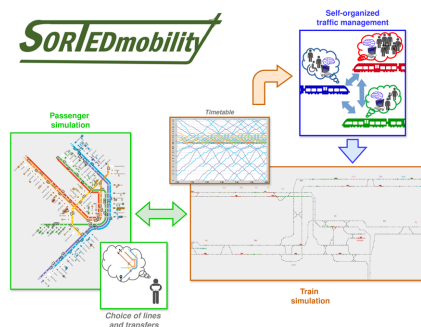
Image-based object detection in a train's surroundings. [Source: Open Sensor Data for Rail 2023.](#)

Contact: [Pierre-Jean Meyer](#)

SORTEDMobility: Self-organization applied to railway traffic management

The European Horizon 2020 project SORTEDMobility explores an innovative approach to railway traffic management based on self-organization. This initiative proposes a decentralized model where intelligent trains operate autonomously and in coordination, offering increased flexibility in the face of demand variations and disruptions. To evaluate its effectiveness, the project relies on three representative case studies: a low-traffic line with light trains in France (Guingamp-Paimpol), a conventional mixed-traffic network in Italy (Pioltello-Rovato) and a dense urban network in Denmark (Copenhagen). An advanced simulation platform has been developed, simultaneously integrating train movements, passenger flows, and all decision-making processes. This platform allows for an in-depth comparison of the performance of the self-organized system against traditional management methods. These initial results reveal that self-organizing railway traffic could be a viable option, showing performance at least equivalent to that of optimized centralized management. However, this approach would require significant regulatory and contractual changes.

[More](#)



Platform deployed for self-organized traffic evaluation.

Contact: [Grégory Marlière](#)

News and events

New projects

TravelWise (project as part of the Horizon Europe programme)

Estas takes part in the TravelWise project. The project will leverage the

full advantages of digitalization, establish a roadmap for a unified air-rail data space, expand the collaborative decision-making process to include multimodal transport, and create integrated operational plans. Additionally, it will design, develop, implement, and validate technical solutions for managing air-rail traffic in both nominal and non-nominal situations. 34 partners are involved. The aviation sector is mainly represented by Eurocontrol, l'ENAC and Brussels, Paris, Athens, Amsterdam and Bologna airports. The rail sector is represented by SNCF, Eurostar, Prorail, FS, EURNEX and Railenium, among others.

Contact: [Joaquin Rodriguez](#)

RITMEA

The RITMEA "Research and Innovation in Eco-responsible and Autonomous Transport and Mobility" project submitted to the 2021-2027 CPER for the Hauts-de-France region is a continuation of the momentum generated by previous major CPER projects, namely the CISIT project (2007-2014), the ELSAT 2020, COPROP and SysMIA projects (2015-2020). RITMEA, which brings together 350 researchers in the region, aims to :

- Achieve scientific objectives linked to the work carried out within the FR CNRS TTM*. The aim is to develop models, methods, techniques and tools to improve transport systems in the broadest sense, in terms of both vehicles and infrastructure, and also to rationalise their use to achieve greater efficiency, savings and less environmental impact by improving the supply chain, modal shift and studying the social and economic impacts,
- Structuring regional research in a major economical sector by making it more efficient, in particular through the acquisition and development of medium-heavy technological resources shared between academic partners and with industrial partners,
- Strengthen the region's international profile and technology transfer on the theme of transport and mobility, through collaboration between academics and industry, by means of contracts, CIFRE PhD theses, and setting up start-ups using facilities such as Euratechnologies, Eurasanté or Transalley.

As part of RITMEA, Estas researchers will continue to develop their techniques for monitoring and controlling critical C/C systems based on discrete event models, with applications to railway control and signalling systems. The work carried out by Estas focuses in particular on issues relating to diagnosis, prognosis and opacity.

* *Fédération de Recherche Transports Terrestres Mobilité*

Contact: [Mohamed Ghazel](#)

End of projects

SORTEDMobility

The SORTEDMobility project came to a successful conclusion in May, as demonstrated by the closing event held on 13 May 2024 at the SNCF (see [link](#)). The event provided an opportunity to present the results of the work carried out during the project. All the presentations are available [here](#). A paragraph at the beginning of this newsletter: SORTEDMobility: Self-organisation applied to rail traffic management'is also dedicated to the project.

Contact: [Paola Pellegrini](#)

A new researcher joins the "Exploitation and Intermodality" team

Bianca Pascariu joined the laboratory on October 1st 2024 as researcher of the "Exploitation and Intermodality" team. Her scientific activities focus on railway traffic management optimization, with a more specific focus on solving real-time railway traffic control by developing and applying state-of-the-art techniques.

Scientific events

ROADEF 2024 - 25ème congrès de la Société Française de Recherche Opérationnelle et d'Aide à la Décision - Amiens, France - 4th to 7th March 2024

- [Real-time railway traffic management with demand prediction: formulation and solution approach](#), **Pascariu B.**, Flensburg J.V., **Pellegrini P.** & Lima Azevedo C.M.
- [Estimation du temps d'arrêt minimal en gare pour la régulation du trafic ferroviaire en temps réel](#), **Zidani M.**, **Pellegrini P.**, **Rodriguez J.**, Côme E. & Barbarino G.

TRA 2024 - Transport Research Arena - Dublin, Irlande - 15th to 18th April 2024

- A methodology for Elicitation of Safety Requirements of Artificial Intelligence based Functions in Railways, **Mahtani A.**, **Sassi I.**, **Himrane O.**, **Bousif A.**
- Simulation based infrastructure critical boundary identification for multi-modal transport hubs, **Collart-Dutilleul S.**, **Bon P.**, **Laubrock M.**, **Mykonyatis G.**
- GNSS-based performance rules and Railway operating, **Marais M.**, **Collart-Dutilleul S.**, **Bon P.**
- MBSE Approach for Railway Digital Continuity, **Debbech S.**, **Collart-Dutilleul S.**, **Bon P.**
- MagRail technologies to secure heavy freight activities in alpine mountains: a driverless perspective, **Collart-Dutilleul S.**, **Koniarski K.**

CAFMET 2024 - International Conference of Metrology - Marrakech, Morocco - 24th April 2024

- Defining safety for autonomous vehicles: challenges and solutions in high-level autonomous vehicle standards, **Chelouati M.**, **Meyer P-J.**, **El Koursi E-M.**

17th IFAC Workshop on Discrete Event Systems - Rio de Janeiro, Brazil - 29th April to 1st May 2024

- An Efficient Algorithm for K-Diagnosability Analysis of Bounded and Unbounded Petri Nets, **Chouchane A.**, **Ghazel M.**

ICCAD 2024 - International Conference on Control, Automation and Diagnosis - Paris, France - 15th to 17th May 2024

- Maintenance dynamic scheduling for a Tunisian railway transport

system, International Conference on Control, Mellouli S., M'halla A., H, **Collart-Dutilleul S.**, Messaoud H.

ICECCS 2024 - 28th International Conference on Engineering of Complex Computer Systems - Limassol, Cyprus - 19th to 21th June 2024

- An Iterative Formal Model-Driven Approach to Railway Systems Validation, Yar A., Idani A., Ledru Y., **Collart-Dutilleul S.**, Mammam A., Vega G.

Journée d'étude Mobilités actives et numérique - Bruxelles, Belgium - 25th June 2024

- Accompagner le changement de mobilité en combinant les méthodes de la psycho-ergonomie à l'utilisation de l'application GPS TravelVu : étude expérimentale sur la commune de Loos-en-Gohelle, **Batistatou, A.**, **Cuvelier, M.**, Mathon, G., Gabaude, C.

Webinaire du CEREMA consacré aux questions de participation des habitants aux projets de mobilité, 25th June 2024

- Participation et sensibilisation : l'exemple de Loos-en-Gohelle, **Cuvelier, M.**, Gabaude, C., **Batistatou, A.**

Euro 2024 - Copenhague, Denmark - 30th June to 3rd July 2024

- A novel and effective integer linear programming formulation for the train routing selection problem, Croella, A.L., Furini F., Ljubic I., **Pascariu B.**, **Pellegrini P.** & San Segundo P.
- Realistic assessment of rail traffic management optimization: a demand-supply simulation framework, Flensburg J.V., **Pascariu B.**, **Marlière G.**, Sfeir G., **Naldini F.**, Rodrigues F., **Pellegrini P.** & Lima Azevedo C.M.
- Track discretisation in railway traffic rescheduling models for next-generation distance-to-go signalling, Versluis N.D., **Pellegrini P.**, Quaglietta E., Goverde R.M.P. & **Rodriguez J.**

CoDIT'2024 : 10th International Conference on Control, Decision and Information - Lalette, Malte, 1st to 04th July 2024

- An Algebraic Formulation of K-step Opacity Problem in Labeled Petri Net Models, **Chouchane A.**, **Ghazel M.**

ODS 2024 - International Conference on Optimization and Decision Science - Badesi, Sardegna - 8th to 12th September 2024

- [A new model for the train routing selection problem](#), Croella, A.L., Furini F., Ljubic I., **Pascariu B.**, **Pellegrini P.** & San Segundo P.
- [Stop-skipping to reduce delays in train rescheduling](#), Di Cola S., **Pascariu B.**, **Pellegrini P.** & Cacchiani V.
- [Integrated demand and supply simulation for realistic assessment of rail traffic management optimization](#), **Pascariu B.**, **Marlière G.**, Sfeir G., Flensburg J.V., **Naldini F.**, Rodrigues F., **Pellegrini P.** & Lima Azevedo C.M.
- [The impact of track discretisation in rescheduling models for advanced distance-to-go railway signalling](#), Versluis N.D., **Pellegrini P.**, Quaglietta E., Goverde R.M.P. & **Rodriguez J.**
- [Hybrid OR-AI algorithms for Railway Traffic](#)

[Management](#), Pellegrini P.

λμ24 - Congrès Lambda Mu - Bourges, France - 14th to 17th October 2024

- Quel rôle pour la SOTIF (ISO 21448:2022) dans la démonstration de sécurité des trains autonomes ?, Himrane O., Tonk A.& **Boussif A.**
- Une approche orientée risques pour la prise de décision dans les trains autonomes : Cas de la fonction anti-collision, **Chelouati M., Boussif A., Beugin J., El Koursi E-M.**

VECoS 2024 - 17th international conference on verification and evaluation of computer and communication systems - Djerba, Tunisia - 15th to 18th October 2024

- ERTMS/ETCS L3: Usable Formal Models for the "Loss of Train Integrity" Operation Scenario, **Saddem-Yagoubi R., Beugin J., Ghazel M.**
- A High Parallelization Method for Automated Formal Verification of Deep Neural Networks, Ben Hafaiedh I., **Chouchane A., Elaoud A., Lamouchi L., Ghazel M.**
- Monitoring of Neural Network Classifiers using Neuron Activation Paths, **Boudardara F., Boussif A., Meyer P.-J., Ghazel M.**

ISOLA 2024 - 12 th International Symposium on Leveraging Applications of Formal Methods - Crète, Grèce - 24 au 31 octobre 2024

- [Securing automatic small railway vehicles using Automatic Train Protection](#), **Collart-Dutilleul S., Bon P., Laleau R.**

Awards

- **IMdR award**

Mohammed Chelouati was awarded for the best PhD project at the λμ LambdaMu Congress of the IMdR - Institut pour la Maîtrise des Risques - for his PhD work supervised by three Estas researchers: Abderraouf Boussif, Julie Beugin and El-Miloudi El Koursi. See 'PhD defenses' below.

Contact: [Abderraouf Boussif](#)

- **IFAC award**

The 2024 "Service" Award was awarded by the French committee of IFAC (International Federation of Automatic Control) to **Mohamed Ghazel**.

Contact : [Mohamed Ghazel](#)

New PhD

Start of the Cheng Bai's PhD in July 2024 for 3 years on : Machine Learning Supporting Mathematical Optimization in real-time Railway

Traffic Management

Dense railway traffic requires efficient tools for real-time traffic management, which are responsible to mitigate the spread of delays after disturbances or disruptions. The current state-of-the-art algorithms are hardly able to solve realistic large-scale problems in real time. Cheng Bai's PhD will focus on the use AI-based methods (Artificial Intelligence) to support the solution of mathematical mixed-integer (MILP) models for real-time railway traffic management. This will combine the speed of the AI methods with the guaranteed quality bounds obtained from the mathematical models and the branch-and-bound framework used to solve them in a classical way. Cheng Bai will investigate and analyze different ways to adapt machine learning architectures and introduce new features used in MILP solvers to fit the specific structures of the problem.

Contact: [Paola Pellegrini](#)

Habilitation to supervise research

Julie Beugin defended her Habilitation to supervise research (HDR) on November 14th 2024. Her work is entitled "Contributions to the Safety Activities of Railway Critical Complex Systems – Advanced Control-Command Systems Context".

The evolution of railway control-command systems, designed to manage rail traffic in an optimized and safe manner, represents a significant lever for increasing the supply of rail transport, thus contributing to the central challenge of decarbonizing our mobility. The technological changes in these systems enable more efficient train operations. However, they also raise questions about the safety measures and conditions that need to be adapted in response to the envisaged changes. Indeed, the increasing number of interconnected elements, mainly due to the integration of new technologies from the “digitalization” era, further increases the complexity of railway control-command systems. This broadens the scope of risk analysis for these critical systems, and raises questions about how to handle the numerous additional interactions brought about by these technologies, whether they are technical, functional, or dysfunctional in nature.

To ensure the safe use of wireless localization and communication technologies in advanced railway control-command systems, the research presented in this HDR thesis aims to contribute to various phases of the development process of these systems in terms of safety. The goal of our work is to adapt and enhance the current risk management processes to meet the challenges posed by the safe use of these technologies, while complying

with the European regulatory framework in this field. Thus, we have developed approaches to allocate safety targets at different levels of decomposition of advanced control-command systems, as well as approaches to demonstrate these targets on technical and operational levels, despite the uncertainties related to the occurrence of certain hazards, particularly those arising from the transmission of satellite signals.

These approaches represent original methodological means of safety engineering that can benefit various railway stakeholders (such as operators, manufacturers, and assessors) faced with the implementation of innovative operational principles using these technologies, such as those based on moving blocks. Additionally, the developed methodologies are also applicable to complex critical systems encountered in sectors other than railways.

Contact: [Julie Beugin](#)

PhD defenses

Mohammed Chelouati defended his thesis entitled "**Contribution to safety assurance of autonomous trains**" on June 05th 2024.

The deployment of autonomous trains raises many questions and challenges, particularly concerning the required safety level, which must be globally at least equivalent to that of the existing systems, along with how to achieve it. Conventionally, ensuring the safety of a global railway system or a defined subsystem includes analyzing risks and effectively handling dangerous situations. Therefore, for any technical railway system, whether it is conventional, automatic, or autonomous, an acceptable level of safety must be ensured. In the context of autonomous trains, safety challenges include aspects related to the use of artificial intelligence models, the transfer of tasks and responsibilities from the driver to automatic decision-making systems, and issues related to autonomy, such as mode transitions and management of degraded modes. Thus, the safety demonstration methodology for autonomous trains must take into account the risks generated by all these aspects. In other words, it must define all the safety activities (related to the introduction of autonomy and artificial intelligence systems), complementary to conventional safety demonstration.

In this context, this dissertation proposes three main contributions towards the development of a safety assurance methodology for autonomous trains. Firstly, we establish a high-level framework for structuring and presenting safety arguments for autonomous trains. This framework is based on a goal-based approach represented by the graphical modeling Goal Structuring Notation (GSN). Then, we propose a model for the situational awareness of the automated driving system of an autonomous train, that integrating the process of dynamic risk assessment. This model enables the automated driving system to perceive, understand, anticipate and adapt its behavior to unknown situations while making safe decisions. This model is illustrated through a case study related to the obstacle detection and avoidance. Finally, we develop a decision-making approach based on dynamic risk assessment. The approach is based on Partially Observable Markov Decision Processes (POMDP) and aims to ensure continuous environmental monitoring to guarantee operational safety, particularly collision prevention. The approach is based on maintaining an acceptable level of risk through continuous estimation and updating of the train's operational state and environmental perception data.

Bishal Sharma defended his thesis entitled "**Rescheduling and Rerouting of Connecting Trains after Perturbations**" on September 18th 2024.

This thesis addresses the real-time Railway Traffic Management Problem (rtRTMP), which involves adjusting train timetables during perturbations. Perturbations in railway networks often lead to significant delays, necessitating strategies to minimize their propagation. An important objective of traffic management is to facilitate passenger transfers through connecting trains, which may become difficult when traffic is disturbed. Pursuing this objective, the thesis focuses on mitigating train delays by reducing connection times during transfers without compromising connections. To achieve this, we extend an existing Mixed-Integer Linear Programming (MILP) formulation for the rtRTMP by introducing two alternative enhancements. Moreover, we pursue the same delay mitigation by extending an Ant Colony Optimization algorithm for the Train Routing Selection Problem (TRSP): this problem reduces the number of alternative

routes to be considered for trains, making rtRTMP instances tractable. We assess the efficiency of the proposed enhancements in reducing the total train delay while preserving passenger connections in multiple instances representing traffic in the Lille-Flandres station control area, located in the north of France. The results demonstrate that the integration of these enhancements, in both the TRSP and the rtRTMP, results in a significant reduction in delay propagation.

Publications in journals

Liang C., Ghazel M., Xie C., Zheng W., Chen W., [A Dynamic Synchronous Interactive Functional Validation Approach for Electric Vehicles](#), in *IEEE Transactions on Intelligent Vehicles*, doi: 10.1109/TIV.2024.3393559, 25 April 2024.

Liang C., Ghazel M., Yusheng C., Zheng W., [Analyzing Rear-End Collision Risk Relevant to Autonomous Vehicles by Using a Humanlike Brake Model](#), in *Journal of Transportation Engineering, Part A: Systems*, Vol 150, No. 7, 3 May 2024.

Sharma B., Pascariu B., Pellegrini P., Rodriguez J., Chaudhary N., [A Real-Time Railway Traffic Management Approach Preserving Passenger Connections](#), in *IEEE Access*, vol. 12, pp. 79066-79081, 03 June 2024, doi: 10.1109/ACCESS.2024.3409183.

Anis M., Collart-Dutilleul S., [Fuzzy filtering of sensors signals in railway transport systems](#), in *Journal of Fuzzy Extension and Applications*, Vol. 5, Issue 2, PP. 223-237, June 2024.

Tonk A., Boussif A., [Application of Systems Theoretic Accident Model and Processes in Railway Systems: A Review](#), in *IEEE Access*, vol. 12, pp. 99872-99893, 17 July 2024.

Peres F., Ghazel M., [A Proven Translation from a UML State Machine Subset to Timed Automata](#), in *ACM Transactions on Embedded Computing Systems*, vol. 23 Issue 5: 72:1-72:33, August 2024. <https://dl.acm.org/doi/10.1145/3581771>.

Pascariu B., Samà M., Pellegrini P., D'Ariano A., Rodriguez J., Pacciarelli D., [Formulation of train routing selection problem for different real-time traffic management objectives](#), in *Journal of Rail Transport Planning & Management (JRTPM)*, vol. 31, September 2024.

Girard A., Meyer P.-J., Saoud A., [Approches symboliques pour le contrôle des systèmes non linéaires](#), in *Techniques de l'Ingénieur*, 10.51257/a-v1-s7467, 10 September 2024.

Liang C., Ghazel M., Xie C., Zheng W., Chen W., [Dynamic Cumulative Human-Like Brake Control Modeling for Autonomous Vehicle Collision Analysis](#), in *IEEE Transactions on Vehicular Technology*, doi : 10.1109/TVT.2024.3497583, 13th November 2025.