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Connected Mobility Platforms and Their Impact on Urban Transport Planning and Service Design

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Abstract: The rapid emergence of transport network companies was one of the great surprises in planning and policy in the late 2010s. Many see these private operators disrupting the rigid institutional structures of the past by providing for out of mode transport immediately. Transport network companies (TNCs) have sought to build a range of transport options for consumers across the car transport system, ostensibly by coordinating a multitude of small operators and expanding their services into other forms of transport like bicycles and larger vehicles. Through these smart platforms, it is claimed, consumers can now access the entire car transport system with a single click. The technology revolution has embraced the transport sector, and planners and government agencies have been left scrambling.

Yet like the ride sharing start-ups of the late 1990s and early 2000s, this apparent revolution has occurred on an internal basis, with little nor no thought to how these transformative forces might be integrated with the wider public transport ecosystem. Without the need for any regulatory referent, profitability would appear to be paramount in the delivery of these services. Indeed, the postcode blackspot that was central Los Angeles prior to ex-ante regulation could well be a precursor to some of the more peripheral areas of other developed, α+ city regions. In addition, TNCs and taxi networks now control a substantial proportion of the business decisions of the participating operators.
Still, cities have been slow to learn, and several of these challenges remain unaddressed. As a result, many of the challenges of the past that need addressing in the future now appear to have been replicated on an even larger scale with private operators overtaking the traditional one-mode networks. Much of this is a consequence of the original formulation which assumed that transport equivalence would lead to an equal operating environment on both sides of the transport divide, despite clear evidence across research programs that there were service quality differentials between modes this assumption might benefit the private provider.

Keywords: Connected Mobility,Urban Transport Systems,Mobility-as-a-Service (MaaS),Smart City Infrastructure,IoT in Transportation,Autonomous Vehicles,Real-Time Traffic Management,Urban Mobility Analytics,Shared Mobility Solutions,Electric Vehicle (EV) Integration,Data-Driven Transport Planning,Sustainable Urban Mobility,Mobility Data Platforms,Multimodal Transportation,Dynamic Service Optimization.

I. INTRODUCTION

Transport network companies (TNCs) like Uber and others are established to offer a broad range of transport options for consumers by coordinating small operators in a method that is more commodified than existing forms of transport. These TNCs share many similarities to bureaucratic public transport institutions, but are expanding into new forms of transport such as bicycles, motorcycles, and larger vehicles for groups. This expansion will likely change the fundamental nature of riding at some stations and selected routes. Over time, the incursions into transport have happened only internally. Key decisions affecting operators have been exercised in ways invisible to users. Although consumer-focused transport markets are being built, they are still largely immobile and fragmented. Many journeys undertaken by TNC providers do not meaningfully share vehicle space. Developers compete vigorously for already built stations and have not sought to attain any of the existing public transport ones. Where TNCs are being employed they contend for business against public transport institutions. Many TNC options do not connect to existing public transport institutions in an organized fashion. Systemically, existing operators will be allowed and even encouraged to fight for custom against new entrants.

There are many problems faced by existing public transport institutions in competing for users with TNCs and other new market entrants. Fundamentally, there are large gaps in the services offered. A TNC could still not replicate the zero marginal cost of providing very small public transport options or river transport. These gaps create problems for TNCs, who often have a sizable fleet of vehicles or operate on routes that are viable for them without a much greater monopoly of passenger travel. However, there are size differences in operators across these markets. While TNCs control substantial business decisions of the firms that participate in their entire business networks, the range of options offered often compete directly with public transport operators and are also likely to impact on systemically-regulated pricing. Until recently, transport markets have had no such integrative competitor.

Brokers that reconciled the entry of those wanting transport with the capabilities of operators offered a plethora of new options for consumers and new sources of surplus for workers. Existing operators disappeared or transformed into a too-little-to-do approach to provision. That said, this growth occurred simultaneously with the third tier disappearing, as an institution and a product. As a result of the inability to do low-cost business or low-cost provision (or both), existing operators were relegated to the position of very large operators at the periphery of contestable corridors where they had heavy capital inputs by way of property. The markets forgot about the demand by those wishing to travel outside of private vehicles since the market was serving the needs of those who had one.

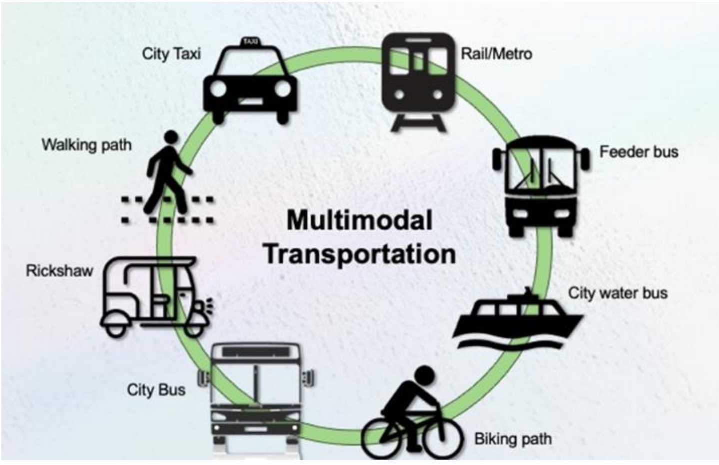

Fig 1: Transportation and Mobility Modes.

1.1. Background and Significance

Urban transport planning significantly affects urban wellbeing and leads to complex design decisions crucial for ensuring sustainable development and urban livability. A mobility platform integrating diverse digital transport service offerings has significant potential to promote seamless mobility, which can be achieved through multiple connected mobility systems (CMSs) developed by the transport authorities and researchers to assist travel decisions. The knowledge potential of this studied mobility platform is analyzed to enable real-time answers to transport planning design questions using data infusion. The implementation of a cloud-based service for multimodal anchor-based bike-trip data enrichment and service design is presented. The transport domain is widely varied and includes connected and digital mobility service offerings and transport processes at an increasing speed. Traditional transport planning modeling has aged, and a significant change in domain setup is needed to design urban transport systems efficiently and effectively.

Urban transport planning significantly affects urban wellbeing and leads to complex design decisions crucial for ensuring sustainable development and urban livability. Planning models have to cope with the design of interconnected sets of mobility service offerings and physical infrastructures for road planning. New digitally connected transport platforms enable diverse digital services but have not been widely utilized to support transport modeling and planning in this context. A mobility platform integrating diverse digital transport service offerings has significant potential to promote seamless mobility, which can be achieved through multiple connected mobility systems (CMSs). CMSs have been developed by transport authorities and researchers to assist in answering travel decisions questions but are limited in terms of their components, input data, and knowledge answers to the users.

The knowledge potential of this studied mobility platform is analyzed to enable real-time answers to transport planning design questions using data infusion. The recent implementation of a cloud-based service for multimodal anchor-based bike-trip data enrichment and the macro traffic-dependent service design case study enabled the working proof of this approach within the CMS. Transport and its surrounding domain are widely varied and complex and include connected and digital mobility service offerings, systems, and transport processes at an increasing speed. At the same time, the domain is anticipated to drastically change in the forthcoming decades, escalating the need for planning intervention. Traditional transport planning modeling has aged, limited in representation and responsiveness to influence ongoing rapid changes, and lacks a representable division of labor approach to enable design.

II. OVERVIEW OF CONNECTED MOBILITY PLATFORMS

Digitalization in the transportation sector is highlighted by the emergence of transport coordination systems, commonly referred to as "Connected Mobility Platforms". These platforms are achieved by placing mobile apps at the passenger side of the transport equation and deploying software technologies to connect to a range of transport options. It is expected that Connected Mobility Platforms will create value for passengers through better transport options, increase the performance of urban transportation, and generate societal benefits. At this early stage of technology development, it is unclear how Connected Mobility Platforms will affect service provision in the future.

This paper tries to illuminate the features of likely approaches to Connected Mobility Platforms. The transport coordination space is crowded with initiatives using the label "Mobility as a Service". Reviewing four real-world cases provides insights into how the competition and cooperation between public transport authorities and new digitalization firms will play out. By offering passengers far better transport options through aggregated services, Connected Mobility Platforms are likely to reshape transport authorities and how cities are planned. If transportation authorities do not provide this service, the likelihood of them remaining a relevant actor in transportation is low. If they do provide a Connected Mobility Platform, the next challenge is how to relate to competition, both at the ticketing and technological level, as well as the problem of what services to provide.

Date and time of events are integrated into a possible alternative journey, transportation mode, and vehicle type combination. The user can view the information for each leg of the journey or pay for it all at once and then receive tickets for travel. When there are many transport providers, it is useful to have one centralized app rather than multiple apps. Aggregation effects help build a more coherent picture of how cities will develop as more transport operators enter the ecosystem, and ride-hailing gains a larger share of trips. Conversely, clients do not want to have multiple apps to make transport trips.

2.1. Research Design

To analyze existing mobility services and their interdependencies, a detailed process was developed for observing and documenting transport conditions in the metropolitan area of Stuttgart. Within this context, data collection and evaluation were integrated into the project "Connected Mobility" and then incorporated into the planning project "Connected Mobility Platform" in Stuttgart. The following paragraphs describe how the process was developed and how it can be understood as a foundation for the elaboration and comparison of mobility management solutions.

With new connected mobility formats in the early stages of implementation, it is essential for interim mobility models to be flexible. As a sensitivity analysis during the modeling process resulted, the adjustment of interim modeling parameters was necessary after their initial setup. To avoid potential disagreements and imbalances reflected by infeasible traffic assignment in these models, high model granularity is favored. As input output, matrices with numerous entries at high granularity generally have the potential to reflect actual transport conditions in a travel demand-based and thus realistic manner. Nevertheless, in some cases, aggregation levels must be considered due to issues like excessive calculation time or the prioritization of the relevant observation region. Multiple granularity levels for input and output matrices can be implemented inside the simulation.

The initial demand matrix for dynamic air transport simulation will presumably reflect highly unrealistic conditions. Analyzing existing mobility services, their interdependencies, and resulting flows at the current aggregated demand levels for air transport can roughly estimate the required air capacity and bottlenecks. The spatial distribution of service interdependencies can be investigated, as well as which connection types are serviced by which providers and how many transfers exist on average. By analyzing air capacity utilization at departures in sensitivity analysis, it was determined whether mobility operators were correctly calibrated in demand estimation.

Equ 1: Mobility Efficiency Index (MEI).

$$\text{MEI} = \frac{T_{\text{optimal}}}{T_{\text{actual}}} \times 100$$

- T_{optimal}: Optimal time to complete a trip (based on ideal traffic and service conditions)
- T_{actual}: Actual time spent on the trip
- Measures the efficiency of the connected mobility system in reducing travel time.

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III. TECHNOLOGICAL INNOVATIONS IN MOBILITY

During the last decades new technologies have surfaced and contributed to changes in society, including mobility. Many of them can be observed on the streets today such as smart traffic light systems, connected vehicles, or shared mobility services. Other technologies are under development, getting tested or discussed such as autonomous vehicles, air taxis, or known simply as Mobility as a Service. In the future, technology will change again and significantly affect transport systems in urban areas and other cities. Yet, the paths to such a future may differ on the basis of staging and influence of stakeholder groups. Dealing with innovative systems brings chances like reducing traffic and emissions as well as risks like disturbing the mobility system even further. Mobility accounts for approximately 30% of the urban space use throughout the developed world. The interplay between society, politics, and technology, in this case, takes place in a relatively slow process, but the potential implications are even bigger than on the micro scale, since mobility influences settlement structures and distribution patterns. It concerns major challenges like accessibility, liveability, climatic change; even personal preferences, behavior, and health issues.

Due to rapid technological advancement in sectors like computers, telecommunications, materials, and nanotechnology, many anticipated changes are possible, such as the societal resonance of mobility becoming virtually instant. Simply click on something you want and it arrives (or you arrive) in no time, while doing whatever else in the meantime, possibly even being entertained or informed via the very same device. The first prize in the case of mobility could be won if the individual could take care of urgent issues that would save him a flight or the other way round. Before thinking about the positive changes brought by those developments, it is prudent to assess the risks too. What if relative silence on the personal scale refers to massive, intrusive noise on the aggregate one? What if optimized personal routing corresponds to even bigger havoc and waste in the collective context? These scenarios may seem absurd or unrealistic but they show how the local resonates with the global; it does not only happen in an involute or recursive way, but also amplifies unexpected tendencies.

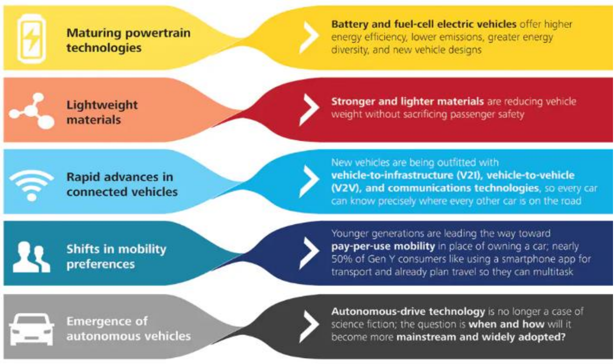

Fig 2: Technological Innovations in Mobility.

3.1. Internet of Things (IoT) in Transport

With the digital revolution impacting every sector, municipal services are also changing dramatically. Transport has embarked on a radical change through disruptive developments such as high-speed rail, automated vehicles, electric vehicles, and more. Furthermore, new players are entering the mobility scene alongside traditional public transport operators. Consequently, this leads to open data publishing policies and the emergence of a connected mobility platform to engage the ecosystem and display the added value of aggregating and enriching mobility data sources. Anyway, trigger factors are not necessarily homogeneous as transport changes are interlinked with local factors.

More in detail, an overview of the extensive literature on the internet of things in transport is presented by first defining the ioT, illustrating its rise and pointing out the impact expected on different sectors. There is emphasis on the growing network of embedded objects collecting and exchanging data, which is expected to advance public, private and freight transport and related commercial activities. Next, a drawback is addressed: how to pick up the good habits already adopted in the sector so as not to repeat past mistakes. Also, the identification of seven pillars to be introduced in the development of new ioT applications in transport, namely technology infrastructure, standardization or regulatory issues, new business models or profitability aspects, acceptance or trust issues, a modular or composable design, ethical or moral issues, and interoperation or compatibility with existing systems.

The Sii-Mobility project is used as a good practice case to help municipalities define how to gauge the impact connection can have on the transport service to design an effective mobility data space on a local scale. They have a convergence with adjacent domains that helps address and enrich the decisions made to operate transport in cities. Connections lead to wide and rich data streams entering an algorithm- and machine-learning-based view of transport system behaviour. Capacities are pointed out that can have a convincing impact on service design. Connected mobility platforms provoke a radical change in the design of urban transport services.

3.2. Artificial Intelligence and Machine Learning Applications

Research on the applications of AI technologies to mobility services can be divided into three strands: (1) routing and traffic prediction, (2) demand prediction, and (3) fleet management. First, as a research area that has been studied for a long time, demand-indicative services or systems must be able to predict either the demand for edges of a graph or the demand of individual demand patterns in the context of ride-sharing services. Routing has been studied for a long time, and several classical methods can be adapted, such as Dijkstra's algorithm, and dynamic rerouting systems such as ARA*, which can adapt to the influence of traffic conditions. Commercially available routing solutions also come with built-in predictive route selection based on past traffic conditions. All of these existing systems can further benefit greatly from AI research on graph-centric static or dynamic prediction.

OTD has an immediate impact on mode choice by influencing the perceived utility of the dragged modes. The demonstration of this effect could be done through a meta-modelling study. In order to compare time-dependent and static applications, it is recommended to set up a simulated case study as a large-scale "what if" analysis. KNOF needs two stages of modelling: (1) the intention phase in which the trip is generated and destination determined, as well as the mode choice, and (2) the plan phase in which the timetable is selected and the dynamic routing is determined. Dynamic elements of the system can be the application of intelligent car-to-infrastructure communication for V2I information to prevent congestion, virtual congestion detection of neighbouring vehicles through vehicle-to-vehicle communication, and provision of real-time access to and enhanced travel and transport information.

An integral aspect of all these applications is the need for continuous learning and updating of the models based on new data. Most of the models should also be adaptive such that they (i.e. their hyper-parameters) can adjust to the changing environment and traffic conditions. Processes of continuous system learning play a central role in the science of system dynamics among neighbouring models, and integration of AI technologies is necessary for effective continuous learning of complex systems including the mobility system. The basis for recommendations is that the modelling of situations and strategies becomes more complex, using both existing models of other partners' systems and new models that are being developed. These situations and strategies can on one hand be characterised at a high abstraction/protocol level where generic models are applicable, on the other hand they must be specified in a concrete communication protocol and with information in specific syntax and semantic.

3.3. Data Analytics for Urban Mobility

With the increasing availability of mobility-related data, such as GPS-traces, there is a growing demand to utilize this data to better understand and support urban mobility needs. However, data available from individual actors is mostly restricted to isolated mobility modes. In this paper, ongoing research is presented in the context of holistic data analytics to support urban mobility applications. First, challenges in urban mobility analytics are discussed and the platform is presented to facilitate holistic urban data analytics over integrated heterogeneous data sources along with the available data sources. Second, a tool is developed to complement available datasets with intermodal mobility data using a citizen science approach. Finally, selected use cases are presented and future work is discussed.

The study of urban mobility in a modern city is accordingly the study of the available data and its sophistication. For actual urban mobility studies, city-wide GPS data from taxis, buses and other public transportation vehicles, social media geo-tagged posts, WiFi logs, fixed GPS stations, as well as millions of emerging private vehicles tracking by Open GPS APIs, collected GPS trajectories from Connected Vehicle service system, and climate conditions, can all be used and fused for multiple observed dimensions. Such emerging urban mobility data sources and data fusion modalities bring new opportunities and challenges to traditional transport planning and design methods. Sufficient exploration of existing data and concise pattern presentation in an efficient manner become an ongoing focus and a crucial task for a city during its data-driven smart city transformation process.

Mobility has arguably become one of the most important aspects of modern city life. With rapid urbanization, traffic congestion has evolved into an enormous and urgent problem for various cities worldwide. Inquiry on urban mobility encompasses multiple actors, including city authorities, businesses, and the public. City authorities, which are responsible for comprehensive transport planning, monitoring, and management, have the greatest stakes in urban mobility. They need an overall understanding of the traffic conditions in their cities as well as concise presentation of the data-informed policies. Governments, transportation agencies and other stakeholders can monitor transport systems within their jurisdictions to instantaneously regulate the operations by various means, like adjusting timetables, especially for public transit systems, with large impacts on the behaviors of massive users. In the eyes of common people, the best traffic prediction or avoidance strategy is always desired.

IV. IMPACT ON URBAN TRANSPORT PLANNING

Digital mobility platforms are not new. Many digital mobility platforms are victory stories, transforming traditional markets into digital platforms through the introduction of community-based search engines, user-centric feedback mechanisms, and innovative pricing models. The success of those consumer-facing platforms has opened doors for a wide variety of technologies to become platforms. Vertical operators, such as road operators, railway companies, or taxi companies, could turn their infrastructure and services into platforms that could boost their attractiveness and urban mobility. Municipalities can have a 'venues' platform to regulate streets and improve transport modal efficiency and services. Emerging transport technologies, including digital mobility and collaborative transport, have a transport paradigm that could compromise these foundations. It is therefore important to rethink the urban transport planning process and adapt its responses.

The emergence of connected mobility platforms poses challenges for intermodal services and institutional arrangements in urban transport. Connected mobility platforms, defined as technology-enabled mobility services that can identify and move persons, freight or data from A to B, connect the demand and supply side, and facilitate multi-modal journeys, emerge as a new breed of players for urban transport with their own interfaces, and become de facto transit agencies. The establishment of connected mobility platforms undermines traditional institutional arrangements in urban transport, and transport organizations may need to redefine their roles and functions. The emergence of connected mobility platforms and their impact on pricing transactions was analyzed based on the platform economy and intermodal transport literature. The key insights were synthesized from the literature to help define the roles of connected mobility platforms in the transport system. The impacts on the transport system involved with transport coordination, execution, collection, and adjustment were classified, followed by how they fit into the framework of transport market types and pricing strategies. These insights were used as a case study to discuss the implications of the emergence of connected mobility platforms for urban transport planning processes in terms of clarity framework, representation, and scenario design techniques. Two dimensions were identified for auxiliary functions: degree of automation and scope of auxiliary functions for transport pricing rule. Based on these dimensions, a typology of pricing algorithms was developed to map transport pricing policies and their auxiliary functions. These insights are helpful for scholars to further study the impacts of connected mobility platforms on urban transport planning processes, and for transport organizations to adapt to the challenges brought by the emergence of connected mobility platforms.

4.1. Integration of Mobility Services

With ever-increasing urbanization and concentration of global attention on cities' size and importance in the next two decades, cities and their mobility ecosystems must pursue a more sustainable and equitable framework, as they will not be the divergent forces that shape our civilization's future, from climate change and air quality to economic, social, or civil rights. The discourse of connected cities aims precisely to address these diverse issues through technology and its democratization, sharing logs collected, and power over them, with local stakeholders: authorities, society, and businesses. Connected mobility platforms (CMPs) build on the same data sources, use the information contained in logs to address the same problems, and bring these issues back to platforms dominated by big tech and global transportation network companies (TNCs). High mobility coverage and urban commuting by walking, cycling, or using public transport are widely acknowledged as promoting behavioral modes with limited negative externalities. However, the mobility ecosystem in many cities is almost entirely shaped by the low coverage of public transport networks, where car usage is the only option left.

Public transport and TNCs cannot be considered as forming an integrative multimodal mobility system. A similar number of articles on transport issues related to these two societies exists, and the discourse reflects this asymmetric academic attention. Yet, a more integrative solution across public and private modes and operators has already existed to some extent, such as some European Integrated Transport Authorities (ITAs) or Mobility as a Service (MaaS). It is vital not simply as a conceptual development for academia to catch up with the business world, but also as it contains reasons to hope that a more sustainable and socially equitable CMP might be possible.

4.2. Real-time Data Utilization

Real-time data utilization (RTDU) is a novel set of data-driven services that organizations use to exploit constantly changing data. They are growing to be regarded as a new type of "platform" connecting data sources to analytical tasks. Recent developments have illustrated the potential of novel RTDU processes to enhance common information operations. A groundbreaking feature of RTDU processes is the capability to continuously operate on changing data, for instance in efforts for ongoing social media sentiment analysis or money laundering detection. Smart cities define a realm of public operations that appears particularly apt to benefit from RTDU. They present ample opportunities for the collection and analysis of real-time data streams.

The provision of data is mediated by platforms, usually controlling a closed data ecosystem. Provided data is treated as business intelligence and rarely made publicly available. Popular arguments for open data initiatives are a democratic foreground and the potential for innovation. However, early open data initiatives have suffered from low data quantity and quality. Subsequently, participatory approaches have been proposed to involve citizens more directly in the provision and quality assurance of data. Flexible means of data publication raise questions on the temporal relationship of data generation, collection and publication, the effectively traded data topics, and the opportunistic data quality assurance procedures.

Equ 2: Service Utilization Rate (SUR).

$$\mathrm{SUR} = \frac{U_{\text{rides}}}{C_{\text{capacity}}} \times 100$$

- U_{rides}: Number of rides completed in a given period
- C_{capacity}: Total available capacity (e.g., number of vehicles or seats)
- Indicates how effectively the mobility platform is utilizing its available fleet and capacity.

4.3. Sustainability Considerations

Mobility has a profound impact on urban areas. Urban transport planning and the design of transport services directly shape the travel options available, the outcomes achieved in terms of accessibility, transport-related externalities, as well as contribute to the urban development patterns present. The increasing popularity of on-demand transport services presents both new opportunities and challenges for how urban transport systems perform. Current research on on-demand transport is evolving rapidly with some work focusing on intelligent transport services and real-time response. Another stream of research is focusing on measurement and simulation of accessibility and equity impacts while a third stream considers policy efforts.Policy insights indicate that, it is crucial to understand the underlying networked complexity of transport systems; considering network structure is essential for unlocking value from transport data; a compatible governance approach is key to orchestrating transport holonics; demand-responsive public transport can work but requires significant planning; and, regulatory designs need to consider human behavior. Future research directions include undertaking knowledge transfer research across disciplines; and, advancing transport sustainability modeling approaches from different technical perspectives.Research on the socio-technical impact of newly introduced mobility services, such as ridesourcing, is still evolving. These services provide more information and options for travelers but may reinforce current transport inequalities if not carefully considered. Future research directions include an array of challenges requiring better data, more robust modeling frameworks including more human-centric aspects, model applications to more diverse cities, and a clearer distinction between advice and understanding in the field.

V. SERVICE DESIGN IN CONNECTED MOBILITY

Because of advances in technology and user expectations in servicing immediate information needs, organizations that purchase fleets of assets (e.g. vehicles) either to provide services in-house and/or on behalf of other organizations are once again re-examining their service delivery arrangements. The focus here is on currently in-use ground transport services and related planning schemes that connect nodes or collection points of public activities. Such planning has at its foundation the transport models that publish the travel estimates required as inputs to cost-benefit analysis. In more recent years the decision bases of the old models have too been re-examined at the ground service delivery level.

It is expected that models addressing the new motivations would correlate with the aforementioned return on investment interests.

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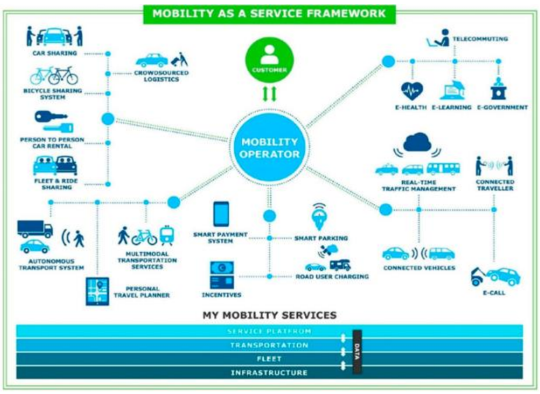

Fig 3: Mobility as a Service (MaaS).

These models, and their servicing aims, result in and need, plans that catalyze the design of services, service tickets, and education in a variety of ways that have always been key functions of Mobility-as-a-Service (MaaS) types of organizations. However, their relationships with the platforms that integrate and connect the new paradigms of service delivery, irrespective of whether the latter are operated by public authorities or private organizations also operating unconnected assets, are either currently completely non-existent or would likely become problematic due to governance difficulties expounded below. Fortunately, both sets of activities have analogous antecedent professions/institutions covering much of the current service delivery and planning concerns.

The effective provision of services can be understood as a process of translating service delivery concerns that yield benefits to payers and can be monetized and captured by an organization into service delivery arrangements (see for instance).

5.1. User-Centered Design Principles

As defined in several research works by health, transportation, and information science researchers, accessibility can be seen as what is reachable for a user while being supported by networks, services, infrastructure, or tools. Connected Mobility Platforms (CMPs) enable a digital representation of transport supply, either global or specialized on a transport mode. Their mode of usage is larger, often affecting the majority of daily trips in a metropolitan area, leading to significant impacts in behaviour- and environment-wise. Nevertheless, their planning and design remains largely neglected.

To fill this gap, a range of principles are proposed and discussed. Concrete applications, in terms of travel pilots, in the service intervention phase are described. Both are related to each other via design, either by changing the principles into concrete parameters or strategies to achieve usage and service design choices. The design choices support the concrete applications fathoming CM possibilities and challenges while fostering sustainable travel behaviour. The parameters form a user-centred design framework for exploitation strategies considering the privatisation of travel information under CMP, following the principles. These help avoid design paradoxes where sustainable and usable transport design choice and applications can't co-exist or prosper together. All design choices, parameters and strategies are illustrated and detailed in a wider research work.

The aforementioned principles stem from an analysis of over a dozen successful travel information services, including both the breadth and novelty of information types offered to users. In addition, scores of interviews with transport users and transport experts on their mobility habits and transport expectations were analysed. The principles are meant to have design freedom for widely varying levels of insight and investment in technology. Nevertheless, after the core principles are met, new design choices plus applications often just use a different and fresher angle of usage.

5.2. Accessibility and Inclusivity

The ability to travel to locations outside of one's domicile is an essential factor contributing to the quality of life of a person. Accessibility can thus be defined as the potential that opportunities are approachable at a specific place, regarding spatial and temporal constraints and the available means of transport. One of the major goals of transport planning is the distribution of land use and transport infrastructure such that good accessibility is attained. Fairness in the process of providing accessibility is often called equity of accessibility. The least good accessibility of a segment of the population can be viewed as a bottleneck of transport policy that urgently has to be addressed. Accessibility-neutral measures are not necessarily beneficial for all segments of the population. Accessibility models help to explore accessibility measures.

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As congestion adds travel time, network operators typically seek to avoid this bottleneck. Geographically, people live in different places, resulting in geographically uneven accessibility. Public transport systems, solidly building on accessibility justice, would increase both transit accessibility and service frequency . This paper sheds light on the chances and challenges which the Transformation of Mobility brings along for the planning of accessible and inclusive transport systems in urban areas. On the one hand, new mobility services promise improved accessibility compared to current transport solutions, particularly for underserved areas. On the other hand, new mobility services may reinforce existing inequalities if these services are controlled inadequately. This study identifies core requirements of the accessibility audit of mobility services and explores how the adoption of new mobility services impacts public transport systems in terms of their accessibility and equity. Furthermore, it provides information about the necessary policy recommendations to facilitate an accessibility audit of new mobility services and to take appropriate countermeasures in case of undesired side effects on public transport accessibility and equity. Overall, the far-reaching and unavoidable transformation of mobility must be seen as a chance rather than a challenge.

5.3. Personalization of Transport Services

In order to enhance the user experience of Personal Mobility Services (PMS), it is necessary to allow prospective users of mobility services to first obtain information about potential trips and then negotiate the entire booking process with their providers. However, the consumer experience of public transit, taxis in multiple locations, ride hailing and similar applications needs to be improved regarding the accessibility and usability of these services. The experience of multimodal travelling results in a discontinuous flow of interaction. This discontinuity has a negative impact on both mobility providers and customers. Mobility providers suffer from opportunity costs related to potential customers not knowing the existence of their services. On the other hand, customers face inconveniences while searching for a potential trip and switch time periods and modes. This results in wasted time searching for sensitive information regarding their trips and multiple negotiations with the relevant service providers… with multiple authenticated income identifiers due to the different services they need to negotiate with. They need to extract information that is represented in various ways, amounts and languages, so they can converge to a single comprehensive travel plan. Security is another important concern. Data replication raises the risk of a loss of integrity and well-formedness of information. As a result, the same piece of data could be present in different formatted representations across disconnected systems. Hence, the problem of performing operations on data that already exist in another form and, thus, the potential corruption becomes paramount. Within this scenario, companions of data can greatly differ regarding their dynamics (due to late updates in one system rather than another) making conflicting beliefs about the very same piece of data possible.

An acceptable answer to overcome such discontinuities has been proposed by the creation of a unifying framework for mobility that allows a coordination of different transportation systems. This idea has appeared in several works while it has been concretely pursued in various applications mostly inspired by Mobile As A Service (MaaS) over the last five years. It proposes service bus systems amounting to a consistent interface providing basic navigation facilities shared among transportation systems. In practice, this solution permits the user to experience travelling as it is offered by a single agency.

VI. CASE STUDIES OF SUCCESSFUL IMPLEMENTATIONS

Connected mobility elements and services have been successfully implemented in numerous cities around the world. However, the impact that success depends on proper transport planning and service design that include all relevant stakeholders in the mobility ecosystem. Four case studies exemplify several lessons learned in this area. Case studies have been selected to represent mobility approaches that differ in mobility culture and system maturity. Therefore, the services implemented in the case studies represent also different levels of maturity. Active actions that foster the mobility platforms are restricted to two case studies, BKK and Gabrovo. By contrast, actions taken in the other two cases constitute only passive measures.

BKK+ in Budapest, Hungary, exemplifies a service-oriented mobile applications development. Starting from a governance model design that combines co-creation workshops run for various stakeholders, BKK+ has been developed as a complete MOD platform that integrates several services including ticketing, parking, and electric scooter rentals. Alongside further development of service offerings and business models, further efforts are needed to broaden integration with transportation to waterborne transport and to improve dissemination efforts of given analytics results to integrate transport planning into the mobility planning systems.

Gabrovo, Bulgaria is evaluated in regard to app development and awareness-raising actions. As the youngest case study service-wise, efforts in developing the Gabrovo mobility app have not been finalized yet but the city has chosen a promising city-context-adaptive citizen-centric approach for the implementation. While adjustments in the engagement

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of various stakeholders and their impacts on joint vision would better fit the local socio-economic circumstances, the selection of UA collaborator and second round workshops can serve as good examples for future initiatives elsewhere. Raising the awareness of the Gabrovo mobility app will need continuous city promotion and education efforts. Therefore, these events will need adaptive plans and flexible-budget activities suitable for both offline and online environments. Attracting involvement will need joint actions and smooth collaboration of the involved actors.

6.1. City A: Smart Mobility Solutions

A holistic definition of Smart City is proposed to cover all aspects of city life. This new term deals with technology aspects but also with cooperation and participatory approaches designed to make all stakeholders aware of current and future patterns and sharing views in order to present a consensual action. This action is crucial due to several reasons: improving citizen quality of life, enhancing city competitiveness, reducing the impact of the City on the environment, and governance purposes. Examples of Smart Mobility are given based on a proprietary hybrid approach of Bangkok addressing all aspects of Smart Mobility. City A has embraced a model of smart mobility. In 2014, the municipality commissioned research into how smart mobility could play a role in the holistic idea of smart cities. At the same time, providers of e-mobility solutions joined forces with regional & local authorities to consider electric vehicles and/or e-mobility related solutions such as e-bikes. Due to fears when the budget was reviewed, initially just one bike depot was considered. The Palo Alto smart mobility prototype builds on/off the city's existing smart city legacy infrastructure and services and deploys new smart mobility services aggregate through a smart mobility platform. Based on stakeholder impressions, this evolution is consistent over time musical Catalog channels. The IoT improvements will be the benchmark services focused on ways to reduce congestion. Traffic conditions are highly dynamic with arrival distributions varying over time. There are other aspects that are not directly analyzed in the catalog as a chance. First, many organizations are bypassing their interests. Secondly, the danger of saturating roads affects v2x protocols. Integrating real operational issues into research is vital to understanding the limits of vehicular networks. In smart cities such as City A, a "smart @" layer is necessary to properly integrate all sourced data in/out from physical agents.

Fig 4: Smart Mobility.

6.2. City B: Integration of Ride-sharing and Public Transit

A mobility prediction platform that combines the elements of ride-sharing with public transit is developed for a city with a significant passenger train service that is currently under- or unutilized. It utilizes a weighted bipartite network structure to model the interaction between subway stations and the regions served by ride-sharing. A partition function is utilized to quantify the extent of integration between the two transport modes. Furthermore, an equilibrium model is developed to predict the patronage for ride-sharing and subway transport modes given their supply. For an inner metro system of the region, its design is considered jointly with the underlying subway system, which helps determine stop locations, frequencies, and service time windows of the ride-sharing service. A heuristic is developed to solve the joint optimization problem in a computationally efficient manner.

The utilization of public transportation systems in Japan is one of the highest in any country in the world, but with the increased popularity of ride-sharing services, there are concerns about the impact of ride-sharing on the viability of public transportation systems, particularly for urban railways that have a large fixed cost. Most studies on this topic have focused on the mathematical modeling and simulation of the rivalry between ride-sharing and public transit. In contrast, a conceptual framework is proposed to explore the potential mutually beneficial relationship between ride-sharing and public transit. A qualitative analysis of its applicability is further presented by imagining a public bike-sharing system in Tokyo. With the recognition that existing taxi-hailing wait times would significantly increase if new ride-sharing services were introduced, it is concluded that a ride-matching service which caters to the latent demand for taxi-hailing services would do well to complement public transport service. However, it is advised that if a ride-hailing service is to directly compete with public transit, it should do so only for areas and periods of low public transport demand.

A significant amount of recent research has focused on two distinct operational aspects of Connection on Demand (CoD) services: ride-matching and vehicle rebalancing. An integrated model and a methodology for solving the model are proposed with a focus on improving service efficiency, user experience, and sustainability in the context of shared

Mobility on Demand (MoD) services. The importance of explicitly modeling the interactions between these two operational aspects is highlighted and the improved performance of the integrated approach over two stand-alone methods is demonstrated conceptually.

Equ 3: Multimodal Integration Effectiveness (MIE).

$$\text{MIE} = \frac{D_{\text{multimodal}}}{D_{\text{total}}} \times 100$$

- $D_{\text{multimodal}}$: Number of trips using multiple modes of transport (e.g., bus, bike-sharing, carpool)
- D_{total}: Total number of trips completed
- Reflects the success of the platform in integrating multiple transport modes into a seamless experience.

6.3. City C: Use of Data for Traffic Management

As a major commercial and academic hub, as well as a gateway to the rest of the world, City C is experiencing increasing traffic volumes. Within the DaWanda project, this presents both challenges and opportunities for improving transport services. For transport planners and service designers, this means addressing new questions in cooperation with other stakeholders in the region such as traffic authorities, police, and public transport providers. Existing data sources are mostly static and do not yield a holistic view of the transportation network that would allow them to address those questions. Therefore, the aim of the task is to capture a broader and dynamic view of the transportation network using different data sources.

On a technical level, this means identifying existing regional data sources that can be used to extract relevant information in the context of urban mobility. Data sources include traffic flow data obtained from the ITZ. The obtained traffic flow data reflects the average speed of the road traffic with respect to the individual road segments. Some of those data sources are publicly available for City C, while others are available on agreement or rely on an API. For public transportation, query logs of the official service for routing and timetable information are used. Data is aggregated hourly for the month of May. Moreover, GTFS data, which provides timetable information for public transportation, is also considered.

To capture a broader perspective of urban mobility in City C, additional data is captured from social media and the web. Twitter data containing hashtag information groups public tweets regarding traffic incidents, complaints, or praise of public transport services. Twitter data is filtered and crawled to obtain timely and relevant tweets. Web data consists of event-centric web markup. Retrieved web pages are filtered by date, which is set with respect to expected events. Retrieved pages in turn can be crawled in depth according to their events. For broader crawls, certain query terms or domains can be considered. In addition, standards such as schema.org can be considered to retrieve structured event-centric web data.

VII. CHALLENGES IN IMPLEMENTING CONNECTED MOBILITY

Various challenges are involved in developing connected mobility systems; many partnerships and joint actions among multiple stakeholders may have to be fulfilled (instead of unilateral decisions by a local authority). Besides promoting cooperation across different levels of government and public transport agencies, new strategies may need to be devised. This section relates the findings of an Amsterdam case study to transport planning themes and contextual challenges that came up, reflecting on challenges and difficulties in adequately considering MCP in planning processes. The results from the proof-of-concept appears to be a step down in a long path where each step needs practical interpretation of new responsibilities for implementing MCP and new considerations for transport planning, service design and even wider urban processes. Driven by technological developments in urban mobility, there is an increasing awareness in several cities worldwide that Mobility as a Service (MaaS) could be applied to enhance transport systems. In response, cities are attempting to develop Connected Mobility Platforms (MCP) to facilitate access to mobility services regardless of different transport modes and providers. Several MCP initiatives are carried out, for instance, in Amsterdam, Helsinki, and London; others have explicitly stated their ambition to develop an MCP, such as Berlin, Boston, and Singapore; and many more cities are assessing possible measures to be undertaken. So far, the development of MCP is nascent. However, it can be anticipated that the need, opportunities, and availability of data, combined with public acceptance of shared mobility solutions, could lead to a rapid development of MCP requiring quick responses from cities.

7.1. Data Privacy and Security Concerns

Traffic monitoring with a subsequent traffic forecast and service matching to demand is a critical component of Mobility as a Service (MaaS) platforms. However, information about user activities raises privacy concerns. This study proposes a privacy-aware zero interaction smart mobility system capable of ensuring user location privacy during traffic

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monitoring with a periodic trajectory obfuscation mechanism. A robust and distributed traffic monitoring scheme is presented, avoiding the trusted third party in traffic monitoring while allowing volunteer location data to enable traffic forecasts and service matching processes. The obfuscation method releases anonymous comments for the supervised traffic monitoring process. Simulation results prove that the proposed method can effectively balance traffic collection privacy, vehicular privacy, and monitoring reliability to prevent data abuse. In addition, better performance is achieved by guaranteeing safety from reverse engineer attacks and user location privacy protection against adversaries.

This section presents a privacy-aware zero interaction smart mobility system, which consists of a trusted party-free privacy-aware traffic monitoring system and a location obfuscation mechanism. The trusted party-free traffic monitoring system aims to improve the vehicular privacy protection of the traffic monitoring system by establishing a privacy-aware system model in an exclusive charge environment. In such a model, the vehicular privacy protection is achieved with pledged trustworthy vehicular systems trusted by traffic control departments to avoid data abuse during monitoring. The obfuscation mechanism releases the aged position data pinned in the last time period rather than the recently collected position observations. This mechanism can also be integrated into the existing tracking method to alleviate the potential attacks against one system. The secure position obfuscation method can enhance the efficiency of the privacy-preserving positioning method while protecting location privacy against adversaries.

7.2. Technological Barriers

Connected Mobility Platforms (CMPs) offer a wealth of potential to enhance urban transport system fluidity in terms of transport-planning and service-design outputs, but many barriers remain. For a CMP to enhance urban transport planning and services in the ways envisaged in this paper, it is essential that a fair proportion of transport operators' service areas and offerings can be effectively connected to it. The greater the proportion of operators connected, the greater the transport planning, modelling and analysis dataset, and the modelling and service control ability to manipulate and schedule vehicles across operator services.

Therefore, the effectiveness of CMPs is contingent on transport operators' data-access, integration and compliance with data-sharing requests and other conditions, as laid out by the CMF and local authorities. Embedded in these conditions is the coordination of data-sharing between key stakeholders. While it is vital that privately-owned and operated transport services collectively comply, it is also essential that necessary government legislative and regulatory frameworks are built. In this regard, cooperation is required among government agencies and between levels of government regarding data-sharing responsibilities, access, and regulatory frameworks.

Technical measures and requirements to ensure responsible and appropriate data-sharing can be more readily enacted and enforced through government legislation. Similarly embedded in conceptual and institutional barriers to CMPs are data security and ownership concerns and a lack of common agreed legislative frameworks for data sharing. Therefore, government action is required to coordinate a resolution of these issues among all stakeholders and develop an agreed national data framework that provides standards, protocols, rules, fees, liabilities, and obligations for data ownership, sharing, protection, privacy, and management. In addition to ensuring compliance with these regulations, CMPs also represent a new field of transport planning and service allocation development.
Significant challenges and questions arise concerning how to share rights over passenger, service, demand and vehicle data. New analytical, modelling, and service-design skills, tools, and knowledge are needed that are so far limited in the profession as well as within transport authorities and infrastructure agencies.

7.3. Regulatory and Policy Issues

Connected mobility platforms rely on joint developments of digital services that are often based on open interfaces (APIs) and shared data, in the spirit of the data economy principles of innovation, interoperability, and co-evolution. In this type of environment, it is essential to find adequate regulatory and policy frameworks to guarantee the provision of fair competitive conditions but also the choice between innovation trajectories and the actual delivery of expected benefits. The need for appropriate public policy frameworks goes along with the inherent complexities, uncertainties, and even contradictions that affect connected mobility platforms. On the one hand, there are clear promises of value, safety, equity, and efficiency that stand behind the development of new platforms that leverage shared data services with new technologies. On the other hand, platforms raise a very wide range of concerns: in terms of finding the best regulatory policy approaches, fiscally protecting public transport and valuable mobility services, guaranteeing the inclusion of equity objectives, finding fair and equal conditions for competition, and finding robust and solid treatment of privacy and liability issues.

It is timely, therefore, to analyse the complexity and uncertainty factors of the digital mobility environment. The analytical framework would draw the factors and trends that determine the regulatory landscape of mobility data sharing platforms, typically from a technological, economic, legal, and social perspective. This framework is also proposed to address the regulatory issues already mentioned for use cases that are typically at the interplay between the new mobility on-demand services from operators and the ancillary data-driven platforms proposed by others. All in all, it is intended to eventually lay the foundations for a thorough analysis of the above-listed regulatory issues. The focus has been narrowed down to the new generation of transport network companies and similar players with an on-demand fleet of taxis, shuttles, or pooled vehicles – a representative use case for future digital mobility systems. The financial pressure of the firms for sustained and rapid market access and growth is acknowledged as an additional complexity factor.

VIII. FUTURE TRENDS IN URBAN MOBILITY

Many projects are being undertaken in cities around the world to establish sustainable mobility ecosystems where transportation service providers can connect and share mobility resources and information as more advanced cities adopt the vision of smart city planning. A sizable conceptual groundwork still needs to be laid to assemble the elements of connected mobility platforms (CMP) and understand their implications for transport planning and service design. CMP is defined as the computational, information, and communication infrastructure for a new mobility ecosystem, in which vehicle and infrastructure designers and operators can discover transportation service providers and negotiate bus and trucks for transportation service requests in cities where connected vehicle infrastructure technology has been deployed. To comprehend how CMP can impact urban transportation planning and service design, it is essential to recognize the transporting resource ow in future urban mobility systems. Urban mobility systems will consist of a diversity of transportation service requests from individuals, logistics facilities, and public sector transport planners; transportation service providers whose vehicle and infrastructure resources can be shared upon request; and the CMP that matches the two to exchange mobility services. Transport demand management uses incentives and disincentives to make travel more sustainable, and CMP enables a wider range of mobility resources to be connected and shared, resulting in access and utilization limits for travelling resources.

Transport planning to fulfill commuting, e-commerce, and goods transport needs in cities continues to be a challenge. CMP makes possible the on-demand design and sharing of mobility services to better fulfil people's transportation service requests by aggregating them as service requests that can be answered with vehicle and infrastructure resources that are part of the service providers' shared capital. CMP brings profound changes to transportation planning as its implications for service design. In terms of designing transportation services, three layers of services differ in their scale of application and granularity of time and space domains. In this context, the service design processes commence with demand detection and analysis: service execution entails service operation and management; and service evaluation extends to be a part of closed-loop transport planning.

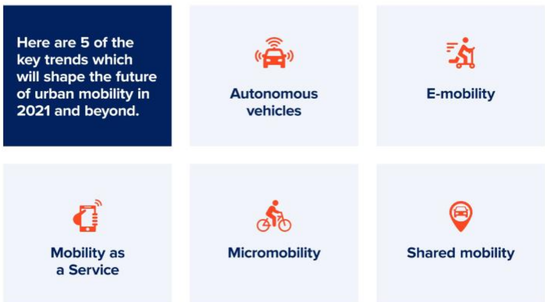

Fig 5: Future of Urban Mobility.

8.1. Emerging Technologies

The emergence of new transport technologies has the potential to generate unintended consequences which can compromise the fundamental underpinnings of successful and efficient cities. These new transport technologies include new mobility concepts, in particular 'intermediate' modes like ridesourcing, digitalised ride-hailing, door-to-door minibus shuttles, and unrivalled digitized forms of car sharing. They also include new vehicles, especially the development of connected and autonomous vehicles (CAVs) and next generation vehicles like electric scooters, smart bikes and "wild" micro-mobility devices. Though recently hailed as models for a new transport paradigm, they all share a substantial common core. These are transport modes which have all or part of their operation informed via digital technologies which unlock cities from many of the current constraints of public transport operation and modelling.

The emergence of transport modes and vehicles significantly different from the traditional bus/rail car paradigm also raises issues about potential 'conversion' of cities to networks and script-based transport matching. The arrival of personal assistants is helping fuel the potential amenity of such networks. In addition, the potential for new services offered for free or on an ultra-low marginal cost basis through advertising is raising the specter of automated 'behavioural experiments' such as nudges and choice architecture.

8.2. Changing User Expectations

The unprecedented availability of travel information, developments in mobile communications, GPS-based positioning, and social media have increased expectations of seamlessness and real-time information provision. There is a need for public transport to inform users of any delays and disruptions with regard to the impacts on their relevant trips in a coherent and integrated way, particularly with regard to interchanges and coordination with feeder transport. Users want to be alerted to changes that could allow them to take a subsequent service that is more advantageous in meeting their travel needs. Bus users want to know about breakdowns and delays of services and any detrimental effects on their relevant trip and want the ability to be advised of alternative transport options that keep them better informed of their effective arrival time at their interim destinations. Similarly, private auto users want to know about breakdowns on their relevant trip and alternative route options that keep them better informed of their likely arrival time.

The emergence of transport apps has provided awareness of the potential of integrating these capabilities for mobility as a service (MaaS). The goal is to overcome the absence of a personal journey manager (PJM) and enable users to monitor their relevant services and awareness of changes and how they affect their expected essential link in the trip chains that are planned and booked. This need is somewhat met by previously mentioned travel apps, which allow users to store and receive information about selected services that they are using. Nonetheless, public transport information still exists in isolated databases caused by disintegrated public transport service delivery, leading to a gap in the provision of intelligent transport systems. A PJM would therefore dynamically manage a user's travel needs across modes and, in doing so, ought to eliminate any of the currently discussed potential corners of the service market.

8.3. Impact of Autonomous Vehicles

In recent years, the deployment of connected and autonomous vehicles (CAVs) has raised interest not only in the advanced transport technology itself but in its socio-technical implications. It is well-known that CAVs are expected to offer a number of connected mobility benefits, which might indisputably include road safety, traffic flow, travel productivity, energy efficiency, accessibility, and equity. Given that the CAV technology has been tested on public roads and in controlled conditions all around the world, various riding apps are being developed. It is also anticipated that the first commercially available fully autonomous vehicle will be released by car companies within a few years. Through the technological process, many CAV technologies are expected to be offered as both system products and service applications for mobility as a service so as to reshape existing urban mobility systems. For example, some taxi companies are expected to provide an autonomous on-demand ride service in cities. Several car companies are planning to integrate semi-automated features into the existing transport models for private social travel. Other services, such as bus or shuttle services, are expected to offer semi-autonomous and highly autonomous travel for transit.

Nevertheless, this technological development is not without socio-technical anticipation. On one hand, various expected user benefits have sparked the exploration of embracing CAVs in the future. Empirical studies might be needed, such as quantitative surveys, modeling-based analysis, and qualitative interviews, to deep dive into perceptions on this emerging technology . On the other hand, caution must be taken to assess potential malefits amid benefits. Public understanding and attitudes toward CAVs will be essential. Additionally, guiding measures such as data regulation, ethical standards, subsidy programs, and transport provision improvement must be discussed and potentially implemented. It is plausible that the comprehension and attitudes toward CAVs across the socio-technical dimension will greatly affect the impact of CAVs on future connected urban mobility. Therefore, various scholars have attended to the socio-technical implications of deployable CAVs.

IX. POLICY IMPLICATIONS FOR URBAN TRANSPORT

Smart mobility can accelerate the transition to a new urban mobility paradigm, with urgent local policy preparation for its emergence in urban transport. Cities and municipalities are the key actors when it comes to designing, implementing, and managing urban transport systems. This matters not only from a governance perspective, but also in order to properly embrace the potential societal, economic, and environmental benefits offered by smart mobility.

Given how rapid and disruptive in nature the emergence of smart mobility systems is likely to be, there is a pressing need for increased policy preparedness in cities and municipalities. There is a risk that the move to smart mobility is not managed correctly. On the downside, this may result in uncontrolled reliance on privately owned vehicles undermining climate and liveability goals, with increases in vehicle travel and parking problems, or worse: social inequities if smart mobility systems are only for parts of urban regions. On the upside however, there is a promise of rapid progress towards lower costs of transport services, improvements to the convenience of transport mobility, fostering transport accessibility, and considerably improving the enjoyment of urban life.

As a result, cities will need to vigorously balance robust regulation and an enabling policy environment, to embrace the opportunities of new technology while minimizing negative side effects. There is an urgent need to define a new, intermediate governance level between the national and the local level, ideally co-created with cities themselves. The policy instruments available to European cities need to be reviewed and upgraded accordingly. The scope of urban mobility policy is likely to expand in such a way that cities will need to develop new capabilities to think of the urban transport system, and to govern and manage its components. This is likely to have implications for organizational change within local government agencies and other public authorities.

To see how smart mobility may emerge, and to identify key issues in readiness preparation for this transition, the accelerating sectoral system of innovation perspective has been used. Emphasis has been placed on ensuring congruence between urban policy preferences and their framing and addressing of critical issues arising over time. While this is essential for developing readiness prior to radical change, crucially this emphasis has necessitated a re-examination of the policy preferences being constructed at all levels, and the role of cities within this. So this line of research will now look at whether policy instrument adjustment can be included as a key dimension within the readiness framework, and to see how this change can be conceptualized.

9.1. Frameworks for Effective Governance

As the current transport sector is undergoing a change triggered by various simultaneous developments, including climate change, digitalisation, and technology development, how to shape transport to meet cities' long-term objectives on sustainability and social equity has become a central question. The transport sector is key to achieving sustainability goals and serving human activities effectively. All transport services and modes can be perceived as a logistic system providing mobility for persons or goods. The transport system should enable travelling and/or transporting to fulfill various demands arising from individual needs or larger/societal processes. On the one hand, this machine that produces transport services is owned and maintained by many public and private actors, while on the other hand, its impacts are felt by all urban residents. Transport and land development are interconnected; the need for land for transport lines, stations, and facilities is an integral part of designing a well-functioning urban area.

Transport today, however, is far from optimal. Congestion, pollution, and spatial/temporal inequalities are widespread. As for other urban technologies, there is room for improvement within the existing paradigms. But technological developments in the coming decade are supposed to have a disruptive effect on the transport system and the urban areas relying on it. Beyond this, configuration effects come into play. Thorough analysis is needed to assess what could unfold if these new trends can work without active governance or how they should be governed to ensure an inclusive and sustainable mobility system.

The advantages of new technologies can better satisfy mobility needs. As the transport system only partially meets requirements, some of the opportunities emerging on the supply side are more promising than others. Prioritizing the former options will be needed unless wider inequalities are to increase in conditions of a poorer transport effort. Advisory and regulatory means can help cities assess which developments would better serve their objectives. An active policy is needed to ensure that the best options become the most widespread.

9.2. Public-Private Partnerships

A Connected Mobility Platform (CMP) enables new mobility services via connectivity applications. Europe has an increased demand for innovative digital applications in Mobility as a Service (MaaS) that exposes highly relevant public transport API as KPI. The aim is to identify relevant use cases for a CMP approach in urban mobility in general and public transport in particular. Four case cities – Málaga, Lisbon, Berlin and Athens – demonstrate the variety of digital behaviour in access and egress of public transport. These use cases can shift urban transport planning and design from static demand predictions to an in-situ demand-based approach. The deployments and their relevance to different actors in the PT industry such as authorities, PT operators, technology suppliers and mobility users are discussed. A preliminary market vision for a CMP solution in PPB deployment is specified alongside an implementation roadmap. This forms a solid co-creative base for refinement via stakeholder workshops in seven further cities and further development into a

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refined go-to-market prototype. The emergence of disruptive digital innovations has profoundly changed the way in how transport services are provided. Connected Mobility Platforms (CMPs) enable new mobility services via connectivity applications. Whereas in still earlier times, new mobility services started via one-off bidding contracts, the new digital players now develop a service without the explicit involvement of the public transport authorities and involve a private technology supplier via a technical tender after a viable service has been demonstrated. The obvious, if often tacit, involvement not merely starts with the initial financial modelling of losses being based on reliable public transport data and key performance indicators. It is hypothesized that the growth of connectivity applications will further widen the gap between the exploiters of the raw data and dark patterns transport providers on the one hand and public transport authorities and technology suppliers exposing API as KPI on the other.

9.3. Funding and Investment Strategies

Urban public transport is funded mainly through operational subsidies. Most public transport operators rely on public funding in the form of operational subsidies, resulting in relatively large deficits for cities due to the defaults on the capital and/or operating grants since the pandemic. Even prior to this systemic crisis, however, public transport financing was on the verge of an imminent, sharp collapse with the emergence of a serious trade-off between solving public finance deficits or updating capabilities that would ultimately lead to better provision of services. Transit operators remained focused on expanding their capital programs and investing heavily in new and improved rail schemes, with little regard to the implications embedded in financially unsustainable business models. The pandemic compounded issues that local and regional agencies had been grappling with long before. It also resulted in reduced overall revenue receipts, greater reliance on the use of transition fund reserves, and a shift to contracted services. The pandemic raised the urgency of addressing those issues, with transit agencies attempting to move forward based on revenues that would not return for several years.

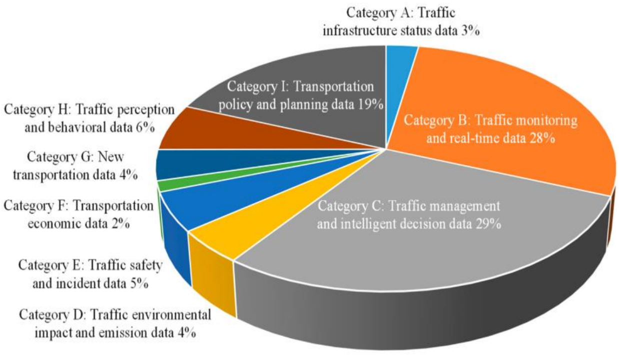

Fig 6: Mobility Platforms and Their Impact on Urban Transport Planning and Service.

Urban areas in North America, Australia, and parts of Europe and Asia are also seeing considerable investments in shared mobility initiatives that target the first or last mile of transit routes. They include on-demand bus services, ride-hailing integration into traditional public transport, and the addition of bike-sharing programs in cities. Rapid developments in shared mobility promise to provide new options with significant impacts to stakeholders in the transport ecosystem: users, shared mobility service providers, public transport operators, urban planners, local and federal governments, and co-existing mode owners/integrators. However, while substantial resources are poured into shared mobility initiatives, the understanding of their performance, user preferences, and impact on urban transport remains limited. Action towards their effective implementation, user promotion, and competitive coexistence with other transport services will be unreasonably risky without sufficient evidence.

Societal and environmental challenges from rapid urbanisation and demographic change are well-known and have already been extensively explored. Connected mobility platforms have been shown to be a promising solution to some of these challenges and are rapidly being developed in industrial contexts. Conversely, academic perspectives available today on connected mobility platforms are limited in number and scope. Existing theory on connected mobility platforms is fragmented with each view failing to provide a complete picture of the connected mobility platform construct. Innovation is needed in investment strategies that can take increasing return strategies into account.

X. CONCLUSION

The increasing complexity of mobility services and the emergence of the Mobility as a Service paradigm contribute to the shift from a transit-centered to a more general mobility-oriented perspective by both academia and transport agencies. Two aspects are emphasized in this transition: on the one side, mobility data do not remain tied to the asset perspective of public transport but open new opportunities for innovative on-demand services configuration and monetization; on the other side, connectivity widens the range of services that may be offered to users that will hold a more active role in the design of their trips. However, these new opportunities ask for reconsideration of many transport planning, monitoring, and evaluation tasks traditionally performed by agencies, as there are new actors and platforms interacting and competing with their own services. Approaches and tools that harness the possibilities opened by connectivity while keeping public authorities at the forefront of transport planning and monitoring are at the focus of this work. A review of the challenges that analytical transport planning has to face and the opportunities opened by available data is done. The latter are also synthesized into three classes of geo-analytics that focus on data-flow analysis, flow configuration and design, and flow constraint monitoring.

Existing opportunities are rearticulated into challenges requiring some further research questions, posing new aspects regarding their evaluation. The research is then positioned with respect to challenges, opportunities, and subsequent research questions. Finally, along with immediate research actions, assessment metrics and a roadmap of their evolution over time are outlined, being intended as hypotheses upon which the scientific debate should focus. While many communities are developing use-cases for the new data currently becoming available, this paper has a wider ambition of discussing wider scenarios and conceptual orientations possibly guiding future developments.

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