ETH zürich

Center for Sustainable
Future Mobility

Center for Sustainable Future Mobility

Annual Report 2024

CSFM

Index

Introduction

Since ETH Zurich established the center in July 2021, we embarked on a journey to develop a community of experts able to address the critical aspects of sustainable mobility. The main objective of the CSFM is to foster the collaboration necessary to effectively exploit synergies, allowing its members and partners to tackle the challenges ahead, aiming for a decarbonized, safe, equitable, and efficient transportation system.

The center's members address a wide range of interrelated research topics within the transportation system. A closer and frequent exchange allows them to nurture relevant relationships and develop new ideas. We also promote close collaboration with industry, particularly with our strategic partners, while fostering continued dialogue and exchange with governmental institutions.

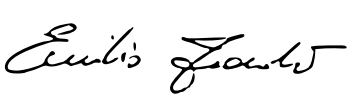
The CSFM **Seminar Series** attracted a significant number of practitioners and industry representatives to ETH Zurich. From the point of view of internal networking, some of our seminars counted with participants from as many as eight different ETH departments, in line with our ambition to promote multidisciplinary dialogue. The **CSFM Symposium**, with its inspiring keynotes, has brought us closer to research from Helsinki and Berkeley at the intersection of data science, transportation research, and data-based policy support. The panel discussion at this event addressed, among other topics, the role of the public administration in leading and regulating mobility data sharing.

The **ETH Mobility Initiative** "Future Mobility" research program continues to support collaboration and research, with five excellent new projects approved. Moreover, eight projects were successfully completed in 2024 delivering relevant results including start-ups and new promising solutions that will be further explored towards implementation. Finally, the **Digital Twin flagship project** of the center delivered tangible results with the first version of the Open Digital Twin Platform for research that was released in March 2024 and a shared instance on an ETH Zurich central Server. This project got recognition also outside the academic community and innosusse will be supporting the further development of the platform for additional two years.

The center will complete in 2025 the first phase of operation, we believe we are on the right path; first of all, the CSFM community is growing, and we are becoming well-known in Switzerland. Additionally, due to our intense international networking, the management office received several invitations to discuss partnership and collaboration with prestigious European institutions, such as ECTRI and the Association for European Transport, where Switzerland is still poorly represented. The active and intense contribution of the CSFM members to the international research community also contributes to awakening the general interest in the center.

This report summarizes the major highlights and developments in 2024. It concludes with an outlook in which we present the ideas and strategic initiatives that will guide the center's development over the next four to five years. These forward-looking perspectives should ensure sustained growth and innovation, positioning the center for future success.

We hope you enjoy reading these pages. The management office is always happy to receive suggestions, ideas, and feedback, so please do not hesitate to contact us



Prof. Emilio Frazzoli
Chair

Dr Gloria Romera
Managing Director

1 CSFM Mission and Strategy

Background

The ETH Zürich launched the Center for Sustainable Future Mobility (CSFM) in mid-2021. This center consolidates and coordinates research efforts of research groups within ETH Zurich, Empa, and PSI and, since 2024, also FHNW. The center contributes to addressing the grand challenges of the transport sector and to deliver research-based solutions for the design and implementation of sustainable transport systems that will be safe, reliable, fast, socially desirable, environmentally friendly, and cost-efficient. In particular, the decarbonization of the transport system is a key goal to which the research activities should contribute significantly.

Strategy

The CSFM's thematic scope extends beyond multidisciplinary to cross-sectoral functionality, exploiting innovation potentials across all modes and services (road, rail, air, waterborne, low-speed, non-motorized, etc.). Transferring insights, models, and methods from one sector/mode/service to the other, as well as exploiting potential synergies whenever meaningful are both widely recognized as critical aspects to optimize the system.

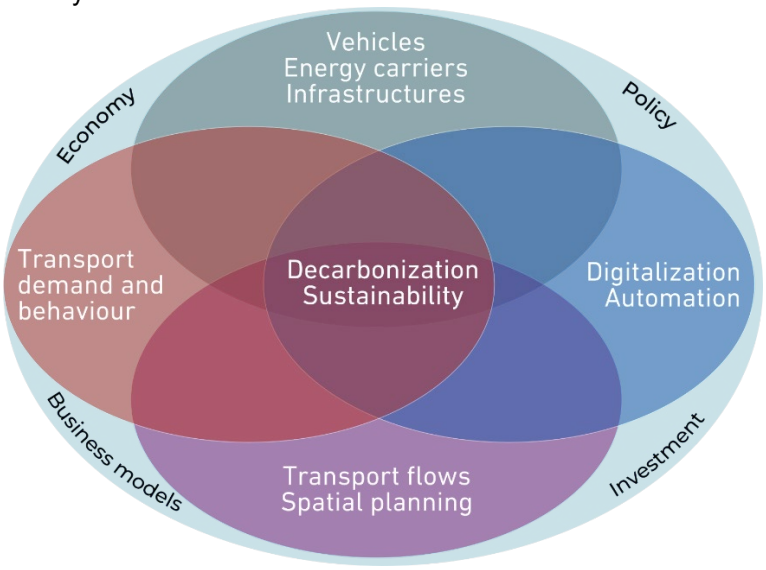


Figure 1: Center for Sustainable Future Mobility (CSFM) research areas: (a) vehicles and infrastructures, (b) digitalization and automation, (c) special planning and (b) factors that influence mobility behavior and transport demand.

Research on new vehicles and energy carriers, as well as the required infrastructure, are critical aspects when aiming to achieve a more sustainable transportation system and reducing emissions. The increased digitalization of modern society as well as the potential automatization of vehicles and traffic management, represent an opportunity to increase the efficiency of the system, for example, by facilitating Mobility as a Service-related solutions. However, it also represents a risk in terms of inducing a higher transportation demand. How cities and spaces are designed and built also influences the demand side. Research to understand the transportation distances and preferences of the residents is therefore needed as well.

As depicted in Figure 1, the mentioned four main knowledge areas represent the major thematic blocks we attempt to address. However, transportation is a complex system with multiple interactions between all related socio-economic and policy factors. Major real issues and potential for improvement lie in the intersections between those mentioned thematic areas or overlapping research topics. The center's role is to connect the different researchers and stakeholders to better address the real issues.

1.1 Organizational Structure and Governance

1.1.1 Steering Committee

The center is jointly run by the Departments of Civil, Environmental, and Geomatic Engineering (D-BAUG) and Mechanical and Process Engineering (D-MAVT).

Francesco Corman, new Steering Committee member

Professor Kay Axhausen served on the Steering Committee until his official retirement at the end of January 2024. From then on, Francesco Corman joined the Steering Committee.

Below is the updated list of current members of the Steering Committee, indicating their group or laboratory, the lead, and the department or institution they belong to.

Emilio Frazzoli Dynamic systems and control (D-MAVT) **Chair from July 2023**	**Martin Raubal** Geoinformation Engineering (D-BAUG) **Deputy Chair**
Ulrike Grossner Advanced Power Semiconductors (D-ITET)	**Anthony Patt** Climate Policy (D- USYS)
Christian Bach Head of the Automotive Powertrain Technologies Laboratory (APTL), EMPA	**Thomas Bernauer** International Environmental Policy (D-GESS)
Francesco Corman Transportation Systems (D-BAUG)	**Christopher Onder** Institute for Dynamic Systems and Control (D-MAVT)

1.1.2 New members in 2024

The CSFM welcomes the following new members:

Silvia Mastellone

Silvia Mastellone is Professor of Signals and Systems at the Institute of Electric Power Systems at the University of Applied Sciences and Arts Northwestern Switzerland (FHNW). Her research interests include control, decision making and signal processing. In particular, decentralized control and estimation of interconnected networked control systems, applied to sustainable optimal operation and diagnostics for power conversion, mobility and energy systems.
Some of the current research projects in her group focus on mobility applications including electric vehicles and railways (in collaboration with SBB).

Stephan Wagner

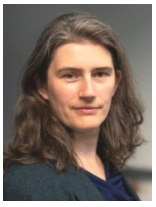
Stephan Wagner is Professor of Supply Chain Management and Faculty Director of the HumOSCM Lab at ETH Zurich. Furthermore, as Head of Department he leads the Executive Board of D-MTEC. He has conducted research on various supply chain management topics, in particular related to supply chain risks, supply chain network design, sustainability, ethical and social issues, and the impact of digital technologies. He has also worked on projects related to the management of logistics service providers and last-mile distribution. His team recently contributed to the Mobility Initiative portfolio with a rail freight research project aimed at understanding preferences and optimization opportunities in this area.

Adrienne Grêt-Regamey

Adrienne Grêt-Regamey is an environmental scientist and landscape planner. She has been Professor at the Chair of Planning Landscape and Urban Systems at the Institute for Spatial and Landscape Development, ETH Zürich (Switzerland) since 2008. Currently, her research focuses on understanding the interactions and/or actions of human's shape landscapes at various temporal and spatial scales, using different land-use decision models in forecasting and back casting modes. She contributes to the Mobility Initiative portfolio with the project "A high-resolution, multi-scale urban land use transport interaction model for sustainable spatial and mobility planning in Switzerland".

Gudela Grote

Gudela Grote is Professor of Work and Organizational Psychology at the Department of Management, Technology, and Economics since 1992. The main objective of her research is to provide psychologically based concepts and methods for integrative job and organizational design, taking into consideration the changing technological, economic and societal demands and opportunities. In particular, she addresses the increasing flexibility and virtuality of work and their consequences for the individual and organizational management of uncertainty. She contributes to the Mobility Initiative portfolio with the project entitled "Designing explainable ML-based systems for collaborative work in the railways".



Eva Heinen

Eva Heinen is Professor of Transportation and Mobility Planning in the Department of Civil, Environmental and Geomatic Engineering. Eva Heinen's interdisciplinary research looks at mobility and transportation at the intersection of sustainable development, transport planning, spatial planning and health. Her research on non-motorised traffic led to an interest group being set up at the World Conference on Transport Research Society (WCTRS). Eva Heinen also has wide-ranging teaching experience. She joined ETH Zurich in July 2024.

1.1.3 Partnership Council

The strategic long-term partners SBB, Siemens, and AMAG together with most relevant private donors of the ETH Mobility initiative constitute the Partnership Council. One of the central competences of the Partnership Council is to approve the thematic scope of the yearly calls of the Mobility Initiative program. The Strategic partners representatives, members of the Partnership Council in 2024 are listed below:

- Heinz Brenner, Head of Business Development Mobility Division, Siemens Mobility AG
- Isabel Götz, Head Research, Scenarios and open innovation, SBB
- Christoph Höschele, Innovation manager, SBB
- Dino Graf, Head Group Communications, Amag Group
- Prof. em. Dr. Alexander Wokaun

2 Research

2.1 Mobility Initiative Program

The *Future Mobility* program is a long-term research program established in 2018 and funded by the ETH Mobility Initiative partners. It focuses on research questions relevant to address the decarbonization, digitalization, and infrastructure development in the coming decades. Projects approved under this framework provide a unique opportunity for close collaboration with the Mobility Initiative industry partners which are AMAG, SBB, and Siemens.

2.1.1 Projects Approved in 2024

Efficient safe train dynamics (ESTRA, F. Corman, E. Chatzi, E. Frazzoli, P. Tiso)

This project will address the mathematical, physical, technical, and organisational conditions allowing and enabling higher degree of automation in railway traffic. Deriving precise values in train dynamics, especially for freight trains, which feature various length, weight, and wagon conditions, and are often carrying partially unknown goods (of partially unknown weight) remain a challenge that results in a too conservative estimation of braking rate and dynamic performance. As a consequence, evaluation of increasing automation results in little added value. This project will leverage data and mathematical modelling for tackling this challenge.

Optimal and flexible operation of uncertain EV charging hubs (FLEXHUB, G. Hug, T.H. Demiray)

This project investigates a new lean, flexible, robust and practical approach for the smart operation of EV charging hubs. Charging hubs combine charging stations for electric vehicles, an electricity grid connection, a battery storage system, and local renewable production. Depending on the use case, charging hubs face several uncertainties, including arrival times, charging demand, energy availability, and electricity prices. Efficient charging hub operation, namely minimizing the charging duration while keeping investments and operational costs within limits, is essential for the e-mobility transition. The smart operation of charging hubs by exploiting flexibility of local storage systems, synergies between customer groups and renewable production on real-time is critical to achieve this.

Tariff design for efficient vehicle to grid integration (TARIFFV2G, G. Hug, C. Schaffner)

The Swiss and European electricity systems are transitioning towards a high share of variable renewable energy sources. While electrification is one of the key strategies for decarbonizing the transport sector, electric vehicle charging could exacerbate peak load events resulting in higher electricity prices and the need for more generation capacity. Well-designed tariffs can incentivize electric vehicle owners to shift charging to off-peak periods or feed electricity back to the system during peak demand.

This project focuses on tariffs for the efficient integration of electric vehicles into the power system and investigates the interaction with other sources of flexibility on the household level such as batteries or hybrid solar battery systems.

Intermodal rail freight mode choice variables for short-distance transportation in Switzerland (RailFreight MC, S. Wagner, J. Shan)

Intermodal rail transport may considerably reduce transport emissions. The European modal shift policy promotes medium and long-distance intermodal rail transport (over 300 km). However, Switzerland's unique geography makes short-distance intermodal rail transport (<300 km) especially important.

This research aims to understand how different factors influence mode choice in Switzerland by using qualitative and quantitative methods. The quantitative analysis tool that will be developed by combining the demand prediction model and intermodal rail planning model will improve the understanding the interactions between demand-side and supply-side decisions in multimodal systems and will support informed decisions about intermodal service design, infrastructure development, rail planning, and policymaking.

A high-resolution, multi-scale urban land use transport interaction model for sustainable spatial and mobility planning in Switzerland (LUMOS, S. Hellweg, A. Grêt-Regamey)

This project will contribute to a more thorough understanding of the interactions between urban land use and mobility by producing a Switzerland-wide, high-resolution land use forecasting model that integrates aspects from travel demand modeling. Accessibility will act as a key feedback component between the travel model and the land use model. The proposed model is designed to operate at multiple scales, from the individual street to inter-city connections while considering a good balance between model sophistication, power, interpretability and transparency. The results have the potential to influence the development of urban land use and mobility infrastructure in a way that balances societal needs with environmental considerations.

More details about these projects can be found in the section of the CSFM webpage dedicated to the Mobility Initiative program.

2.1.2 Projects finalized in this reporting period

MILE: Multimodal robotic last mile (Call5 – 2022, M. Hutter)

This project contributed to the development of one of the most innovative autonomous last-mile logistics robots by including specific capabilities needed for efficient Last Mile delivery. The main achievements in this project were:

- Local autonomy: implementing model-free reinforcement learning (RL) techniques and privileged learning to develop a versatile controller capable of smoothly transitioning between walking and driving modes, jumping off tables, and overcoming other obstacles.
- Full autonomy in cities: introducing city-scale global navigation and localization by leveraging pre-mapped digital twins. To create this digital twin for a new campus or city district, the team uses an off-the-shelf reality capture device to generate georeferenced point cloud data. Based on this data, a global navigation graph is constructed, incorporating human input. Notably, the navigation graph

only necessitates sparse waypoints at each intersection, as the developed hierarchical controller effectively handles obstacles encountered between these waypoints.

- Towards real deployment: The team finally conducted autonomous navigation missions in different urban environments for a total distance of more than 100km. These experiments took place in Zurich (Switzerland), Seville (Spain), and NEOM (Saudi Arabia). More information.

EVAdopt: Incentives for Electric Vehicles Adoption (Call4 – 2021, M. Filippini)

Electric vehicles are an essential component for the decarbonization of the passenger transport sector. Nevertheless, their market share is currently a small percentage of the whole vehicle fleet, and there is not yet a clear understanding of which measures would help promote the adoption of electric vehicles by the broader population. The goal of the EVAdopt project was to measure the effectiveness of a series of non-monetary treatments aimed at increasing the adoption of electric vehicles among car owners.

The results show striking perceptual biases of car owners concerning their range and charging needs that are typically overestimated while the cost advantages of battery electric vehicles (BEVs) are underestimated. Most car owners have misperceptions about the number of trips they would have to interrupt per year to recharge if they owned a BEV, the number of charging instances needed per week, and the cost advantages of electric cars. Hence, addressing these psychological barriers and concerns with personalized information that is based on driving and parking behavior of each individual, can be a scalable non-monetary intervention to increase EV adoption and complement other policy instruments.

Maintaining train schedule STABILITY and managing time table reserves via digitalised railway intervention planning (Call3 – 2020, B. Adey)

This research project proposed methodologies to help asset managers plan future interventions more effectively and efficiently using digital tools. It included the development of decision support tools for considering intervention planning in the development of train schedules, to achieve this, it was necessary to develop first tools that provide far in advance the information related to when and which interventions are required on different components of infrastructure, as well as the extent of the required track possession windows, the failure risks when postponing interventions, and the associated costs.

Within the first part of the project, the team modeled the intervention planning process at the SBB after conducting several interviews with stakeholders who make decisions in the process. This allowed the team to understand and map the different responsibilities, required inputs to make decisions, and where the outputs of the decisions taken flow. The result of understanding the intervention planning process allowed the team to identify the areas in which the use of digital tools could improve the overall efficiency and effectiveness of planning process, specifically by supporting the interaction between asset managers, track asset managers, network coordinators, and production and project managers.

The team then addressed the decision-making and how it could be facilitated with appropriate input data for planning interventions. They also developed the needed methodology to impute the missing asset condition data based on Bayesian networks, Analytical Hierarchy Process and Monte Carlo Simulation.

As the next step, the team developed algorithms to make initial complete and consistent estimates of the type and time of future interventions on SBB railway bridges, tracks, and switches at the component level. The algorithms enabled the use of wide range of existing data ranging from expert opinion where there is no data available to the detailed condition reports available in the SBB databases. An indication of the failure risks is obtained for each railway asset, this information is used to prioritize component-level interventions.

Finally, an algorithm to maximize the net-benefit of interventions was developed to determine optimal component-level intervention programs for railway networks. The algorithm was tested on a 25 km railway network located in the canton of Berne between Brügg and Zollikofen. The results indicate that the algorithm considering dependencies can substantially reduce the service disruptions needed to execute interventions. More information

REASSESS: Early detection and assessment of railway substructure moisture problems (Call3 – 2020, O. Frey, A. Wieser, E. Chatzi)

REASSESS addressed a remote-sensing-based approach to efficiently and timely detect railway track anomalies that serve as a proxy for subsurface ballast moisture. Detection methods based on three remote sensing systems, 1) satellite imaging radar (synthetic aperture radar - SAR), 2) (airborne) laser scanning, and 3) train-based ground penetrating radar (GPR), were investigated and assessed using reference data provided by the industry partner.

Satellite imaging radar method relays on retrieving surface displacements from interferometric time series of satellite radar data (TerraSAR-X). The performance of the satellite-based detection method is compared to chord-based measurements, which are obtained from survey trains, and which are currently used by railway industry to detect anomalies on a network-widescale. The new proposed approach employs statistics derived from variations of surface displacements along the railway track retrieved with persistent scatterer interferometry (PSI). The results show that validation remains challenging and cannot be applied as a replacement but rather as a useful additional source of information to chord-based techniques. In the future, high-resolution wide-swath (HRWS) imaging radars may however provide the necessary spatial resolution and spatial coverage needed for a network-wide satellite-based detection.

Airborne laser scanning for deformation and moisture proxies: The team investigated the detection and quantification of ballast moisture proxies in airborne LiDAR point clouds. The first focus was on optimally extracting surface deformations. They compared (i) approaches sensitive only to displacements perpendicular to the surface and (ii) machine-learning based approaches exploiting the structure of the ballast to derive 3D displacements. The other focus was on more direct moisture proxies, like clay fouling or vegetation changes. While we could not find a benefit of the LiDAR data for these proxies, the sensitivity for deformation analysis could be increased substantially through spatial filtering with and without exploiting rails and sleepers within the point clouds. The team learned that non-deformation moisture proxies can be better determined using images instead of point clouds. Direct estimation of 3D displacements of the ballast from point clouds is challenging because the structure is not unique and salient enough.

Finally, the team investigated the use of train-based **Ground Penetrating Radar** (GPR), as a promising solution for early and accurate detection of moisture accumulation in the ballast. We have conducted both simulated and experimental analyses, with the latter carried out on a controlled railway track section, established in collaboration with SBB AG. The findings demonstrate that GPR systems can effectively detect moisture infiltration in railway tracks, albeit certain challenges still need to be addressed for ensuring accurate and automated assessment. Toward such automation, the team will be coupling the GPR derived condition indicators with a reinforcement learning based decision support tool for optimizing maintenance policies.

Test railway track: Data is gathered on a test railway track at the initial dry condition and, subsequently, at increasing water contents of the substructure over the steel, wooden, and concrete sleepers. The water content is assessed via ground truth tests in the laboratory on collected samples.

The experimental results demonstrate the potential of adoption of GPR technology for moisture assessment in the track substructure. Assessing the water content of the track substructure from a single GPR measurement is a challenging task. The intention is to capitalise on more observations over time, enabling robust detection and dense spatial tracking of moisture content. Early detection of moisture accumulation in the substructure can form a potent tool for supporting preventive maintenance actions.

While the three techniques have the potential to outperform the state of the art in terms of efficiency, cost reduction and early detection, further development and improved raw data and detecting algorithms are required to really make them a robust tool suitable for real applications. The research will continue in following projects, particular towards better algorithms for on board Ground Penetrating Radar. More information.

RailPower! Power and energy for the future railways (Call3 – 2020, G. Hug, F. Corman)

The electric energy consumption of the transportation sector, private and public, is expected to increase in the coming decades as the frequency of offered train connections and number of freight trains rise and the trend of electrification of road vehicles continues.

The objective of this project was to provide a comprehensive view on the electric energy needed by the railway and supplied by the 16.7 Hz system while at the same time identifying opportunities to connect PV systems and to leverage the 16.7 Hz grid for providing charging of electric vehicles (cars and buses) at the train station.

As a main deliverable of the project, a calibrated simulation model was developed and is nowavailable to compute instantaneous power requirements and therefore estimate peaks. Additionally, power peaks in real life have been measured and analyzed. have been analyzed revealing the underlying complexity of the phenomena. Finally, the calibrated model was applied to determine the power consumption impact of different energy efficient driving simulations approaches.

The collaboration between the rail experts in the Transport Systems group (D-BAUG) and the Power Systes Lab (D-ITEC) in this project was critical to provide expertise in two very different knowledge areas: train operation on one side and electric network planning and operation on the other side. A novel electric railway Energy Management System (EMS) with integration of train demand, EV charging, energy storage, regenerative braking capabilities of trains, and renewable generation was proposed. Additionally, a method has been proposed that uncovers the potential of leveraging EV charging flexibility to prevent overloading in the combined EV charging and railway operation. Finally, a stochastic problem is formulated to derive optimal EV charging decisions despite uncertainties in the train demand and renewable generation.

LROD-ADAS: Long-range obstacle detection for early alert advanced driving assistance systems (Call3 – 2020, R. Siegwart)

Digitalization and new robotic systems technologies offer opportunities to rethink the future of rail mobility in terms of real-time capacity optimization and complete on-board situational awareness. This comes at a time when key railway infrastructure must enter a transition period to next generation safety management and traffic control systems. By shifting the focus from trackside instrumentation to on-board solutions, we can enhance system safety, efficiency and robustness.

Common sensors for the task of obstacle avoidance such as 3D laser range finders (LiDARs) suffer from maximal ranges of up to 300m, insufficient for the problem at hand. Therefore, this project will investigate an actuated system of visual cameras combined with a range detector (e.g. a long-range 1D laser).

The most significant achievement of the LROD project was the development of the hardware sensor setup for long-range obstacle detection. The custom actuation mechanism enables precise measurements at long range with high focal length cameras and accurate laser rangefinders.

Additionally, and in order to be able to achieve any meaningful measurements at long range, accurate calibrations was required for the individual system components and the system in it's entirety. Significant work went into high-precision camera calibrations, calibrations of the actuation mechanism and the calibration of deployed sensors utilizing infrastructure as a calibration target.

Typical object detectors are limited by their training data and might fail to detect previously unknown obstacles. The development of an obstacle agnostic anomaly detection pipeline was the third key component. The system is trained without any example of obstacles and learns to detect any out-of-the-ordinary scenes, which might pose a danger to the vehicle. The team collected a custom dataset to verify the performance of the new system, that resulted in a successful proof of concept. The documentation is still being finalized.

MULTIMODALITY: Multimodality in the Swiss New Normal (Call4 – 2021, K.W. Axhausen)

When a large share of the workforce adopts home-office, transport demand might be affected via several channels. The most obvious one is teleworkers not commuting. However, more indirect effects might play a role too.

The team assumed that the main leverage influencing the new transport equilibrium is threefold:

- The population share having access to hybrid work forms and wanting to work remotely.
- The home office population reconsidering mobility tool ownership, and
- their possibly different activity patterns than the regular workforce.

As part of this work, a unique dataset was collected, tailored to elicit work from home (WFH) preferences and resulting changes in mobility tool ownership (MTO) such as owning a vehicle or public transport season ticket. The addresses were drawn from a stratified sample of the German-speaking part of Switzerland, from the address registry of the Federal Statistical Office.

The team observed a shift from very high home office frequencies (during the pandemic) to two or three days (after the pandemic). Meanwhile, home office access remains at high levels (47%) suggesting that employees who have gained access to the new work form during the pandemic are still (partially) working from home. A large portion would like to increase WFH frequencies, in particular, the population currently not having access (potentially reducing the share not working from home to roughly 30%).

Statistical models explaining who wants to work remotely on how many days as well as how this choice is linked to reassessing mobility tool ownership was then integrated into the travel demand synthesis pipeline (eqasim) of the multi-agent transport simulator (MATSim) for the case of Zurich.

A substantial reduction in the number of trips is achieved in the present simulations, especially during peak hours, while the mode shares remain stable. Home office adoption ultimately seems to improve traffic conditions for motorists suggesting that congestion on major commuting axes could be substantially reduced. Additionally, the research results provide evidence against off-setting rebound effects, which are found by other studies in literature. More information

IARMO: Interactive Augmented Reality-guided Maintenance Operation (Call4 – 2021, M. Meboldt)

Training employees to troubleshoot, repair and maintain equipment is a highly demanding and critical process, which requires profound technical knowledge of the systems and how the parts interact. As infrastructure equipment and maintenance processes become more sophisticated, working with paper manuals and data sheets becomes increasingly challenging. It is therefore crucial to investigate means to support maintenance operators in handling this complexity. Augmented Reality (AR) can assist employees when interacting with sophisticated equipment, dealing with elaborate processes and working in challenging environments.

This project investigated the benefits and implementation hurdles of AR instructions during complex maintenance procedures at SBB. It also investigated a new generation of context-aware AR support system that combines AR instructions with real-time behavior recognition to provide optimal support.

Overall, the results of the project highlight the benefits of AR and particularly of AR systems that provide real-time feedback to operators. It also showed open challenges that need to be addressed for the technology to be deployed in the railway industry, in particular:

- **Advancing the capabilities of real-time feedback systems:** The AR app investigated was highly customized to the specific use case of the clutch check and requires further development to be applicable to other use cases.
- **Scalability:** The maintenance processes tested within the IARMO project were implemented over several months involving both software engineers and researchers, while regularly consulting with expert technicians. The economic deployment of the technology requires a significant reduction in implementation time. In addition, maintenance personnel should be able to digitalize their processes independently without a deep technical understanding of AR technology.
- **Integrating AR guidance into daily maintenance operations:** While the AR applications were tested during real maintenance operations, technicians were supported by a supervisor and ETH personnel. Allowing operators to use AR independently requires both operational adjustments and the integration with the existing IT infrastructure (i.e., SAP).

The team also created a startup and official ETH spin-off: Ucentrics that receive last summer the Innosuisse Startup Innovation Project grant that will support the development with 1.13 Mio CHF over the next 2 years.

2.2 Digital Twin of the Swiss Mobility System

The “Digital Twin of the Swiss Mobility System” is the flagship project of CSFM. It aims to develop a platform of integrative character to be deployed and used for all CSFM members to facilitate and promote the exchange of **mobility data** and **analytical tools** to support research, collaboration, and outreach activities for all members and partners and with emphasis on open-source solutions, accessibility and discoverability of data sets and tools and repeatability of results.

Towards Implementation: The Open Digital Twin Platform for Research on the Swiss Mobility System (ODTPR-SMS)

The first version of this Platform was built within the framework of a collaborative project with the Swiss Data Science Center (SDSC) funded by the ORD program of swissuniversities. The total federal donation for this project, approved in 2023, was **750 kCHF** (490 kCHF for CSFM-ETH Zurich).
The platform consists of modular open software that allows users to connect basic functional (core) modules and specific additional modules created to access, process, and analyze mobility-related datasets. Each user can create their modules by adopting some basic guidelines. These modules may allow users to analyze data, simulate scenarios, or transform data to extract information and gain insights. These modules can then be connected within the platform and combined with other modules.
The new modules can also be shared with the community, for example, to allow the reproduction of published results or comparison of different tools or datasets. Therefore, this platform promotes FAIR[1] principles among the Mobility Research community.

The first version of this platform was released in March 2024 and is publicly accessible at https://github.com/odtp-org/odtp. The documentation, tutorials, and manuals can be found at https://odtp-org.github.io/odtp-manuals/.

Additionally, to use the platform locally on your machine, it has been deployed on a server in ETH Zurich and can be accessed remotely. A graphical user interface simplifies the interaction with the platform, and we are working on making this Interface as straightforward to use as possible.

Use Case: Accessing eqasim and MATSim within ODTP

An example of combining tools within an ODTP workflow can be seen in the following Figure. We combine eqasim data loader, eqasim, MATSim, and visualization dashboards. Eqasim data loaders enable data loading from remote repositories and make them available to downstream modules. Eqasim transforms and models the loaded data using a sequence of statistical methods into the synthetic population and their activity patterns representative of the Swiss population. MATSim then simulates the movements of all people based on their preferences and travel needs and allows for the evaluation of changes in transport infrastructure and policy. Finally, the visualization dashboards enable us to visualize the implications of these changes.

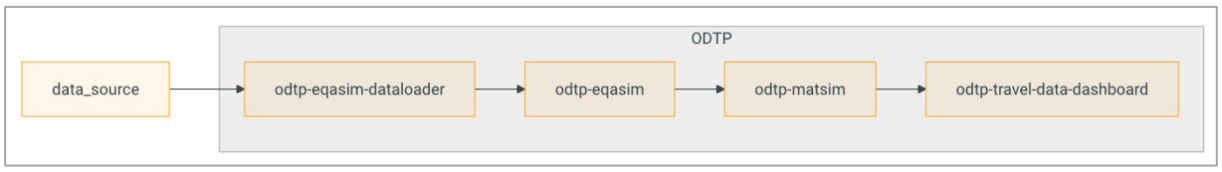


Figure 4. An example of an ODTP workflow to create and visualize a Digital Twin of the Swiss Mobility System.

[1] FAIR Data Principles: Findable, Accessible, Interoperable and Reusable

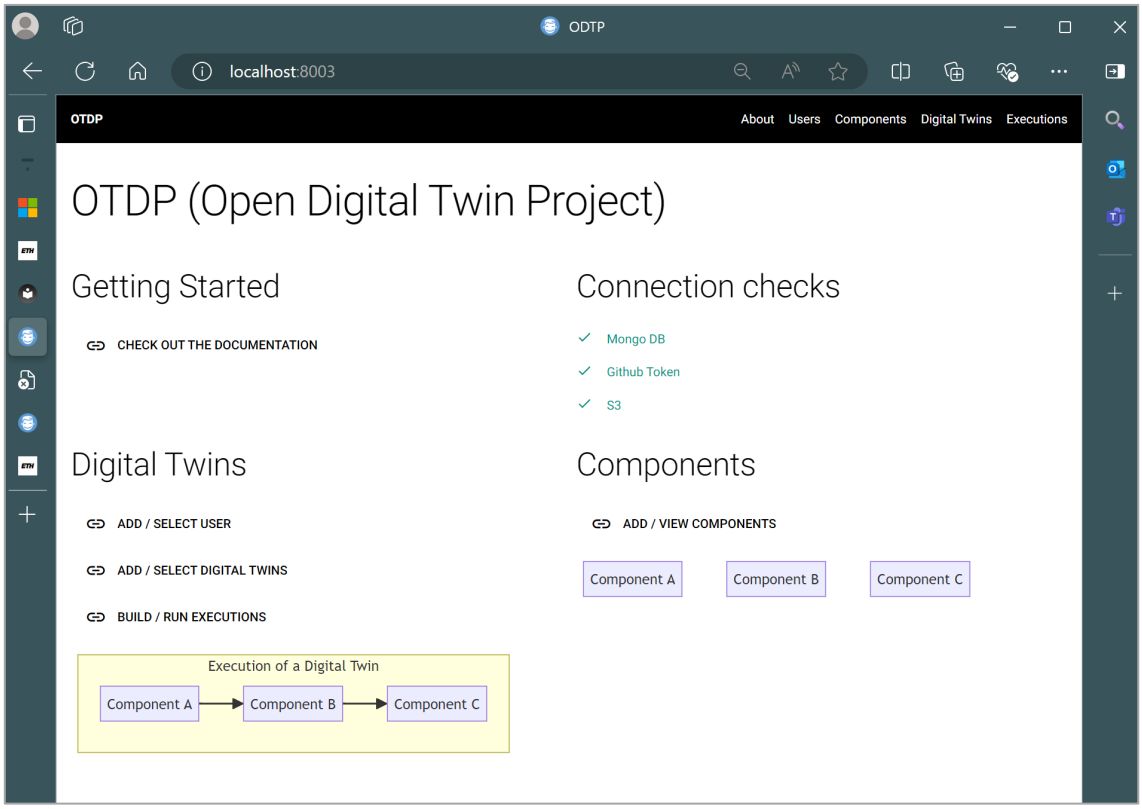


Fig. 5. The first version of the Graphical User Interface (GUI) of the Open Digital Twin Platform (ODTP)

Large-scale agent-based model of Switzerland

From 2024, the large-scale agent-based simulation model of Switzerland based on eqasim and MATSim developed at ETH Zurich is regularly updated and maintained within the Digital Twin group of the CSFM.

This model was developed over the past twenty years by Kay Axhausen's group, who retired in January 2024. Thanks to the timely knowledge transfer, this competence remains within the Digital Twin team at CSFM.

Several research groups from ETH Zurich use this agent-based model of Switzerland: The Power Systems Laboratory, Institute of Cartography and Geoinformation, Institute for Transport Planning and Systems (who were also, until recently, the leading developers of the model), Institute for Dynamic Systems and Control and the Infrastructure Management Chair, as well as across Switzerland at EPFL, FHNW, ZHAW, USI. The model allows us to investigate in a very accurate and detailed way the impact of infrastructure projects, new transportation offers, and different transport policies on the mobility system and its demand, making the model particularly interesting for research projects connected to Swiss federal offices, cantons, and cities.

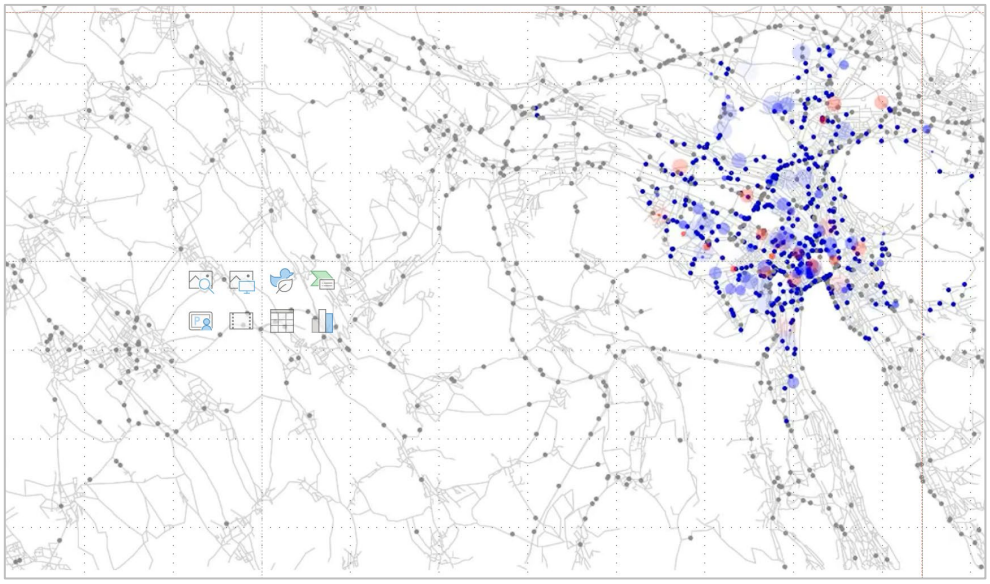


Figure 6: Visualization of the movements of the automated on-demand vehicles in Zurich using MATSim. (full video can be accessed at: https://polybox.ethz.ch/index.php/s/kPpVNBhNNE5Kquo)

MATSim (www.matsim.org): Multi-agent transport simulation (MATSim) is an open-source agent-based simulation initially co-developed by TU Berlin and ETH Zurich. It simulates every person and vehicle on an individual (agent) level. All agents, through an iterative process, learn to adapt and find better solutions to their travel routes and modes, thus allowing the user to study complex outcomes of transport policies and infrastructure projects.
Eqasim (https://github.com/eqasim-org) is an open-source activity-based modeling pipeline developed initially at ETH Zurich by Sebastian Hörl and Milos Balac. It can be used to generate a synthetic population and their detailed travel and activity patterns. The synthetic data describes every person and their socio-demographics. Each person is enriched with a detailed sequence of activities, including GPS coordinates, start and end times, and activity types. While these data can be used in various disciplines, like energy and health, we primarily use it as an input to the Swiss agent-based transport model based on MATSim.

Immersive Analytical Interfaces for Mobility Data

Within the context of the Digital Twin project, complementary funding from Hasler Stiftung will allow the team to explore the potential of Immersive Analytical Interface to visualize Mobility Data.

Immersive analytics is an emerging research field in Human-Computer Interaction (HCI) to facilitate visual reasoning. While immersive analytics presents significant benefits for spatial data analysis, particularly in representing complex time-oriented geodata like human movement trajectories, it also poses challenges. Previous studies have highlighted the potential of AR in data visual analysis. This research envisions to advance immersive spatial data analysis by integrating 3D representations cartographic methods, and geospatial analytical models. The objective is to propose immersive interfaces that can support high-level knowledge extraction. Furthermore, transportation planning and policymaking require knowing the correlations between human travel patterns and infrastructures and facilities. The idea is to utilize AR devices to superpose data visualizations and real-world places to enable users to better understand human mobility. In this project, we will design and implement a prototype and evaluate the advantages and disadvantages. The proposed method will be openly accessible (Hasler Stiftung. May 2024 – May 2025, 44.950 CHF).

CSFM transportation data catalogue

The Digital Twin team has been actively engaging with various groups working with mobility data, who may, in the future, use and enrich the Open Digital Twin Platform with their tools or by providing access to collected data. This collaboration led to the idea of preparing a catalogue to help discover and access available datasets. In November 2024, the team launched the first inventory of datasets collected and maintained by CSFM members. This inventory, which includes links to data, metadata, and contact information, is now available on the CSFM website.

At CSFM, one of our core objectives is to facilitate seamless access to data and tools within the transportation research community. By sharing and utilizing data generated by different groups, the team aim to foster collaboration and advance interdisciplinary research that supports sustainable mobility.

This first version of the catalogue is just the beginning, and we recognize that many useful and relevant data sets may still be missing. We encourage all colleagues and partners to contribute by adding additional references. Doing so will not only enhance the impact and visibility of specific research projects but also strengthen our collective knowledge base.

Educational offer supported by CSFM in the area of Mobility and transportation data

Since 2024, the team of the Digital Twin is offering the following educational activities:

- **Agent-based Modeling in Transportation**, Milos Balac and Grace Kagho. Introduction to agent-based modeling in transportation. The lectures and exercises offer an opportunity to learn about agent-based transport models' current methodology, how agent-based models are set up, and perform a practical case study using MATSim to evaluate the implications of transport policies.
- **Basics of Java and Best Practices for Scientific Computing,** Milos Balac. Introduction to programming in Java, version control, software packaging, and cluster computing.
- **Advanced Geospatial Data Mining and Visualization,** Chenyu Zuo and Stefan Ivanovic. This course provides knowledge in advanced methods for extracting and visualizing big geospatial data. Through a combination of lectures, hands-on exercises, and real-world case studies, participants will develop practical skills and knowledge for analyzing and visualizing complex spatial datasets.

Developed in 2024 to be first offered in the Spring semester 2025:

- **Computer Programming & Data Science – An Introduction with Python,** Kevin Riehl and Milos Balac**.** This course provides foundational programming, data science, and software engineering knowledge using Python. Through lectures, hands-on exercises, and real-world case studies related to transportation data science, participants develop practical skills and knowledge for creating simple programs to analyze datasets, implement algorithms, conduct simulations, and more.

Visitor and students

- Dmitrii Grishchuk, 15.04.2024 – 15.07.2024, Brno University of Technology
  Participated in further improving the agent-based transport model of Switzerland within the Digital Twin project.
- Hussein Mahfouz, 01.11.2024 – 31.01.2025, Leeds University (with Eva Heinen)

Hussein came as a visiting PhD student to ETH to learn how to develop an agent-based model for Leeds, UK, based on MATSim and eqasim.
- Chao Chen, Andrew Ding are Student Research Assistants since 01.12.2024 participating in developing visualization and validation measures for mobility digital twins.
- Fabian Brülisauer, Student Research Assistant since 01.08.2024, working for the Immersive Analytical Interfaces for Mobility Data project

Outlook

Activity towards developing a digital twin of Switzerland will continue and intensify in 2025 and beyond. While the first project with SDSC will conclude in December 2024, the scientist involved in it will continue working until mid-2025, refining the current implementation and integrating additional components.

Additionally, funds have already been secured for an essential platform expansion through an innovation project funded by Innosuisse starting in early 2025: *A Collaborative Mobility Digital Platform – From big data to zero emissions.* This project aims to develop Digital Twins of Mobility for the Geneva and Lausanne Regions based on the technology developed within the CSFM Digital Twin project. Thanks to the implementation partners, it will be possible to use **real-time passenger data** in model development and calibration, which will make available the generated know-how and tools to other regions and companies.

The consortium:

- Authorities (Canton de Genève, Canton de Vaud, Ville de Lausanne)
- Public transport operators (transports publics genevois (tpg), transports publics lausannois (tl), transports publics fribourgeois, Verkehrsbetriebe Zürich)
- Engineering firms (Citec, Transitec, Mobil'homme)

tpg, tl, and Ville de Lausanne will be the implementation partners in the project, while others will be supporting the project with their experience and know-how. Jointly, we will co-create the future of transport modeling in Switzerland.

A very important aspect of this project is that it will develop tools with the potential to drastically reduce the costs and time associated with creating transportation models. As the tools are adopted widely in different cantons and communities, they will facilitate the interaction and coordination between different responsible units, which would have an enormous impact on Switzerland. Innovation project, Innosuisse 1 Mio CHF Project budget (**~700k** CHF to CSFM) over 2 years.

3 Outreach and Networking Events

3.1 CSFM Symposium on May 29, 2024

The Center for Sustainable Future Mobility (CSFM) Symposium 2024 took place on May 29th. The event featured a keynote by **Marta González**, Professor of City and Regional Planning at the University of California. She presented her research on using mobile phone data to create models for managing demand and planning infrastructure development, understanding transport congestion, and defining urban structure and accessibility.

Juho-Pekka Virtanen, Product Owner of the Digital Twin at the Forum Virium Helsinki, shared insights on digital twins for mobility. He discussed the motivation, conceptual definition, and applications of digital twins, emphasizing data integration challenges over conventional traffic flow simulations and 3D city models.

Following the keynotes, young scientists presented their work in the poster award pitches, encouraging participation in the poster session.

A panel discussion concluded the morning session with **Sara El Kabiri** from the Swiss Federal Office of Spatial Planning (ARE), **Patrick Bützberger**, Head of Transport Planning at SBB, and the keynote speakers, moderated by **Emilio Frazzoli**. Patrick Bützberger briefly introduced the transport simulation activities at SBB, emphasizing the challenges and benefits of predicting mobility behaviour for transport operators. Sara El Kabiri outlined the Federal Office of Spatial Planning's role in mobility policy and sustainable development in Switzerland.

CSFM Symposium 2024

The panel addressed the importance of the transition towards sustainable transportation, emphasizing the complexity of the system and the need for collaboration among stakeholders. They stressed the necessity of dialogue and a shared vision among public administration, service providers, and society,

along with practical examples and pilot projects to demonstrate viable solutions. Adequate models and data accessibility are crucial for guiding decisions, despite challenges in data sharing. Collaboration should be incentivized, and public authorities must be technologically competent and ready to act as regulators.

The afternoon session featured presentations of ongoing Mobility Initiative projects:

- Autonomy-enabling Infrastructure for Future Mobility Systems (InsideOut) by **Mingjia He**, Institute of Dynamics Systems and Controls (D-MAVT)
- Power and Energy for the Future Railways (RailPower) by **Georgia Pierrou**, Power Systems Laboratory (D-ITET), and **Michael Nold**, Transport Systems (D-BAUG)
- Multimodality in the Swiss New Normal (Multimodality) by **Daniel Heimgartner**, Transport Planning (D-BAUG)

The event concluded with a focus on the CSFM Digital Twin project, a lighthouse project of the center, highlighting current use cases by **Stefan Ivanovic** from the Digital Twin team, and **Yanan Xin** from MIE Lab at the Chair of Geoinformation Engineering, IKG, on leveraging the CSFM-Open Digital Twin Platform (ODTP) for evaluating machine learning model robustness in mobility prediction.

Best Poster Award

The Best Poster Award was granted to **Marc Albert** from the Institute for Dynamic Systems and Control (D-MAVT) for his poster Autonomy-enabling Infrastructure for Future Mobility Systems: An Inside-Out Approach. The jury, consisting of Marta González, Juho-Pekka Virtanen, Sara El Kabiri, and Patrick Bützberger, evaluated the candidates based on content novelty, applicability towards CSFM goals, poster design, and their three-minute pitch.

The presentations by external guests and CSFM members, the panel discussion, as well as the poster session, provided opportunities to present the latest research results and engage in discussions.

3.2 Mobility Initiative Workshop 2024

The Center launched the 7th call of the Mobility Initiative on a dedicated workshop organised at ETH Zurich last March 12th. The workshop brought together about 40 researchers and partners to discuss project ideas for the Mobility Initiative call for proposal. 14 project ideas were presented and discussed at this occasion most of which were follow up after the event and resulted in a total of 11 applications to the Mobility Initiative call. The approved projects are listed in the previous section of this report.

The workshop connected the domain experts and the Mobility Initiative partners. A particular asset of the workshop is that it allows to explore potential synergies between ideas proposed by different partners enriching considerably the project proposals. Several ideas presented were the followed up in bi-lateral discussion and resulted in concrete project proposals submissions.

3.3 Seminar Series

A seminar series was launched in the spring semester 2023. With this series, we aimed at creating a new communication vehicle within the incipient CSFM network by addressing issues relevant to the rather interdisciplinary community, the centre's industry partners and other institutions active in the field of sustainable mobility. One of the objectives of this seminar series is also to facilitate the interaction and exchange between CSFM members that may not be aware of the research work being conducted in other groups. This year we started with an event on new regulations for Autonomous Vehicles in Switzerland, in March we discussed the factors influencing he adoption and charging patterns of electric

vehicles and a seminar is planned for 12 December on Technological perspectives and scientific challenges of Automatic train operation.

3.3.1 New Regulations for Autonomous Vehicles in Switzerland (11.1.2024)

With the latest developments in autonomous driving and a multitude of pilot tests going on in different cities, it seems critical to develop the necessary regulations also in Switzerland. In this seminar, we discussed the challenges posed by these technologies to regulators and society with **Professor Emilio Frazzoli,** Institute for Dynamic Systems and Control (ETH Zurich), **Stephen Milford**, University of Basel, on ethical aspects of regulating Autonomous Vehicles, **Professor Thomas Probst**, Chair of Law of Obligations, European Private Law and Comparative Law, University of Fribourg, on the legal framework an overview of key issues, **Armin Jost** from the Federal Roads Office, on the current mandate and status of the regulation, **Xilin Zhou**, from SwissRe on the crucial role of insurance for autonomous vehicles and finally the perspective of operators on safety and cybersecurity regulations for AV presented by **Amin Amini** from Loxo.

▪Number of participants: 71 with 55 external to ETH Zurich, 4 departments represented

3.3.2 Factors Influencing the Adoption and Charging of Electric Vehicles (19.3.2024)

At this CSFM Seminar Davide Cerruti, Ursa Bernardic and Professor Massimo Filippini from the Center for Energy Policy and Economics (CEPE) presented the latest research results along with insights from Dr. Luca Castiglioni of SFOE/BFE on policy and research, and a industry perspective from Dr. Martin Everts, Managing Director of AMAG Energy & Mobility.

The presentations were followed by a lively discussion moderated by **Massimo Filippini** and allowed the audience to pose questions and a discussussion with the experts. Several comments related to the potential of using BEVs to provide flexibility to the grid. It seems clear that smart solutions for bi-directional connection to the grid may be available, but adequate regulation and suitable business cases to deal with the additional complexity are critical, too. Additionally, the users ov BEVs may not be ready to cope with this complexity which should be provided by the Distribution System Operator (DSO) or the car companies.

▪Number of participants 56 Participants with 14 external to ETH Zurich and 6 departments represented.

3.3.3 Technological Perspectives and Scientific Challenges of Automatic Train Operation (12.12.2024)

This seminar delved into the future of rail transport with Automatic Train Operation (ATO). This technology promises to revolutionize train operations, potentially enhancing network capacity, traction energy efficiency, and infrastructure utilization. Despite its huge potential, several technological and organizational challenges remain.

This event brought together experts from science, railway operations and industry to discuss the latest advancements and challenges on the topic.

▪Number of participants 98 Participants with 70 external to ETH Zurich.

3.4 Other dissemination and communication Measures

The primary platforms for disseminating information about the Mobility Initiative call for proposals, as well as news and events from CSFM, are currently the CSFM webpage and LinkedIn channels. To enhance communication effectiveness, particular emphasis has been placed on adapting those channels to the specific profile of the CSFM members and partners tailoring content to resonate with our audience. In the past year, we successfully published 18 news articles, with 10 originating from the center management office. We also regularly publish news highlighting member achievements and event organized by our partners or related ETH institution which are published also in other channels, and relevant funding opportunities.

LinkedIn has emerged for CSFM too as a pivotal platform for sharing corporate news and allowing scientists to showcase their accomplishments and activities.

Below a selection of news and dissemination activities, particular emphasis of our news channels is set to disseminate news about the Mobility Initiative project:

- Introducing the new CSFM transportation data catalogue (7.11.2024)
- Maintaining train schedule STABILITY and managing time table reserves via digitalised railway intervention planning (29.10.2024)
- New Mobility Initiative projects approved (13.9.2024)
- Multimodality in the Swiss New Normal, new insights and evidence released under the recently concluded Mobility Initiative project (5.7.2024)
- OMISM: On-board Monitoring for Integrated Systems Understanding & Management Improvement in Railway (15.5.2024)
- EVAdopt: De-biasing Electric Vehicle Adoption with Personalized Nudging (15.3.2024)
- Innovation Booster of the New Mobility Labe (different calls) (12.2.2024)

Transportation Research Arena

The Center for Sustainable Mobility collaborated with the initiative of the Federal Office of Transport and the State Secretariat for Education, and other relates Swiss institutions, to curate a joint booth at the Transport Research Arena (TRA). This synergistic effort allowed to showcase cutting-edge research, innovation, and sustainable solutions within the area of transportation. Additionally, the joint booth served as a platform, exemplifying the collaborative spirit of Swiss institutions dedicated to advancing mobility research. Visitors explored a diverse array of projects, ranging from state-of-the-art technologies to impactful policy initiatives, all of which underscore Switzerland's commitment to shaping the future of transportation. The contribution of Center for Sustainable Future Mobility consisted in four project highlights the Mobility Initiative project and an overview of the CSFM research community as well as our Digital Twin flagship project.

Swiss booth at the Transport Research Arena, with Thomas Gugler (SBB), Manuel Schneider (Flatland association), Markus Liechti (FOT), Johanna Tudeau (SBFI), Erik Nygren (Flatland), Andreas Lüssi, Deputy (Swiss embassy in Ireland), Gloria Romera (CSFM), Felicity Wakefield and Robert Ampmah (Network Rail and Global Centre for Rail Excellence in Walles)

3.5 Entrepreneurship

The CSFM supported in 2024 the calls of the Innovation Booster focused on "New Mobility". This initiative, backed by Innosuisse, aims to ignite the entrepreneurial enthusiasm among researchers within the CSFM network. The CSFM is actively engaged in promoting this initiative across its members, extended network, and ETH Zurich, encouraging students and researchers to take on the challenges presented and develop ideas that have the potential to evolve into impactful commercial solutions. By fostering a spirit of innovation and collaboration, the CSFM aims to contribute significantly to the success of the Innovation Booster and the advancement of pioneering solutions toward sustainable future mobility.

We hope to be able to contribute further, particular in the form of providing support to the expert evaluation and engaging young scientist to apply for this funding opportunities.

4 Outlook

Strategic Focus and Future Challenges

In the coming months, the center's primary focus will be securing support for its next phase. The ongoing reformulation of ETH center guidelines introduces significant uncertainty, impeding the completion of a comprehensive development plan. In particular The mentioned reformulation process will entail substantial changes in the conditions and roles of all ETH centers, which must be factored into planning the center's future direction and operations. Consequently, strategic planning efforts must remain adaptable to these impending changes in governance.

Despite the absence of finalized plans, the Steering Committee has engaged in a thorough reflection on the center's core strengths and added value over the past few months. Key points include:

Thematic Scope: We aim to preserve the broad thematic scope of our activities. Urban planning and mobility behavior are critical to achieving any transformation of the system. The optimization potential of increased digitalization in operations and maintenance of assets is also still critical. Exploiting big data, artificial intelligence, as well as data sharing between actors to foster mobility solutions are topics that are developing very fast, making applied research increasingly important to be able to successfully exploit and anticipate solutions and new developments Additionally, addressing the vehicles, energy provision, and infrastructure necessary for low environmental impact transportation, along with the required business models, policies, and investments, remains a critical and multidisciplinary problem the center should contribute to address.

Industry Collaboration: Industry and academia mutually enrich each other through collaborative research projects, where practical applications and industry needs inspire academic inquiry, leading to innovative solutions that benefit both. These collaborations allow academia to gain critical insights into impactful research questions and problems while the industry benefits from exposure to new trends and methodologies that, although maybe not mature for immediate appliation, provide a glimpse into future solutions and what future workforce skills will be needed.

Community Building: The center has successfully connected researchers and practitioners working in complementary areas, growing the CSFM community from the initial 40 members to over 350 networked participants. This includes individuals interested in following up and joining the center's events.

Expanding Partnerships: While our collaboration with current strategic partners has been excellent and their initial long-term support crucial for building the community and launching a successful research program, both we and the Mobility Initiative partners recognize the need to broaden our partner base. During this period, the center engaged in extensive discussions with potential partners, including visits from industry representatives and governmental institutions interested in exploring collaboration with ETH Zurich. Additionally, we have worked with the ETH Foundation to develop a more flexible membership contribution model. The final decision will depend on how the center and the Mobility Initiative evolve under the new guidelines.

International Cooperation: Transportation is a global issue, and leading universities share our drive to support the ongoing transformation of the transportation system. Institutions like Chalmers, Delft, and MIT also host mobility and transportation centers. We aim to leverage our connections with these institutions to nurture and develop a cost-neutral exchange program, increasing engagement and interest among young participants.

Communication and Outreach: We believe that it is crucial for the future of the center to clearly and systematically articulate what the center brings to its members, ETH Zurich, and Switzerland. For that, we aim to not only redefine the center's strategic focus, but also to further develop our communication and outreach efforts to enhance the impact of the center's activities. This includes increasing engagement with our community, promoting our activities, and ensuring that the value and impact of the research by the CSFM members and in particular the Mobility Initiative program are clearly communicated to all stakeholders. By strengthening these efforts, we hope to build a more robust and connected network that supports our mission and goals.

Open Digital Twin Platform: The achieved results and attention in this short time confirmed the potential of this idea. The activity taps into the very critical aspects of establishing infrastructure and process that promotes collaboration ecosystem in which discovering and sharing data, as well as analytical and simulation tools is facilitated so that can more easily be exploited for the community to explore and develop solutions for the mobility system.

Annex

Publications

An, Y., J. Chen, H. Blum, B.T. Adey, C. Haas and M. Pollefeys (2024) OptXR: Optimization of Maintenance Processes with Extended Reality and Digital Twins, poster at the *Center for Sustainable Future Mobility Symposium 2024 (CSFM 2024)*, Zurich, May 2024.

Arcieri, G., C. Hoelzl, O. Schwery, D. Straub, K.G. Papakonstantinou and E. Chatzi (2024) POMDP inference and robust solution via deep reinforcement learning: an application to railway optimal maintenance, *Machine Learning*, 113 (10) 7967–7995.

Arcieri, G., T. Rigoni, C. Hoelzl, D. Haener and E. Chatzi (2024) Ground penetrating radar for moisture assessment in railway tracks: An experimental investigation, paper presented at the *11th European Workshop on Structural Health Monitoring (EWSHM 2024)*, Potsdam, June 2024.

Balac, M. (2024) Digital twin of Swiss mobility, presentation at the *2nd CEETRA Annual Meeting*, Vienna, July 2024.

Bernardic, U., D. Cerruti, M. Filippini, J. Savelsberg and G. Ugazio (2024) De-biasing electric vehicle adoption with personalized nudging, *Economics Working Paper Series*, 24/390, ETH Zurich, Center of Economic Research (CER-ETH), Zurich.

Bernhard, P., D. Haener and O. Frey (2024) Detection of Railway Track Anomalies Using Interferometric Time Series of TerraSAR-X Satellite Radar Data, *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing*, 17, 11750–11760.

Chuo, S.Y.-P., H. Mehranfar, B.T. Adey and G. Elshani (2024) Connecting predictive algorithms to BIM to improve the planning process, paper presented at the *12th International Conference on Bridge Maintenance, Safety and Management (IABMAS 2024)*, Copenhagen, 2024.

Chuo, S.Y.-P., H. Mehranfar and B.T. Adey (2024) The use of BIM in the railway intervention planning process to support the early estimation of future interventions, *report*, IBI, ETH Zurich, Zurich.

Chuo, S.Y.-P., S. Moghtadernejad, B.T. Adey and H. Mehranfar (2024) Estimation and prediction of track component condition states based on condition data availability to support the digitalized estimation of future interventions, *report*, IBI, ETH Zurich, Zurich.

Dong, H., E. Chatzi and O. Fink (2024) Towards Multimodal Open-Set Domain Generalization and Adaptation through Self-supervision, *arXiv*, 2407.01518, ETH Zurich, Zurich.

Dong, H., G. Frusque, Y. Zhao, E. Chatzi and O. Fink (2024) NNG-Mix: Improving Semi-Supervised Anomaly Detection With Pseudo-Anomaly Generation, *IEEE Transactions on Neural Networks and Learning Systems*, DOI: 10.1109/TNNLS.2024.3497801.

Dong, H., Y. Zhao, E. Chatzi and O. Fink (2024) MultiOOD. Scaling Out-of-Distribution Detection for Multiple Modalities, *arXiv*, 2405.17419, ETH Zurich, Zurich.

Grisiute, A., N. Wiedemann and M. Raubal (2024) Network Design and Evaluation for the E-Bike City Vision, poster at the *Center for Sustainable Future Mobility Symposium 2024 (CSFM 2024)*, Zurich, May 2024.

Heimgartner, D. and K.W. Axhausen (2024) Hybrid work arrangement choices and its implications for home office frequencies, paper presented at the *103rd Annual Meeting of the Transportation Research Board (TRB 2024)*, Washington, DC, January 2024.

Heimgartner, D. and K.W. Axhausen (2024) Multimodality in the Swiss New Normal. Data collection methods and response behavior in a multi-stage survey with linked stated preference designs, *Arbeitsberichte Verkehrs- und Raumplanung*, 1895, IVT, ETH Zurich, Zurich.

Heimgartner, D., A. Sallard, M. Balac and K.W. Axhausen (2024) Multimodality in the Swiss New Normal (SNN): Future Mobility Research Program, IVT, ETH Zurich, Zurich.

Heimgartner, D., A. Sallard, M. Balac and K.W. Axhausen (2024) Multimodality in the Swiss New Normal (SNN), presentation at the *Center for Sustainable Future Mobility Symposium 2024 (CSFM 2024)*, Zurich, May 2024.

Kagho, G.O., M. Balac, M.A.B. van Eggermond and A. Erath (2024) Simulation of policies for automated ride-hailing and ride-pooling services, *Arbeitsberichte Verkehrs- und Raumplanung*, 1891, IVT, CSFM, ETH Zurich and FHNW, Zurich and Basel.

Lee, J., M. Bjelonic, A. Reske, L. Wellhausen, T. Miki and M. Hutter (2024) Learning robust autonomous navigation and locomotion for wheeled-legged robots, *Science Robotics*, 9 (89) DOI: 10.1126/scirobotics.adi9641.

Levis, A. (2024) How can we tax electric cars without slowing down the electromobility transition?, blog post, ETH Zukunftsblog.

Levis, A. and T. Bernauer (2024) Neue Abgabe auf Elektroautos: Wie sollte diese aus Sicht der Schweizer Wohnbevölkerung aussehen?, *5th Wave of the Swiss Mobility Panel*, ISTP, ETH Zurich, Zurich.

Lordieck, J., M. Nold and F. Corman (2024) Microscopic railway capacity assessment of heterogeneous traffic under real-life operational conditions, *Journal of Rail Transport Planning & Management*, 30, 100446.

Mehranfar, H., B.T. Adey and S.Y.-P. Chuo (2024) Improvements in providing overviews of future bridge interventions, their possession windows, and costs, paper presented at the *12th International Conference on Bridge Maintenance, Safety and Management (IABMAS 2024)*, Copenhagen, June 2024.

Mehranfar, H., B.T. Adey and S.Y.-P. Chuo (2024) Input Component Data for Determining Intervention Programs, *dataset*, IBI, ETH Zurich, Zurich, DOI: 10.3929/ethz-b-000677521.

Mehranfar, H., B.T. Adey and S.Y.-P. Chuo (2024) A Methodology for Determining Optimal Component-Level Railway Intervention Programs, paper presented at the *Georg Nemetschek Institute Symposium & Expo on Artificial Intelligence for the Built World*, Munich, September 2024.

Mehranfar, H., B.T. Adey, S. Moghtadernejad and S.Y.-P. Chuo (2024) Using algorithms to provide track managers with consistent and complete early estimates of possible future maintenance interventions: Project STABILITY under the ETH Mobility Initiative, *report*, IBI, ETH Zurich, Zurich.

Mehranfar, H., B.T. Adey, S. Moghtadernejad and S.Y.-P. Chuo (2024) An algorithm to improve the efficiency and effectiveness of determining multi-component intervention programmes for railway networks that result in the lowest disruptions to service: A case study of Zollikofen-Brügg railway network - Project STABILITY under the ETH Mobility Initiative, *report*, IBI, ETH Zurich, Zurich.

Mehranfar, H., B.T. Adey, S. Moghtadernejad and C. Fecarotti (2024) Improving the planning of future track interventions using digital tools, presentation at the *10th Transport Research Arena (TRA 2024)*, Dublin, April 2024.

Mehranfar, H., B.T. Adey, S. Moghtadernejad and S.Y.-P. Chuo (2024) Automated early estimation of bridge interventions, possession windows and costs, *Infrastructure Asset Management*, 11 (3) 128–144.

Mehranfar, H., S.Y.-P. Chuo, S. Moghtadernejad and B.T. Adey (2024) STABILITY: Improving railway intervention planning through digitalisation, poster at the *Center for Sustainable Future Mobility Symposium 2024 (CSFM 2024)*, Zurich, May 2024.

Meister, A., M. Balac, L. Zheng and K.W. Axhausen (2024) Route choice model integration into MATSim, presentation at the *8th Annual Meeting of the Cycling Research Board (CRBAM 2024)*, Zurich, September 2024.

Meister, A., Z. Liang and M. Balac (2024) Probabilistic routing for agent-based simulations, *Arbeitsberichte Verkehrs- und Raumplanung*, 1889, IVT, CSFM, ETH Zurich and HKUST, Zurich and Hong Kong.

Meyer, N. (2024) Despan–Deformation spotter and analysis workflow for elongated point clouds, *sofware*, IGP, ETH Zurich, Zurich, URL: https://github.com/gseg-ethz/despan.

Naghizadeh, E., P. Tiso and E. Chatzi (2024) Crack Detection in Train Wheelset Axles Based on Nonlinear Higher Order Harmonics of Breathing Crack, presentation at the *IMAC-XLII International Modal Analysis Conference*, Orlando, January 2024.

Nold, M. and F. Corman (2024) Calibration of vehicle simulations by using acceleration sensors, paper presented at the *24th Swiss Transport Research Conference (STRC 2024)*, Ascona, May 2024.

Nold, M. and F. Corman (2024) Results of the project Rail Power: Power and energy for the future railways, poster at the *Center for Sustainable Future Mobility Symposium 2024 (CSFM 2024)*, Zurich, May 2024.

Nold, M. and F. Corman (2024) Increasing realism in modelling energy losses in railway vehicles and their impact to energy-efficient train control, *Railway Engineering Science*, 32 (3) 257–285.

Nold, M. and G. Pierrou (2024) Power and energy for the future railways (RailPower), presentation at the *Center for Sustainable Future Mobility Symposium 2024 (CSFM 2024)*, Zurich, May 2024.

Pierrou, G., C. Valero-De la Flor and G. Hug (2024) Optimal EV charging scheduling at electric railway stations under peak load constraints, *Electric Power Systems Research*, 235, 110612.

Schneider, L., G. Grote and D. Boos (2024) Establishing Control through targeted explanations How XAI enables Stakeholder Negotiations about the Distribution of Accountability and Control in Safety-Critical Domains, paper presented at the workshop on *HCXAI at the ACM Conference on Human Factors in Computing Systems (CHI) 2024*, Honolulu, USA.

Schneider L., G. Grote, and D. Boos (2024) No One Size Fits All: Testing different XAI approaches for heterogenous user groups, paper presented at the *Symposium on Human-AI Interaction at the Workplace at the 53rd Congress of the German Psychological Society (DGPS)*, Vienna, Austria.

Wei, M., Y. Feng, C. Chen, P. Luo, C. Zuo and L. Meng (2024) Unveiling public perception of AI ethics: an exploration on Wikipedia data, *EPJ Data Science*, 13 (1) 26.

Weinold, M., B. Arendt, D. Dedic, B. Weißenburger and R. McKenna (2024) Mapping Future Air Travel Demand from Open Data, poster at the *Center for Sustainable Future Mobility Symposium 2024 (CSFM 2024)*, Zurich, May 2024.

Wilder-Smith, M., V. Patil and M. Hutter (2024) Radiance Fields for Robotic Teleoperation, paper presented at the *IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS 2024)*, Abu Dhabi, October 2024.

Yan, T.-H. (2024) Enhancing decision-making in railway maintenance and inspection through the integration of on-board monitoring (OBM) technique into infrastructure management, *Doctoral Thesis*, ETH Zurich, Zurich.

Yan, T.-H., C. Hoelzl, F. Corman, V. Dertimanis and E. Chatzi (2024) Integration of On-Board Monitoring (OBM) data into infrastructure management for effective decision-making in railway maintenance, *Railway Engineering Science*.

Zuo, C., M. Balac, J. Grübel and K.W. Axhausen (2024) OD-Vis: A Map-based Dashboard for Insight Discovery of OD Data, paper presented at the *European Cartographic Conference (EuroCarto 2024)*, Vienna, September 2024.

Zuo, C., M. Wei, P. Zhang, C. Chen and L. Meng (2024) Assessing maps for social topic representation: a qualitative content analysis of maps for sustainable mobility, *International Journal of Cartography*, DOI: 10.1080/23729333.2024.2392212.

Financial Summary 2024

Material costs	Budget 2024	Expenditure 2024
Management Office (Office, IT)	14'135.00	7'354.91
Rep., Coordination, Gov	2'600.00	894.60
KTT, Communication	23'400.00	22'477.47
Mobility Initiative - Events	2'700.00	1'962.20
TOTAL material costs	**42'835.00**	**32'689.18**

Personnel costs		
Total MO	247'000.00	254'794.05
Digital Twin	80'300.00	70'915.20
TOTAL Personal costs	**327'300.00**	**325'709.25**

TOTAL costs	**370'135.00**	**358'398.43**

Revenues	2024
Mobility Initative:	200'000.00
ETH Zurich Executive Board:	120'000.00
CSFM Membership fees:	26'500.00
TOTAL Revenues	**346'500.00**

Difference yearly expenditure/revenues	**-11'898.43**

CSFM Reserves (2021-2023)	**166'227.11**

ODTPR-SMS

Budget and financial status of the ETH Zurich part of the ODTP-SMS grant (swissuniversitites)

ODTPR-SMS	**Budget**	**Expended**	**Saldo**	**Budget**	**Expended**	**Saldo**
Material costs						
Total	5'000.00	4'299.57	700.43	5'000.00	6'406.59	-1'406.59
Personnel costs						
Total	204'815.00	157'831.35	46'983.65	275'185.00	322'223.50	-47'038.50

Funds transfered to 2024	**47'684.08**	Final Saldo	**-761.01**

Members

DEPARTMENT/ Name	Institute / Lab
BAUG	
Brian Adey	Infrastructure Management
Eleni Chatzi	Structural Mechanics and Monitoring
Francesco Corman	Transport Systems
Eva Heinen	Transportation and Mobility planning
Stefanie Hellweg	Institute of Environmental Engineering
Adrienne Grêt-Regamey	Institute of Spatial and Landscape Development
David Kaufmann	Institute for Spatial and Landscape Development
Anastasios Kouvelas	Traffic Engineering and Control
Martin Raubal	Institute of Cartography and Geoinformation
CHAB	
Thomas Schmidt	Electrochemistry
GESS	
Thomas Bernauer	International Political Economy and Environmental Politics
Tobias Schmidt	Energy Policy
Bjarne Steffen	Climate Finances and Policy
INFK	
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Siyu Tang	Computer Vision and Learning Systems
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Russell McKenna	Energy Systems Analysis
Christopher Onder	Institute for Dynamic Systems and Control
Aldo Steinfeld	Institute of Energy and Process Engineering
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Volker Hoffmann	Sustainability and Technology
Stephan Wagner	Supply Chain Management
USYS	
Anthony Patt	Climate Policy
Michael Stauffacher	Tdlab
Empa	
Miriam Elser	Vehicle Systems Group
FHNW	
Silvia Mastellone	Institute of Electric Power Systems

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