14th ITS European Congress, Toulouse, France, 30 May-1 June 2022

Paper ID 344

Next generation traffic management for proactive multimodal network optimization

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Abstract: This paper describes the technical approach of the FRONTIER EU project that aims to provide the network and integrated traffic management strategies of the future, taking into account new types and modes of transport and automated vehicles (including their logical and physical requirements), the minimization of pollution and capacity bottlenecks (including congestion and traffic jams), the reduction of accidents, and the need to reduce the cost of mobility for all users (both citizens, public authorities and businesses). On the operational level FRONTIER facilitates the transition towards resilient multimodal autonomous mobility by establishing the processes of collaboration and arbitration among stakeholders while developing the business models that will address the commercial viability of the identified solutions. FRONTIER develops, applies, and tests autonomous management systems, secured by design, that will constantly evolve using data generated from real-time monitoring of the transportation system, knowledge generated by operators and decision makers, and simulation models providing system optimal solutions accounting for new mobility services and technologies. These systems support and enact proactive decisions, realising our vision to empower a seamless transition to an autonomous and integrated transport management for future mobility services. The validation plan of FRONTIER involves pilots in three sites (Oxfordshire UK, Athens GR and Antwerp BE) focusing on three main themes: Smart Infrastructures and CAVs integration; Multimodal mobility for passengers and freight cross-stakeholders collaboration; Network performance analysis for planning and policy making.

Keywords:

Automated and connected vehicles, multi-stakeholders collaboration, organisational and business modelling, supply demand optimisation, transport simulation and performance analysis

Introduction

Mobility is undergoing an unprecedented transformation as it enters a new era where connectivity becomes seamless and electric. Automated vehicles are incipient, and a multitude of disruptive

mobility services and business models are changing the ownership and market landscapes. Also, the continuous demographic shift and consequential urbanisation, with an estimation that by 2030 60% of the global population will be living in urban areas, places significant pressure on the transport networks that serve large conurbations. This transition brings a considerable level of uncertainty to traffic and network management operators. Among the different functions that network management operators have under their responsibility, are handling integrated multimodal services, deploying network management strategies and planning in infrastructures of varying technological readiness under mixed traffic environments where automated and conventional vehicles will coexist. Stakeholders thus need to be prepared to provide solutions for effective traffic and network management strategies, processes and tools that will address these problems under continuously changing conditions for demand, as well as dealing with the technological shifts between now and the coming decades. Such solutions will require the incremental transition to autonomy as the decision making will be too complex for human operators to handle in real-time. There will be the need to deliver cost effective solutions that significantly decrease high levels of congestion and ensure networks' resilience also in extreme situations, improve the Citizen's quality of life by supporting the reduction of transportation related emissions (including CO2, NOx and particulates), adhere to sustainability goals set by EU regulations, and improve citizens' safety for the realization of a zero traffic accidents vision.

Cooperative Intelligent Transportation Systems (C-ITS) and the emerging area of 'digital-age transportation systems' are the means for efficiently moving into this new era of autonomous traffic and network management. For this, C-ITS handled by a variety of transport network operators in a multimodal environment need to be able to automate the coordination of traffic, support the cooperation of different organizations, and offer highly responsive and personalised services that can dynamically adapt to different supply scenarios. Moreover, they need to be capable of leveraging, storing, and processing the huge amounts of information being generated by physical and 'social' sensors in a massively interconnected multimodal system in order to achieve dynamic optimisation and management for the entire transport network. Transport data for traffic and network management need to be enriched with information coming from new mobility technologies and services such as Connected Automated Vehicles (CAVs), unmanned aerial vehicles, micro mobility sharing systems, or other smart systems. The new generation of simulation as well as operational systems for future traffic and network management need to cater for proactive decisions and maintain network equilibrium.

In this landscape, the FRONTIER [1] project aims to provide the network and integrated traffic management strategies of the future, taking into account new types and modes of transport and automated vehicles (including their logical and physical requirements), the minimization of pollution and capacity bottlenecks (including congestion and traffic jams), the reduction of accidents, and the need to reduce the cost of mobility for all users (both citizens, public authorities and businesses). At the operational level FRONTIER facilitates the transition towards resilient, multimodal, and autonomous mobility by establishing the processes of collaboration and arbitration among stakeholders while developing the business models that will address the commercial viability of the

identified solutions. FRONTIER will develop, apply, and test autonomous management systems, secured by design, that will constantly evolve using data generated from real-time monitoring of the transportation system, knowledge generated by operators and decision makers, and simulation models providing system optimal solutions accounting for new mobility services and technologies. These systems will support and enact proactive decisions, realising our vision to empower a seamless transition to an autonomous and integrated transport management for future mobility services.

Approach

The FRONTIER concept is based on an integrated approach for improving decision making in the multimodal transport system. Given the large number of stakeholders and agencies with operational responsibilities, an integrated multimodal approach will add value by allowing operators to coordinate operational and planning decisions and resources at a city, regional and national scales, and share relevant technical knowledge. Information sharing and integrated systems and technologies will help operators to identify and respond to supply disruptions (i.e., traffic incidents) and short-term fluctuations of demand (i.e. special events). In addition, those actions will improve operations and help to reduce recurring congestion, along with the delivery of intelligent transportation technologies that help streamline traffic demand, redirect traffic to alternative multimodal routes along the network, improve tolling and pricing practices, and manage ramp metering. The FRONTIER technical approach can be seen in Figure 1 and is organised into 4 main axes realising a proactive decision support traffic and network management control centre oriented on the OODA loop, and integrates heterogeneous, real-time, and dynamic streams of transportation data.

Smart sensing (Observe)

Smart sensing provides a secure data infrastructure for handling data produced by in-vehicle and infrastructure sensors; application of modern Information and Communication Technologies (ICT) (Cloud computing, Internet of Things (IoT), etc.); increased availability of modalities and services (including public transportation, car sharing, car2go; logistics operations, etc.); the travellers; all related to the proliferation of connected devices and systems. The data infrastructure will contain adapters based on existing and where applicable (i.e., innovative mobility services, Operational Design Domains for CAVs, etc.) new standards for all necessary data sources. Open-source big-data solutions will be deployed to support the retrieval, fusion and harmonisation of transport and non-transport related data provided by a multitude of sources. A primary output of the data fusion subsystem will be the real-time traffic state estimation using connected vehicle data as well as very few (strategically located) infrastructure spot detectors for flow observability. This will be realised both for motorways (estimation of density, speed, flow for all mainstream links; flow for all on-/off-ramps) and urban links approaching traffic lights (estimation of queue length and flow) and will underpin the operation of the simulation models, the application of traffic control strategies and the provision of traveller information. A publish-subscribe middleware will realize an Event Driven Architecture (EDA) and will support a Service Oriented Architecture (SOA) and infrastructure for components and end user services. It will be based on an open source Enterprise Service Bus (ESB) for large SOA architectures and will be fully compatible with all major industry standards (such as Java Business Integration,

Service Compliance Architecture, Web Service Definition Language).

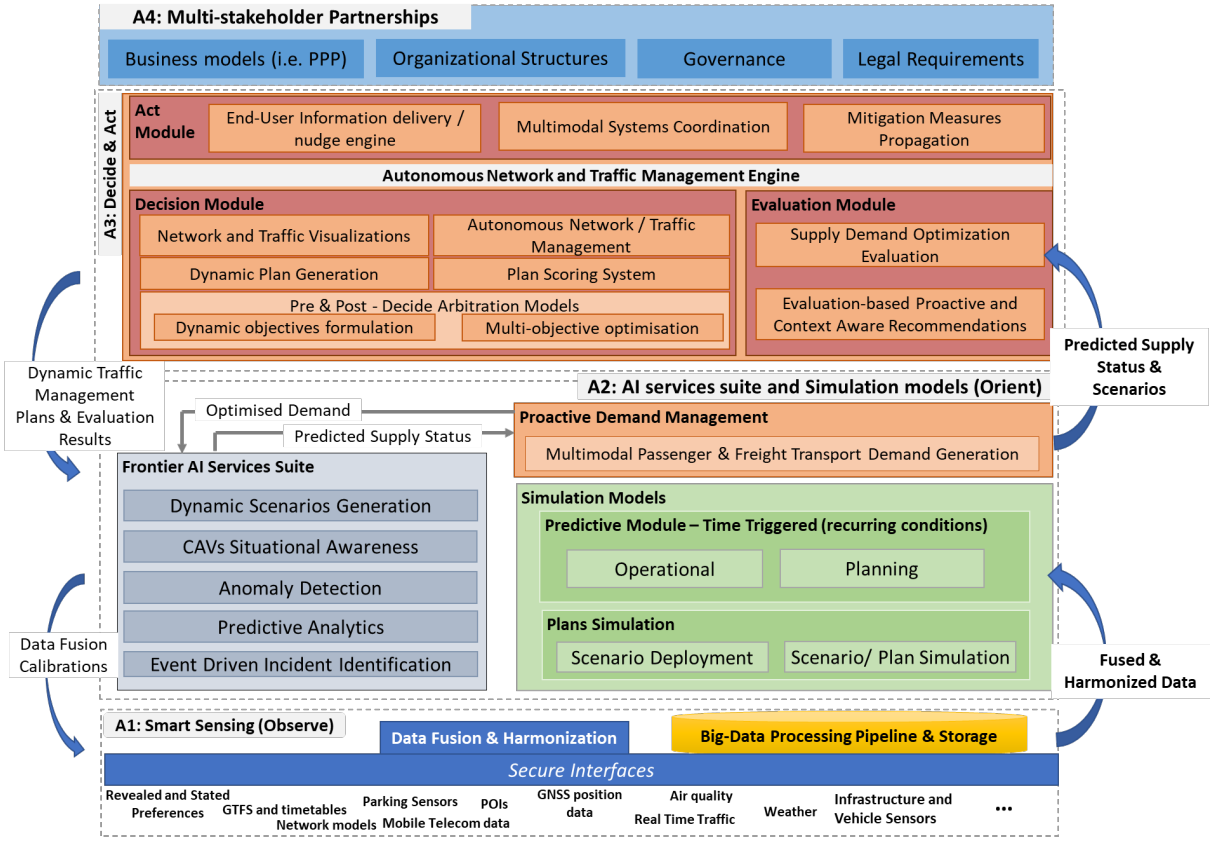

Figure 1: The FRONTIER Architecture for Next generation Traffic Management

AI Services Suite and Simulation Modelling (Orient)

AI services will enable semantic enrichment with background knowledge and data mining on real-time data streams. In addition, those services will perform data analytics by using new multi-level algorithms in order to optimize the quality and power of the information coming from any part of the aggregated space of the raw data. Novel intelligent services will be realized on top of Probabilistic Stream Processing (PSP) and will generate real-time, data-driven predictions, as well as enable the identification and classification of unusual situations. These services will be developed using open source predictive analytics libraries and extended deterministic models and will offer a multitude of components with specific functionality and computational requirements in order to support the FRONTIER's proactivity functionality. It is envisaged that they will contain services for traffic estimation and prediction; multimodal demand projections; level of service for innovative mobility offerings (i.e. location of floating vehicles of a sharing schemes), infrastructure availability (i.e. electric vehicle charging stations, parking spaces), event driven identification of situations of interests (i.e. bottleneck build-ups). Outputs from these services will generate scenarios that will feed into online simulation models as to enable evaluation of different network and traffic control response plans. Microscopic simulation models will be developed for mixed traffic (mixture of conventional and connected automated vehicles) and assess user optimal route guidance for connected automated

vehicles via feedback control algorithms. The optimal control solutions will take into account available short-term predictions of the demand profiles and macroscopic models for mixed traffic. Furthermore, microscopic simulation models will make use of novel traffic control measures for mixed traffic (mixture of conventional and CAVs). These models will allow the simulation of alternative ITS policies that can be used for the mitigation of congestion created at bottlenecks (on-ramp merge areas, lane-drop areas, tunnels, bridges, etc.). The novel control strategies will include Adaptive Cruise Control (ACC) time-gap adaptation, lane-change advice, and variable speed limits for connected automated vehicles.

Autonomous Network and Traffic Management Engine (ANTME) and Act services (Decide and Act)

A real-time engine will recommend strategies to each manager, after consideration of the aggregate effects of their combined efforts. The proposed engine will empower traffic operators to devise and deploy traffic management plans through different levels of automation, thus allowing the completion of complex decision taking tasks. In addition to information sharing and coordinated decision making, investment in new technologies for network control would allow agencies to manage the demand on their facilities in a coordinated fashion, with additional potential for decreased congestion and improved travel speeds along the network. Technologies such as dynamic signal timing, ramp metering, and dynamic wayfinding could streamline traffic flow through the network by balancing traffic demand across the network, improving travel time reliability and increasing average speeds. ANTME will employ self-learning functionalities for: the evaluation of corridor operational performance using multimodality related KPIs and based on real-time data provided by various monitoring systems, archived historical data, and results from the application of analytical or simulation models; response plan recommendations and summary of plan effectiveness and impact analysis on network; regular review of system performance and calibration of system configuration and business rules to allow continual improvement of the system operation and effectiveness; determination of near-future transportation network operations performance based on projected changes in traffic demand and the implementation of demand management and supply management strategies. Furthermore, real time updates and nudges to travellers will inform commute decisions, redistributing traffic demand and making the best use of existing infrastructure capacity. Our innovations will extend concepts of mobile multimodal route planners for proactive and timely information delivery.

Multi-stakeholder partnerships.

FRONTIER aims to develop collaborative business models involving the key stakeholders/organizations that formulate the multimodal and traffic management ecosystem. Multi-stakeholder cooperation agreements will be developed, and appropriate arbitration models will be identified for conflict resolution within the partnership in order to ensure its viability and sustainability in the long run. In the context of the business models, the associated costs, benefits, and risks of implementing smart traffic management systems will be assessed and various cases of system optimal providing insights into the financial viability, economic robustness and deliverability of the solution will be analysed. The Governance Group (that could include service operators (road, public

transport, private transport), traffic control centres, data providers, transport system end-users) of the collaborative business models will be developed, with the following key responsibilities: establishment and regular review of key performance metrics and goals; assessment of system performance against the performance metrics and goals; establishment and maintenance of operational procedures and arbitration models for conflict resolution; establishment and maintenance of business rules and coordinated operational response plans; advice on cross-jurisdictional issues and operational solutions; identification of potential system improvements; resolution of operational and maintenance issues escalated via the operational teams.

Validation Plan and Pilots

FRONTIER will receive input, will make use of test infrastructures to deliver its vision and will be evaluated in real life conditions in three European areas (Oxfordshire, UK; Athens, Greece; Antwerp, Belgium). The areas have been carefully selected to capture a wide spectrum of functionalities and support research outcomes which can be further adopted throughout Europe, and beyond, after the end of the project. The use cases which will be designed, evaluated, and piloted in all three areas, are grouped in three main thematic areas:

Smart Infrastructures and CAVs integration.

Using the RACE testbed [2], FRONTIER will answer questions related to centralised, decentralised and hybrid traffic management approaches with the inclusion of CAVs. The effects of CAV-specific traffic management functionality and the impact of dynamic definition of Operational Design Domains (ODDs) and vehicle control transferring to driver will be investigated. Scenarios of using autonomous vehicles as controllers of traffic will also be explored. The idea is the use of autonomous vehicles as moving speed limiting enablers to control the flow of traffic at urban and rural settings for e.g. easing bottlenecks on approaches to intersections in mixed traffic scenarios. The RACE testbed will also provide the means to validate our proposed smart infrastructure classification index by trailing different infrastructure configurations and by measuring their impact on the operation of CAVs through on demand activation/deactivation of infrastructure systems at RACE. Findings from the trials, will feed simulation models to analyse scenarios where infrastructures of different smart-readiness are emulated, including extensions of current microsimulation models (car following, lane changing and gap acceptance) to accommodate the simulation of CAVs for decentralised traffic management at individual, or connected intersections.

Multimodal mobility for passengers and freight and cross-stakeholders collaboration.

The goal will be to optimize interoperability of the existing and future traffic management systems and symbiotic relationships of various stakeholders, focusing on identifying and exploiting truly multimodal opportunities (from the supply side) between various mobility service providers, other involved stakeholders (including energy network operators for charging infrastructures) and traffic management systems. Our aim is to showcase an interconnected, integrated, and interoperable network of systems and organizations that address future mobility needs and cooperate seamlessly to account for the needs and take advantage of future opportunities. The operational scenarios will validate our multi-source data fusion architecture for proactive event detection and supply-demand optimisation.

Sources will include, traffic (ATC, CCTV, OBD, etc.), weather, incident, parking, public transport, events, air quality, traffic management (diversions, restrictions, etc.) data. One facet of cross-organisational collaboration will be performed through a 'sandbox environment' where data generated as part of traffic management can be shared through open interfaces. The proposed ANTME for real time traffic management will be tested for high-resolution traffic management approaches by exploiting 'reverse crowdsourcing' tools, where information is pushed, in a coordinated way, to individual travellers/driver through e.g. social GPS apps and other city specific applications. We will also examine freight transportation, in multimodal / synchromodal transport, with a focus on inland waterway transport. Currently this relies on separate network and traffic management structures, operated by public entities, different than for road transport. The integration of both will be pursued taking into account autonomous inland shipping services.

Network performance analysis for planning and policy making.

The aim is to provide quantitative and qualitative assessment of the impact of new forms of mobility (CAVs, MaaS, micromobility, crowdsourcing, drone deliveries, electric vehicles, and their special needs in terms of charging infrastructure, etc.) in the traffic network through the use of analytical tools such as econometric models and simulations. The management/optimisation of special lanes (bus, bicycles, HOV) as well as the requirements for automated vehicles in terms of parking infrastructures will also be considered. This will lead to the formation of pro-active, truly multimodal solutions, reinforcement of weak areas and in-depth preparation against threats. Traffic simulation models for various scenarios will be devised, accounting for network resilience analysis due to special events, future smart infrastructure improvements as well as CAVs impact. Through this, a set of optimal traffic management strategies will arise allowing us to increase the network's capacity and efficiency by assigning better the traffic load among existing and future modes. In-depth investigation of V2I and V2V requirements in the new transport era (new modes and vehicles entering the transport network, availability of smart sensors, IoT, etc.) will be performed. Related scenarios for urban network management of mixed traffic (autonomous and conventional) with different penetration levels of CAVs will be investigated. The scope will be optimisation of flow on different settings (mainly different types of intersections and a corridor composed of a sequence of intersections) as part of a decentralised traffic management approach. This will involve the emulation of different levels of V2I functionality to build a roadmap for future traffic management applications.

Conclusions and Outlook

FRONTIER expects to address a number of challenges, paving the way towards network and traffic management for future mobility. Different traffic management approaches (centralized/decentralized and mixed) will be studied in order to better understand how to use each approach in which type of settings. New organizational, business and arbitration models will be studied in order to improve the collaboration of different stakeholders, while considering any conflicting interests that may exist. On a technical level, data management and data fusion pipelines will be developed, taking into account recent EU directives that promote data sharing and use in mobility data spaces. Novel approaches on traffic state estimation and traffic prediction with state-of-the-art AI and machine learning

methodologies as well as data driven simulations will also be the focus of FRONTIER. A major stream of work will focus on improving traffic management in the presence of CCAM. The related work will study innovative approaches related to considering CAVs as controllers of traffic and detecting traffic incidents from data that emerge from connected vehicles. Moreover, optimal traffic management strategies under different penetration rates of CAVs will be identified, whereas the operation of CAVs under different conditions and respective ODDs will be evaluated. FRONTIER will also develop information service for traffic management operators and travellers. The related work will focus on studying how to optimally support operators' decisions for optimal network management and travellers' choices in a multimodal transport system.

References

1. FRONTIER project url: http://www.frontier-project.eu/
2. RACE Testbed for Connected and Autonomous Vehicles: https://race.ukaea.uk/test-facilities/cav/