



COSYS Département ESTAS laboratory newsletter

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COSYS Department

Components & Systems

Évaluation des
Systèmes de
Transports
Automatisés et de leur
Sécurité

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Editorial by the director

In this first issue of 2024, we present a risk assessment and decision support approach dedicated to autonomous trains. The developed approach, based on the partially observable Markov decision processes, enables continuous monitoring of the environment to guarantee operational safety. Next, a new achievement of the traffic management team is outlined. It pertains to the integration into our RECIFE platform of real-time prediction of passenger flows and their assignment to trains. In the News section, three recently launched projects are presented; the first concerns a collaboration with the Italian company TRENOLab on various algorithms for managing rail operations. The second, REINFORCERAIL, is a Franco-German project focusing on the use of artificial intelligence to optimize rail traffic management. Finally, MobiLoos, supported by the ESTAS and LaPEA laboratories as part of the ExcellencES program of the Plan d'Investissements d'Avenir, aims to accompany changes in mobility behavior with a view to reducing the related carbon footprint.

Still in the News section, a short presentation is given of the PERFORMINGRAIL (Shift2Rail) and Navette Autonome projects, which have just been completed. Other items are also listed. They concern the start of new PhD theses, the recruitment of a new research fellow who has just joined the Safety team, some scientific events in which laboratory staff have taken part, and a list of new publications.

We hope you enjoy reading our newsletter. Also, should you need any details regarding the discussed item, please feel free to get in touch with the indicated contacts.

[Mohamed Ghazel](#), Director of ESTAS

Autonomous trains : risk-based decision-making approach

In autonomous trains, the tasks and responsibility of dynamic (and operational) risk assessment, as well as the decision-making process now lie within the autonomous driving system. The Safety team at ESTAS, within the scope of Mohammed Chelouati's thesis, has developed a risk-

based decision-making approach for autonomous trains, using Partially Observable Markov Decision Processes (POMDPs) for continuous monitoring and evaluation of environmental collision risks. By consistently maintaining an acceptable risk level through ongoing risk estimation (in terms of occurrence probability and severity degree), the approach supports the decision-making capabilities of the autonomous driving, enabling safe and informed decisions despite the uncertainties in the train's operational state and environmental perception data.

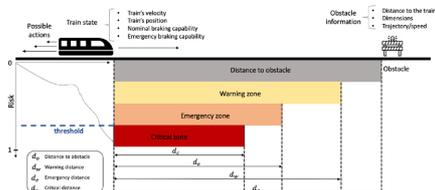
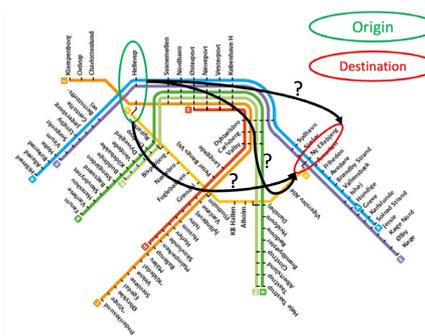


Illustration of a case study concerning the dynamic assessment of the risk of collision with an obstacle on the track.

Contact : [Abderraouf Boussif](#)

Taking account of passengers in RECIFE*

The laboratory's 'Traffic Management' team has proposed a variant of the RECIFE-MILP algorithm defining train routes and timetables in the event of disruption, to incorporate passenger choices and delays. This variant is integrated into a predictive optimisation approach, with a demand prediction module based on artificial intelligence and a module for assigning passengers to trains. The first module predicts future passenger flows using data observed in real time. The second assigns passengers to trains. The RECIFE-MILP algorithm then uses the assignment to optimise the timetable. The integration was validated on a case study of Copenhagen's urban rail network. The results show that it is possible to take account of passenger choices and delays in real time without reducing the efficiency of the system compared with conventional approaches.



Example of possible choices for a passenger on Copenhagen's urban rail network.

*RECIFE : REcherche sur la Capacité des Infrastructures FERroviaires - Research on railway infrastructure capacity

Contact : [Paola Pellegrini](#)

News and events

New projects

Contribution to algorithm design

The collaboration is part of the TRENOLab development of prototype tools

for the optimization of problems related to the design of rail services. These tools can cover, among other things, the optimization of crew schedules, the production of timetables or the real time traffic management. With this service, Université Gustave Eiffel participates in the design of algorithms in the field of activity of TRENOLab through discussions focusing on the implementation and refinement of algorithmic choices.

The contract is financed by TRENOLab Srls.

Contact : [Paola Pellegrini](#)

REINFORCERAIL - Railway Efficiency Fostered by Operations Research Empowering Artificial Intelligence

The REINFORCERAIL project proposes a new intelligent Traffic Management System (TMS) component based on artificial intelligence (AI). First attempts have shown that AI-based traffic management is principally possible at the cost of designing complex models and performing energy-thirsty training. To alleviate these challenges, two methods enabling real-life automatic railway dispatching are pursued. First, neural networks are designed to identify which trains possibly need rescheduling at which time during perturbed operations, which significantly reduces the problem size. Second, AI agents are hybridized with Operations Research (OR) methods, which allows to give quality bounds and fosters the trust required to implement a fully automated application.

The partners of the project are : Université Gustave Eiffel, SNCF, TU Dresden, DB Netz.

Contact : [Paola Pellegrini](#)

MobiLoos - Encouraging and supporting changes in mobility behaviour

In 2017, the laboratory carried out an action research project, CISMOP, which aimed to build, with and for the population of the peri-urban area of Loos-en-Gohelle (62), a transition towards more sustainable mobility to reduce the dependence of this peri-urban area on the private car. This project has paved the way for the development of a low-carbon daily mobility project, integrated into the town's transition project for the 2020-2026 term of office, with the aim of providing a systemic response based on the needs expressed by local residents.

The municipal team is now focusing on implementing alternative mobility solutions, and collaboration with research is continuing as part of an experimental study into the issue of changing mobility behaviour (the MobiLoos project), a necessary complement to financial and human investment in alternative solutions and mobility services. The conclusions of this research will provide information on the conditions for sustaining and disseminating the approach. The aim of this project is to develop a method that can be replicated in other areas.

This action research project is being conducted by the ESTAS and LaPEA laboratories and is being funded as part of the CityFab project under the PIA's ExcellencES programme. (Plan d'Investissements d'Avenir).

Contact : [Marielle Cuvelier](#)

End of projects

Safe implementation of the Moving Block operational concept : Successful closing event of the European PERFORMINGRAIL

project (2020-2023) (2020-2023)

The PERFORMINGRAIL project, supported by Shift2Rail, came to a successful close at the end of June 2023, as demonstrated by its closing workshop held on 15 June 2023 at the University of Birmingham and entitled "One Step Closer to Safe and Effective Moving Block Rail Operations" (see <https://www.performingrail.com>). This event provided an opportunity to present the results of the work carried out during the project by its five work packages. At the end, this work made the following contributions to the safe implementation of the Moving Block operational concept within future rail control-command and signalling systems.

- The first work package (WP1), led by the Gustave Eiffel University and more specifically by the ESTAS laboratory's "Safety" team, has contributed to the specification of requirements and minimum operational performances for systems with moving blocks.
- WP2, led by the Italian inter-university consortium CINI, contributed to the modelling and formal analysis of these systems, with strong involvement from the ESTAS 'Safety' team.
- For WP3, the Spanish SME ROKUBUN provided its expertise for the development of autonomous train localization solutions using navigation satellites.
- WP4, led by Delft University of Technology, developed a model for optimising rail traffic on an infrastructure operated by moving blocks, in partnership with the ESTAS laboratory's "Traffic" team.
- WP5, led by the University of Birmingham, has implemented its railway simulation platform for the purpose of testing and validating moving block systems.

*PERformance-based Formal modelling and Optimal tRaffic Management for movING-block RAILway signaling

**The aim of the Shift2Rail Joint Undertaking was during the period 2015-2023 to coordinate and manage research and innovation investment in the rail sector at European level, as part of the European H2020 programme. Its missions have now been taken over by Europe's Rail as part of the Horizon Europe programme. ([link](#)).

Contact : [Julie Beugin](#)

Autonomous Shuttle on Demand project

The final presentation of the Autonomous Shuttle on Demand project for the SNCF's Innovation department took place on June 19, 2024 at the SNCF's premises.

The aim of this project was to design an algorithm for optimising the operation of an autonomous on-demand shuttle service on a dedicated infrastructure. We proposed an integer linear mathematical model to capture the characteristics of the problem. We then proposed a heuristic algorithm to solve realistic instances. In the course of the project, the bilateral collaboration between the Gustave Eiffel University and SNCF was extended to the IRT SystemX, which made it possible to design and build an experimental platform integrating the designed algorithms and the MATSim mobility simulator. The results obtained from this experimental platform have made possible to quantify the impact of optimisation on a large number of performance indicators.

Contact : [Paola Pellegrini](#)

A new researcher joins the "Safety" team

Abderraouf Boussif joined the laboratory on November 1st 2023 as researcher of the "Safety" team. His scientific activities focus on safety assurance of autonomous railway systems, with a more specific focus on the safety of systems integrating artificial intelligence.

Scientific events

IEEE MT-ITS 2023 - 8th International Conference on Models and Technologies for Intelligent Transportation Systems - Nice, France - 14th to 16th June 2023

- [Analysis of the robustness of railway traffic management to driving behaviour noise](#), David B., **Pascariu B.**, **Pellegrini P.**, **Marlière G.**
- [A full factorial sensitivity analysis for a capacitated flex-route transit system](#), **Shahin R.**, **Hosteins P.**, **Pellegrini P.**, **Vandanjon P.O.**

ECC 2023 - Workshop "Formal methods for data-driven control systems" of the European Control Conference - Bucarest, Romania - 13th to 16th June 2023

- Mixed-monotonicity reachability analysis of uncertain neural networks, **P.-J. Meyer**

IFORS 2023 - 23rd Conference of the International Federation of Operational Research Societies - Santiago, Chili - 10th to 14th July 2023

- Integrating passenger demand prediction in real-time rail traffic management, **Pascariu B.**, **Flensburg J.V.**, **Pellegrini P.**, **Lima Azevedo C.M.**

IFAC 2023 - 22nd World Congress of the International Federation of Automatic Control - Yokohama, Japan - 10th to 14th July 2023

- Reachability Analysis of Neural Networks with Uncertain Parameters, **P.-J. Meyer**

ODS 2023 - International Conference on Optimization and Decision Science - Ischia, Italy - 4th to 7th September 2023

- A consensus algorithm for decentralised real-time railway traffic management, **D'Amato L.**, **Trianni V.**, **Pellegrin P.**
- Artificial Intelligence for self-organized train re-routing and re-scheduling in real-time, **D'Amato L.**, **Naldini F.**, **Tibaldo V.**, **Trianni V.**, **Pellegrini P.**
- Integrating passenger demand preferences in real-time rail traffic management, **Pascariu B.**, **Flensburg J.V.**, **Pellegrini P.**, **Lima Azevedo C.M.**
- Train Rerouting and Rescheduling in case of Perturbation: Focus on Passenger Connections, **Sharma B.**, **Rodriguez J.**, **Pellegrini P.**, **Chaudhary N.**

AI4RAILS 2023 - 4th International Workshop on "Artificial Intelligence for RAILwayS" - Ischia, Italy - 4th to 7th September

2023<

- Designing self-organizing railway traffic management, D'Amato L., **Naldini F.**, Tibaldo V., Trianni V., **Pellegrini P.**

SAFECOMP 2023 - Workshops Computer Safety, Reliability, and Security - Toulouse, France - 19th September 2023

- [Rear-End Collision Risk Analysis for Autonomous Driving](#), Liang, C., **Ghazel, M.**, Ci, Y., Faouzi, N.E.E., Wang, R., Zheng, W. in Computer Safety, Reliability, and Security. SAFECOMP 2023 Workshops. SAFECOMP 2023. Lecture Notes in Computer Science, vol 14182. Springer, Cham.

EWGT 2023 - Euro Working Group on Transportation - Santander, Spain - 6th to 8th September 2023

- Rail traffic optimization integrating recife-milp and linear regression demand prediction, **Pascariu B.**, Flensburg J.V., **Pellegrini P.**, Lima Azevedo C.M.

ISTC 2023 - IEEE Conference on Intelligent Transportation Systems - Bilbao, Spain - 24th to 28th September 2023

- [Integrated and colony optimization and mixed integer linear programming for multi-objective railway timetabling](#), Coviello N., Medeossi G., Nygreen T., **Pellegrini P.**, **Rodriguez J.**

VECoS'23 - 16th International Conference on Verification and Evaluation of Computer and Communication Systems - Marrakech, Morocco - 18th to 20 October 2023

- A sound abstraction method towards efficient neural networks verification, Boudardara F., Boussif A., **Ghazel M.**

MSR'23 - 14ème Colloque sur la Modélisation des Systèmes Réactifs - Toulouse, France - 22nd to 24th November 2023

- Vérification formelle d'un système de signalisation ferroviaire à base de cantons mobiles (Poster), Saddem-Yagoubi R., **Beugin J.**, **Ghazel M.**

New PhDs

Thesis of Abdelrahman Ibrahim

Start of this PhD thesis in November 2023 on the formal verification of neural ODE for safety evaluation in autonomous vehicles. The thesis is funded by the CLEAR-Doc program of Université Gustave Eiffel, co-supervised by Pierre-Jean Meyer and Mohamed Ghazel, and with a 6-month international mobility planned in the Department of Marine Technologies of NTNU in Trondheim, Norway.

Contact : [Pierre-Jean Meyer](#)

Thesis of Manal Zidani

Start of the CIFRE PhD thesis with SNCF DGEX in June 2023 on Integratin of OR and AI for Real-Time Railway Traffic Management. Most existing approaches for real-time railway traffic management are

based on the application of optimization algorithms to a simplified model of reality, aiming to minimize a predefined objective function. The considered problem representations typically include input data that are fixed arbitrarily, to some extent. Moreover, they are seldom appropriately validated. In this thesis, we propose to integrate optimization and artificial intelligence to overcome the intrinsic limit of the former. In particular, we aim at improving the precision of optimization input data.

Contact : [Paola Pellegrini](#)

Thesis of Maissa Mati

Start of this PhD thesis in October 2023 on "railway infrastructure optimisation » (railway safety) with funding of the CERTIFER GAPAVE Chair. Stations and complex rail nodes are frequently identified as critical points in the operation of the rail network. The configuration or reconfiguration of their track plan is often decided by experts without the use of optimisation approaches. The aim of this thesis is to propose a decision-support tool algorithm to assist decision-makers in the choice of track plan reconfiguration. In particular, the algorithm will provide a selection of reconfiguration choices that will best cover future demands and that will also take into account other criteria or constraints such as investment costs, operating costs, safety aspects, urban right-of-way constraints or the management of passenger flows in stations.

Contact : [Paola Pellegrini](#)

PhD defense

Reza Shahin defended his thesis entitled "**Incorporating Ad Hoc Stops into Public Transport: A Study of Flex-Route Transit**" on January 26th 2024.

In recent years, there has been an ascending trend towards the adoption of flexible transit solutions like Demand Responsive Transit (DRT), primarily due to the enhanced convenience they offer to passengers. However, this flexibility comes with an associated economic burden. Consequently, transport authorities are presently exploring methods to augment the flexibility of Conventional Public Transport (CPT), which is more conservative compared to DRT. This gives rise to the significance of Flex-Route Transit (FRT), an innovative system amalgamating the benefits of both DRT and CPT. In the doctoral dissertation presented here, we conduct an exhaustive investigation of FRT frameworks. Specifically, we scrutinize pertinent academic literature, highlighting extant research lacunae. Then, we formulate a Mixed Integer Linear Programming (MILP) model extending the state of the art to include previously neglected problem features, and we supplement it by a set of valid inequalities to enhance its linear relaxation. We also introduce a heuristic algorithm to procure a feasible solution and employ a warm start technique to boost the MILP solution. Subsequently, a comprehensive full factorial experimental design sensitivity analysis is carried out. Here, we evaluate the system's saturation levels under various demand scenarios, focusing on the elongated wait times for passengers. In the final contribution chapter, a stochastic MILP model for the FRT is proposed, wherein certain initial parameters of the base MILP are elevated to variable status. We conclude the dissertation by outlining prospective avenues for future research.

Publications

Guest editing

Siri S., Pasquale C., Bhourri N., De Schutter B., **Ghazel M.**, Viti F., Innovative Control Approaches for Smart Transportation Systems, Guest Editorial, Journal Control Engineering Practice, Vol. 135, Elsevier, August 2023.

Contribution to a collective book

Liang C., **Ghazel M.**, Accident Prediction Modeling Approaches for European Railway Level Crossing Safety, Chapter in book : New Research on Railway Engineering and Transport, Intechpen, ISBN 978-1-83768-620-9, March 2023.

Cuvelier M., Gabaude C., Mathon G., Construire la transition vers une mobilité plus durable en périurbain - L'exemple d'une recherche-action à Loos-en-Gohelle, Ouvrage "L'action publique locale et régionale en matière de mobilité : un paysage en transition ?", CEREMA, Edition Les Presses Universitaires de Grenoble, ISSN 978-2-7061-5485-0, novembre 2023.

Papers

Sharma B., Pellegrini P., Rodriguez J., Chaudhary N., [A review of passenger-oriented railway rescheduling approaches](#), European Transport Research Review, 15:14, May 2023.

Boussif A., Tonk A., **Beugin J., Collart-Dutilleul S.**, [Operational Risk Assessment of Railway Remote Driving System](#), Safety and Reliability Journal, July 2023, DOI: 10.1080/09617353.2023.2226965.

Boudardara F., Boussif A., **Meyer P.-J., Ghazel M.**, [A review of abstraction methods towards verifying neural networks](#), ACM Transactions and Embedded Computing Systems, July 2023, DOI : 10.1145/3617508.

Boudardara F., Boussif A., **Meyer P.-J., Ghazel M.**, [INNAbstract: An INN-Based Abstraction Method for Large-Scale Neural Network Verification](#), IEEE Transactions on Neural Networks and Learning Systems, October 2023, DOI: 10.1109/TNNLS.2023.3316551.

Chelouati M., **Boussif A., Beugin J., E. Koursi E. -M.**, [A Risk-Based Decision-Making Process for Autonomous Trains Using POMDP: Case of the Anti-Collision Function](#), IEEE Access, December 2023, doi: 10.1109/ACCESS.2023.3347500.

Shahin R., Hosteins P., Pellegrini P., Vandanjon P.O. and Quadrifoglio L., [A survey of flex-route transit problem and its link with vehicle routing problem](#), Transportation Research Part C: Emerging Technologies, 158:104437, January 2024, DOI doi.org/10.1016/j.trc.2023.104437.

Versluis N.D., Quaglietta E., Goverde R.M.P., **Pellegrini P. and Rodriguez J.**, [Real-time railway traffic management under moving-block signalling: A literature review and research agenda](#), Transportation Research Part C: Emerging Technologies, 158:104438, January 2024,

DOI doi.org/10.1016/j.trc.2023.104438

D'Amato L., **Naldini F.**, Tibaldo V., Trianni V., **Pellegrini P.**, [Towards self-organizing railway traffic management: concept and framework](#), Journal of Rail Transport Planning & Management, 29:100427, March 2024, DOI doi.org/10.1016/j.jrtpm.2023.100427 .

Chouchane A., **Ghazel M.**, [Fault-prognosability, K-step prognosis and K-step predictive diagnosis in partially observed petri nets by means of algebraic techniques](#), Automatica, Elsevier, Vol. 162, April 2024, DOI doi.org/10.1016/j.automatica.2024.111513 .

Université Gustave Eiffel - ESTAS 20 rue Elisée Reclus BP 70317 F-59666 Villeneuve d'Ascq Cedex
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