**COORD: On-demand fleet orchestration and coordination with existing transit network operations.**

**Executive Summary:**

In 2022, Public Transport of Fribourg (TPF) transported 34.5 million passengers across its 66 bus routes and 3 rail lines, with this number continuously on the rise. TPF is expected to face important challenges in the years to come due to the growth of demand, efforts towards environmental impact and sustainability and integration of new technologies in efficient, sustainable, and reliable operations of public transport. Similar trends and challenges apply to almost every urban area in CH and worldwide. This project intends to revolutionize how emerging technologies and their applications reshape public transport services by providing flexible collective transport with increased accessibility, sustainability and reliability. COORD aims to integrate in real-time multi-sensor public transport data with Machine Learning, traffic modeling and optimization to comprehensively explore the benefits of flexible on-demand transport for public transport improvement. Emerging transportation paradigms like dedicated and dynamic bus lanes and on-demand services, coupled with strong forecasting and optimization methods will create more reliable, efficient and sustainable public transport services. TRANSFORM will pioneer a unique blend of quantitative methods and engineering principles to create a one-of-a-kind multi-sensor mobility observatory for high-quality monitoring, prediction, and management of public transportation in the city of Fribourg with a strong interest from the city for a field implementation. The project will develop two parallel themes. Thread 1 focuses on the optimization of station-based on-demand micro-transit services as a first- or last-mile solution for public transit. Thread 2 aims at conceptualizing on-demand services as an interconnected transport alternative to fixed-line buses in instances of demand surge or congestion uncertainty. The synchronization and coordination of fixed- and flexible-line services will result in improved services even in case of abruptions and non-recurrent events. The project aims to employ novel and often disruptive technologies to solve pressing mobility issues (congestion, livability, sustainability, safety and equity) for the city of Fribourg. The developed framework will be generic, scalable and adaptable for public transport management and services to enhance mobility at urban and interurban levels to other Swiss cities and worldwide. For transport authorities and municipalities, COORD provides understanding, methods, models and algorithms for multi-modal traffic management.

A diagram of a bus service

Description automatically generated

**Application to NCCR Automation Phase II Industry Call**

**Main applicant:** *Prof. Nikolas Geroliminis, EPFL*

**Category:** *2*

**Partner(s): *Company:*** *Transport Publics Fribourgeois (TPF),* ***Address:*** *Route du Vieux-Canal 6, 1762 Givisiez,* ***Collaborator:*** *Mrs****.*** *Gaelle Abi Younes,* ***Role:*** *Transport and mobility engineer*

**Related NCCR Theme(s)/Thread(s):** *Theme 3.1 Thread A*

**Level of support:** *PostDoc*

***Funding request:*** *18 months of Post-doc at an annual rate of 90,000CHF plus 16% Social charges plus 4,000CHF for conference travel* ***(Total budget: 160,600 CHF)***

**Proposal title:**

COORD: On-demand fleet orchestration and coordination with existing transit network operations.

**Project description:**

**Introduction**

Mobility-as-a-Service platforms revolutionized the transport and mobility sectors. Multiple transportation options, including public transit and on-demand travel alternatives, are bundled to provide travelers with integrated, efficient, and sustainable mobility solutions. Through high-level coordination between different urban transport providers, MaaS supplies users with innovative, up-to-date, and diversified transport options, simultaneously ensuring user convenience and efficient utilization of available network resources and infrastructure. The new era of sharing information and the “Big data & AI world” has paved the way for reinforcing the efficiency and the widespread of MaaS platforms. By integrating multi-sensor data, optimization with uncertainty, and traffic modeling, this project aims to comprehensively explore the benefit of implementing Intelligent Transportation Systems (ITS) in public transportation enhancement through collaboration with Transport Publics Fribourgeois (TPF). TPF with more than 60 city and regional lines and more than 30M passenger-trips per year faces significant challenges in the everyday operations related to spatio-temporal demand uncertainty, higher congestion in the city, and increased demand for public transport. Emerging transportation alternatives, like ride-hailing and high-capacity on-demand services, coupled with technological advancements such as vehicle-to-vehicle and vehicle-to-infrastructure communication all have a great potential to complement the current public transit structure and operation. All the previous elements will be embodied within a single MaaS platform that will enable the development of more efficient and reliable services for all travelers in the region to be integrated by TPF in their system. The proposed development in this project encompasses two distinct threads designed to address critical challenges in the domain of the design and operation of smart mobility bundles in public transportation.

* Thread 1 focuses on the optimization of station-based on-demand micro-transit services as a **first- or last-mile solution** for public transit. In the first stage, based on a large amount of real data from thousands of bus trips (GPS of buses, passenger counts and congestion indices), we will identify areas where public transit services are deficient and in the second stage, we will envision, design, and orchestrate a complementary service to public transit.
* Thread 2 aims at conceptualizing on-demand services as an interconnected transport alternative to fixed-line buses in **instances of demand surge or congestion uncertainty**. The synchronization and coordination of fixed- and flexible-line services will result in improved services even in case of abruptions and non-recurrent events, that TPF considers as a unique opportunity to enhance their current services.

**Thread 1: On-demand micro-transit as a first- or last-mile solution to public transit**

Unlike fixed-schedule and fixed-route high-capacity public transit, on-demand services are characterized by fast-responding medium-capacity vehicles with flexible schedules and routes [1]. These innovative services have a myriad of advantages, among which are increased efficiency, improved user convenience, greater service reliability, and better matching efficiency compared to traditional taxi or public transport alternatives. Within this context, the Dial-a-Ride Problem (DARP) is a fundamental aspect of the on-demand service operation: the vehicle-to-passenger matching, and passenger-to-passenger pairing is a class of optimization problems that is NP-hard. The optimization framework of DARP matches passengers and dispatches vehicles with the objective of minimizing travel route costs, maximizing operator’s profit, or guaranteeing the best quality of service [2], all while abiding by waiting time, detour time, and capacity constraints [3]. Dynamic versions of DARP which we refer to here by on-demand micro-transit, consider that users book their trips with a relatively short notice period. Algorithmic approaches to solving the problem include exact methods like Branch-and-Cut [4] or graph-based ILP [5] in static and semi-static settings, heuristics [6] and meta-heuristics methods [7] for the dynamic problem settings. Given that trip requests arrive dynamically with no prior knowledge of the demand, meta-heuristics are better suited for this type of implementation. Under on-demand micro-transit services, the optimization scheme for the trip assignment follows a first-come first-served basis where requests are inserted in a micro-transit vehicle route. However, due to the dynamic nature of the problem, the progressive uncovering of new information or the potential vehicle breakdown calls for a re-optimization run to improve solution quality. In this case, resorting to learning techniques is advantageous for the re-optimization rounds, mainly because altering the different matching decisions improves the system’s future performance. Besides being a user-oriented service, the employed optimization technique must ensure the sustainable aspect of on-demand services, by mainly maintaining a reasonable balance between user delays and total detour by vehicles.

An additional layer of complexity comes into question when the operational framework of micro-transit services is intended to complement fixed-schedule services. Under this thread, the aim is to jointly optimize on-demand systems and public transit in areas where public transit services are deficient or underperforming. Ubiquitous sensing and travel demand forecasting pave the way for this complementarity between the different systems. The envisioned optimization technique to be developed will leverage collected travel and traffic information to produce an integrated demand-responsive, robust, user-oriented algorithm to secure a sustainable and satisfactory service structure by ensuring timely synchronization and coordination between first- or last-mile on-demand services and fixed-schedule transit. Under this realm, on-demand alternative transports travelers from their origin location to their transfer hub location, or their transfer hub location to their destination location.

**Thread 2: Interconnected and coordinated flexible and fixed line services.**

Fixed-schedule and fixed-route public transit services are subject to sporadic disruptions, unforeseen delays, and sudden non-recurrent events that compromise service quality and jeopardize the system’s reliability. This thread aims to design and orchestrate a robust station-based, medium-capacity, on-demand micro-transit service that is well-integrated and fully-coordinated with the existing public transit operations, even if some competition between the two modes remains indisputable [8]. Under this research scope, on-demand micro-transit is expected to relieve the overburdened transit service operation. A MaaS platform dynamically receives travel requests, including pick-up and drop-off station locations [9]. Based on the congestion state, the service quality of public transit, the micro-transit fleet operation, and the historical demand pattern, the MaaS system recommends one of the following three alternatives: a micro-transit trip, a public transit trip, a composite micro-transit and public transit trip with transfer. Therefore, choosing which passengers will be served by which mode will be addressed by a pervasive optimization approach, integrating predictions of the near-future demand and the state of the system, and actions controlling the movement of vehicles to the right location at the right time to serve “matched” passengers. For the matching and dispatching of passengers within micro-transit services, some aspects of the assignment metaheuristics will be utilized from thread 1. The challenge here is to provide efficient routing mechanisms for large networks and achieve high utilization of public transport and on-demand vehicles through collective travel and short excess time for travelers. The proposed MaaS bundle is distinctive in its features and algorithmic design because it can ensure a resilient transport network in anticipated events like bus bunching or bus delays and unforeseen events like accidents or vehicle breakdowns.

**Contributions to the goals of the selected category:**

TPF manages a multi-modal fleet of buses with many yearly passengers utilizing its bus routes and rail lines. With the expected surge in travel demand, the need for innovative solutions to improve public transit efficiency, coverage, and reliability is undeniable. This project will utilize the data from TPF to envision and design innovative multi-modal MaaS bundle solutions to enhance the service quality of the transport system. The research outcome will be easily implementable and adaptable to different public transit operator network structures. TPF and EPFL have also applied for additional funding related to the direct implementation of the developed algorithms of NCCR Industry project for a Proof-of-Concept for budget that cannot be included in NCCR (mini-van rentals, implementation costs etc). This project will contribute to the Threads A and C of Theme 3.1 in phase II.

**Collaboration mechanisms:**

TPF is an experienced public transport provider with extensive expertise in human-centric mobility. Over the years, TPF has accumulated a massive amount of diversified data revolving around travel demand patterns, transit sizing and scheduling, bus and train delays, and seasonal and daily fluctuations in travel times. The acquisition of this type of data constitutes the foundation of the envisioned MaaS bundle to be advanced by this project. In addition to the data provision, TPF will set out the main features of the MaaS system by pinpointing the desired quality of service, the high-level objectives to be achieved, and the operational framework. More elaborately, the transit company delineates the service scope by specifying the potential micro-transit fleet size, the intermodal transfer locations, and the intended geographical coverage area. It additionally identifies the required quantitative and qualitative Key Performance Indicators (KPIs) like maximum request waiting time, passenger detour time, abandonment rate, and Vehicle Kilometers Traveled (VKT). EPFL’s role is to analyze the provided travel data, identify sources of disruptions and service deficiencies, and conceive the service-oriented optimization module within the MaaS platform in alignment with the preset TPF objective and framework. At the maturity stage, the outcome of this research has great potential to be tested and integrated to contribute to TPF’s efforts towards implementing innovative technologies to achieve reliable and sustainable transport operations.

Regarding IP handling, TPF fully recognizes the importance of publishing the outcomes of this project and, therefore, approves making the provided data publicly available after its anonymization. This implies the need for creating aggregated profiles and masking the bus stops and the exact day of operation. This does not constitute any hurdle to the course of the project because the envisioned algorithm development and scenario testing only necessitate aggregate travel patterns.

The Postdoc involved in this project is planned to work at EPFL, in close contact with TPF employees, in particular with Mrs. Gaelle Abi Younes who previously completed her Master’s thesis at EPFL on on-demand micro-transit services and has been awarded the best Master’s thesis in her section. This collaboration is expected to ensure a smooth and continuous interchange between EPFL and TPF that guarantees the success of this research project. A letter of commitment from our industrial partner is enclosed in this application.

# Bibliography

|  |  |
| --- | --- |
| [1] | J.-F. Cordeau, «A Branch-and-Cut Algorithm for the Dial-a-Ride Problem,» *Oper. Res.,* Bd. 54, p. 573–586, 2006. |
| [2] | J. Y. Jung, R. Jayakrishnan und J. Park, «Dynamic Shared-Taxi Dispatch Algorithm with Hybrid Simulated Annealing,» *Computer-Aided Civil and Infrastructure Engineering,* Bd. 31, 2015. |
| [3] | J.-F. Cordeau und G. Laporte, «A tabu search heuristic for the static multi-vehicle dial-a-ride problem,» *Transportation Research Part B: Methodological,* Bd. 37, Nr. 6, pp. 579-594, 2004. |
| [4] | K. Braekers, A. Caris und G. Janssens, «Exact and meta-heuristic approach for a general heterogeneous dial-a-ride problem with multiple depots,» *Transportation Research Part B: Methodological,* Bd. 67, p. 166–186, 2014. |
| [5] | J. Alonso-Mora, S. S. Samaranayake, A. Wallar, E. Frazzoli und D. Rus, «On-demand high-capacity ride-sharing via dynamic trip-vehicle assignment,» *Proceedings of the National Academy of Sciences,* Bd. 114, pp. 462-467, 2017. |
| [6] | Y. Luo und P. Schonfeld, «A rejected-reinsertion heuristic for the static Dial-A-Ride Problem,» *Transportation Research Part B: Methodological,* Bd. 41, 2007. |
| [7] | C. Bongiovanni, M. Kaspi, J.-F. Cordeau und N. Geroliminis, «A machine learning-driven two-phase metaheuristic for autonomous ridesharing operations,» *Transportation Research Part E: Logistics and Transportation Review,* Bd. 165, 2022. |
| [8] | L. Rayle, D. Dai, N. Chan, R. Cervero und S. Shaheen, «Just a better taxi? A survey-based comparison of taxis, transit, and ridesourcing services in San Francisco,» *Transport Policy,* pp. 168-178, 2016. |
| [9] | R. Yao und K. Zhang, «Design an intermediary mobility-as-a-service (MaaS) platform using many-to-many stable matching framework,» *Transportation Research Part B: Methodological,* 2024. |