LUISS

Master's Degree in Strategic Management

Industry Dynamics

# Innovation and Digitalization in Public Transport:

# Smart Mobility and Sustainability

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A.A. 2024/2025

## Table of Contents

# Introduction

The primary objective of this study is to determine whether and how digitalization is transforming local public transport, with a focus on urban transit systems such as buses and metro networks. The central research question guiding this study is: *If and how is digitalization transforming municipal public transport? What are the environmental, social, and economic impacts of these innovations?*

This investigation emphasizes the integration of advanced technologies—including big data analytics[1] , cloud computing[2] , and augmented/virtual reality[3], artificial intelligence[4] —and analyzes several key areas of impact.

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[1] Big data analytics refers to the systematic processing and analysis of large amounts of data and complex data sets, known as big data, to extract valuable insights. Big data analytics allows for the uncovering of trends, patterns and correlations in large amounts of raw data to help analysts make data-informed decisions. This process allows organizations to leverage the exponentially growing data generated from diverse sources, including internet-of-things (IoT) sensors, social media, financial transactions and smart devices to derive actionable intelligence through advanced analytic techniques. https://www.ibm.com/think/topics/big-data-analytics#:~:text=Big%20data%20analytics%20refers%20to,intelligence%20through%20advanced%20analytic%20techniques

[2] Cloud computing is the delivery of computing services—including servers, storage, databases, networking, software, analytics, and intelligence—over the internet ("the cloud") to offer faster innovation, flexible resources, and economies of scale. You typically pay only for cloud services you use, helping you lower your operating costs, run your infrastructure more efficiently, and scale as your business needs change. https://azure.microsoft.com/en-us/resources/cloud-computing-dictionary/what-is-cloud-computing

[3] Augmented reality is a technology that overlays digital information on objects or places in the real world for the purpose of enhancing the user experience. It is not virtual reality, that is, the technology that creates a totally digital or computer created environment. Augmented reality, with its ability to combine reality and digital information. https://www.tandfonline.com/doi/full/10.1080/02763869.2012.670604

The areas of impacts that are going to be analyzed are: environmental, so the lowering energy consumption, and mitigation of other indicators inherent to the transport sector; social, so improvements in accessibility, user satisfaction, and social inclusion, which are critical for reducing disparities and enhancing the quality of urban life; and economic, so the evaluation of changes in average operational costs, fare structures, and overall cost efficiency.

Urban mobility is facing increasing challenges due to rapid urbanization, growing congestion levels, and rising environmental concerns. More than half of the global population currently resides in urban areas, and projections indicate that this figure will rise to 68% by 2050 (United Nations, 2023). This shift has placed great pressure on public transport networks, which are often outdated, inefficient, and struggling to meet increasing demand. The consequences of inefficient transport infrastructure

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[4] Artificial intelligence (AI) is the development of computer systems that can perform tasks that typically require human intelligence, such as learning, reasoning, problem-solving, and perception. It involves creating machines or software that can simulate human cognitive abilities and make decisions or perform tasks based on data and algorithms. https://cloud.google.com/learn/what-is-artificial-intelligence

are obvious in major metropolitan areas, where congestion leads to excessive commuting times, increased emissions, and economic losses.

In response, digitalization has emerged as a key strategy to modernize public transport systems and enhance their efficiency. Through the integration of advanced technologies such as big data analytics, artificial intelligence (AI), cloud computing, and the Internet of Things (IoT), cities and transport authorities can improve service reliability and quality, optimize operations, and make mobility more sustainable. The economic impact of congestion is particularly concerning. In the European Union alone, it is estimated that traffic congestion costs the economy approximately €100 billion annually, equivalent to about 1% of the region's GDP (European Commission, 2023). In highly congested cities such as London, New York, and Mumbai, commuters spend between 150 and 200 hours per year in traffic (McKinsey, 2022), contributing to lost productivity and rising fuel consumption. Traditional approaches to congestion management, such as expanding road networks, are revealing to be insufficient. Instead, digital solutions, including AI-driven traffic management and dynamic public transport scheduling, offer a more effective alternative by optimizing traffic flow and reducing bottlenecks.

Transportation's strategic importance is further underscored by its close alignment with the United Nations' Sustainable Development Goals [5] and the commitments of the Paris Agreement[6] , making it a key element in

[5] The 2030 Agenda for Sustainable Development, adopted by all United Nations Member States in 2015, provides a shared blueprint for peace and prosperity for people and the planet, now and into the future. At its heart are the 17 Sustainable Development Goals (SDGs), which are an urgent call for action by all countries - developed and developing - in a global partnership. They recognize that ending poverty and other deprivations must go hand-in-hand with strategies that improve health and education, reduce inequality, and spur economic growth – all while tackling climate change and working to preserve our oceans and forests. https://sdgs.un.org/goals

[6] The Paris Agreement is a legally binding international treaty on climate change. It was adopted by 196 Parties at the UN Climate Change Conference (COP21) in Paris, France, on 12 December 2015. It entered into force on 4 November 2016. Its overarching goal is to hold "the increase in the global average temperature to well below 2°C above pre-industrial levels" and pursue efforts "to limit the temperature increase to 1.5°C above pre-industrial levels." However, in recent years, world leaders have stressed the need to limit global warming to 1.5°C by the end of this century. That's because the UN's Intergovernmental Panel on Climate Change indicates that crossing the 1.5°C threshold risks unleashing far more severe climate change impacts, including more frequent and severe droughts, heatwaves and rainfall. To limit global warming to 1.5°C, greenhouse gas emissions must peak before 2025 at the latest and decline 43% by 2030. The Paris

bridging gaps between communities and fostering both economic and social development. Furthermore, environmental sustainability is another major driver of digitalization in the transport sector, which accounts for approximately 25% of global carbon dioxide emissions, with road transport being the largest contributor (International Energy Agency, 2023). If no significant interventions are implemented, emissions from urban mobility are expected to continue increasing.

Digital tools have the potential to make public transport more sustainable by optimizing route efficiency, promoting multimodal transport solutions, and facilitating the integration of electric and autonomous vehicles. For example, the city of Shenzhen, China, has fully electrified its 16,000-bus fleet, leading to an annual reduction of 1.3 million tons of $CO_2$ emissions (IEA, 2023). Similarly, Stockholm has implemented smart mobility strategies that have contributed to a 15% decrease in urban transport emissions over the past decade.

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Agreement is a landmark in the multilateral climate change process because, for the first time, a binding agreement brings all nations together to combat climate change and adapt to its effects. https://unfccc.int/process-and-meetings/the-paris-agreement

Another key factor driving digitalization is the increasing reliance on data-driven mobility planning. Public transport operators worldwide are using real-time analytics to improve service reliability and passenger experience. AI and IoT technologies enable transit agencies 9 to predict demand fluctuations, optimize bus and metro schedules, and dynamically adjust vehicle dispatching to reduce delays. London's Transport for London (TfL) has implemented AI-powered traffic coordination systems that have led to an average reduction in journey times of between 12 and 18% (Transport for London, 2022). Similarly, Barcelona's smart mobility strategy, which uses real-time passenger flow data to adjust bus frequencies dynamically, has reduced average wait times by 25% (Barcelona City Council, 2023). These examples demonstrate how digitalization is improving efficiency while making public transport more attractive for urban residents.

The global shift towards smart mobility is also being shaped by emerging trends in digital public transport. One of the most significant developments is the rise of Mobility-as-a-Service (MaaS), which integrates different transport modes—such as buses, metro, ride-sharing, and bike-sharing—into a single digital platform. Helsinki's Whim app is a leading example, allowing users to plan, book, and pay for multimodal trips in real-time (Hietanen, 2021). Another notable trend is the increasing deployment of autonomous and connected public transport, with cities such as Oslo and Singapore already conducting pilot programs for self-driving buses. Meanwhile, electrification is accelerating, with cities such as Amsterdam aiming to transition to a fully electric bus fleet by 2030. The widespread adoption of AI in transport management is further transforming the sector, with predictive analytics being used to optimize schedules, prevent disruptions, and enhance safety. In cities like Beijing and Tokyo, AI-driven ticketing and facial recognition payment systems are becoming increasingly common, further streamlining urban mobility.

Given these developments, it is evident that digitalization is not merely a technological upgrade but an essential transformation of how urban transport systems function. As cities continue to grow, and the challenges of congestion and emissions become more pressing, digital public transport solutions will be critical in shaping sustainable, efficient, and inclusive urban mobility. Governments and transit agencies must embrace these technological advancements to ensure the long-term resilience of urban transport networks and create smarter, more connected cities.

To analyze these dynamics, the study adopts a qualitative, exploratory research approach, combining a narrative literature review with desk research and case study analysis. The literature review is based on academic articles retrieved from databases such as Web of Science, alongside reports and publications from international institutions. Key search terms included "smart mobility", "digitalization", "public transport", and "innovation". This was complemented by desk research, which allowed for the collection of up-to-date data and examples of digital mobility practices at both national and international levels. Furthermore, the study incorporates a case study on ANM (*Azienda Napoletana Mobilità*), offering an empirical contribution that highlights concrete applications of digital solutions in urban public transport. This combination of methods ensures that the research captures both theoretical perspectives and real-world practices.

The thesis is structured as follows:

Chapter 1 – Theoretical Framework: Public Transport and Industry Dynamics, delves into the theoretical underpinnings of public transport systems. It discusses the environmental, regulatory, and economic aspects that shape the sector and examines the historical evolution of industry dynamics.

Chapter 2 – Digitalization in Public Transport, focuses on the digitalization of public transport. Through general case studies and analysis of emerging technologies and their practical implications.

Chapter 3 – Case study ANM and the Future of Public Transport Innovations, provides a case study on ANM and reflects on future developments in the sector.

By adopting this approach, the study aims to offer a comprehensive understanding on the potential of digital technologies in revolutionizing urban mobility.

# Chapter 1 – Theoretical Framework: Public Transport and Industry Dynamics

## 1.1 Public Transport as an Industry

The term “public transport” (PT) refers to all collective modes of land passenger transport services that are available to the general public on a non-discriminatory and continuous basis. This definition encompasses systems operating on predetermined routes and timetables, where access is contingent upon fare payment. Importantly, “public” denotes the universal accessibility of these services rather than the ownership model, meaning that PT services may be provided by either public or private entities. Conceptually, PT is a complex sociotechnical system comprising interconnected elements such as infrastructure, technology, finance, and diverse actors, all working together to fulfill the societal function of passenger transportation (Bauer & Herder, 2009; White, 2017; Hirschhorn, F., & Veeneman, W. 2021).

In addition, it is useful to clarify which sectors—according to ATECO and NACE classifications—are considered as part of the public transport industry and to discuss their economic significance. Under the NACE[7] system, public transport is primarily included in Section H "Transportation and Storage," with a more focused classification found in NACE code 49.40, which encompasses urban and suburban

[7] 7 The 'statistical classification of economic activities' in the European Community, abbreviated as NACE, is the classification of economic activities in the European Union (EU). The term NACE is derived from the French title: *Nomenclature statistique des activités économiques dans la Communauté européenne*. Various NACE versions have been developed since 1970. https://ec.europa.eu/eurostat/web/nace

passenger land transport services. The Italian ATECO[8] system parallels this classification by grouping similar activities under the transport services category. Public Transport is classified in ATECO code 49.31.00, which pertains to "*trasporto terrestre di passeggeri in aree urbane e suburbane*" (urban and suburban passenger land transport). It is important to distinguish this code from similar ones, such as 49.32.00 (non-scheduled road passenger transport) and 49.39.00 (other land passenger transport not elsewhere classified), which cover different transport modalities

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[8] ATECO is the classification of economic activities adopted in Italy by Istat for statistical purposes, i.e. for the production and dissemination of official statistical data. The management of the classification is entrusted to Istat in the various updating phases to which it is subjected both at national and international level. At national level, the classification is also used for other administrative purposes (for example, tax purposes). https://www.istat.it/classificazione/classificazione-delle-attivita-economiche-ateco/

(ISTAT, 2024). This classification allows for accurate statistical and fiscal reporting, facilitating eligibility for public funding and tenders (ISTAT, 2023).

Regarding their economic weight, data indicate that sectors related to public transport contribute, on average, approximately 3–4% to the total value added in the services sector in OECD[9] countries, with Italy generally exhibiting figures toward the lower end of this range. In terms of employment, these sectors typically account for around 2–3% of total service employment both in the EU (on average) and across OECD countries. For instance, OECD reports

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[9] The OECD (Organisation for Economic Co-operation and Development) is a forum and knowledge hub for data, analysis and best practices in public policy. We work with over 100 countries across the world to build stronger, fairer and cleaner societies - helping to shape better policies for better lives. https://www.oecd.org/

suggest that the transport sector as a whole contributes roughly 3.5–4% of value added and 3–4% of employment in advanced economies, with public transport representing a significant subsegment of these figures (OECD, 2021; Eurostat, 2022; ISTAT, 2021).

Public transport plays a fundamental role in urban mobility, providing millions of people with daily access to workplaces, education, healthcare, and social activities. It is a unique sector that not only delivers essential services but also contributes significantly to economic, social, and environmental objectives. Unlike many other industries, it operates within a complex landscape shaped by regulatory frameworks, public policies, and evolving technological advancements. Market forces alone often fail to ensure the profitability and quality of these services, which is why governments and local authorities intervene through subsidies, regulations, and strategic investments (OECD, 2019; UITP, 2020).

Historically, public transport has evolved under the dual pressures of increasing urbanization and the need for sustainable mobility solutions. As cities grow and congestion intensifies, the demand for reliable, efficient, and inclusive transit services rises. This evolution has not only pushed operators to innovate technologically but also prompted significant regulatory reforms aimed at improving service standards and ensuring equitable access. These reforms provide the foundation for a strong, integrated system that supports both public service and market efficiency.

## 1.2 Characteristics of the Public Transport Industry

The public transport industry consists of various modes of transportation, including buses and metro systems. These systems are typically structured around networks that serve densely populated areas, balancing efficiency and accessibility (Vickerman, 2020). One of the defining characteristics of the industry is its dual nature: it is both a public service and a business sector. While many public transport systems are subsidized by governments due to their social and environmental benefits, private operators are increasingly playing a role, particularly in areas such as ride-hailing[10], micro-mobility[11] , and high-speed rail (Graham & Marvin, 2021).

The key players in the public transport ecosystem include government authorities, private operators, infrastructure providers, and technology firms (Banister, 2019). Government agencies typically plan, fund, and regulate transport services, ensuring accessibility and affordability. Private operators, on the other hand, bring efficiency and innovation, often operating under government contracts. For

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[10] Ride-hailing is when a rider "hails" or hires a personal driver to take them exactly where they need to go. The transportation vehicle is not shared with any other riders, nor does it make several stops along a route. https://www.ecolane.com/blog/ride-hailing-vs.-ride-sharing-the-key-difference-and-why-it-matters

[11] Micromobility refers to a range of small, lightweight vehicles, driven by users personally. Micromobility devices include bicycles, velomobiles, e-bikes, electric scooters, electric skateboards, shared bicycle fleets, and electric pedal assisted (pedelec) bicycles.

example, companies such as Transdev and Arriva manage public transport networks across multiple countries (European Commission, 2022). Technology firms have also become essential players in the sector, introducing smart ticketing systems, AI-driven traffic management, and Mobility-as-a-Service (MaaS) platforms that integrate different transport modes (Hietanen, 2021).

Business models in public transport vary significantly. Traditional state-funded models rely on public subsidies, whereas public-private partnerships (PPPs) allow for shared investment and operational risk (Deloitte, 2020).

Public Private Partnerships (PPPs) are defined by the Federal Transit Administration as “contractual arrangements between a public or governmental agency and a private entity that facilitates greater participation by the private entity in the delivery and operation of an infrastructure project, facility or service". Many forms of PPPs exist, such as project finance type or concessions, where the line between the public and private organizations is not fixed but continuously changing depending on the situation and agreement.

Public-Private Partnerships (PPPs) have been introduced in the public transportation sector to leverage the efficiency and innovation typically associated with private sector management, particularly in systems that exhibit characteristics of natural monopolies—such as urban and suburban transit networks—which were historically operated mainly by the public sector in many regions (ITF, 2017).

Some countries, such as Japan and the United Kingdom, operate under a fully privatized model, where transport services compete in a deregulated market (Preston, 2018). The choice of business model directly impacts service quality, innovation, and financial sustainability.

Local public transport services exhibit intrinsic natural-monopoly characteristics, since key assets such as warehouses and vehicle fleets entail high fixed costs and extensive network effects.

Across the literature, “network effects” in the economic sense refer to consumer surplus gains, agglomeration effects, and complementary market growth that arise as more users join a system (Laird, Nellthorp, & Mackie, 2005; Holtz & Smith, 2007).

In economic theory, network effects describe how the value of a good or service grows as more people use it. These effects are central to network industries, which deliver services over interconnected node–link topologies and are distinguished by high fixed costs, durable capital assets, and increasing returns to scale (Laird, Nellthorp & Mackie, 2005; Janošková & Kráľ, 2020). High fixed costs arise because building infrastructure—whether rail lines, bus depots, or signaling systems—requires substantial upfront investment that does not change with usage (Hulten, 2007; Canning & Bennathan, 2007). Durable assets such as tracks, stations, and vehicles represent long-term investments whose value accrues over decades, while increasing returns to scale mean average costs fall as more users join the network (Laird, Nellthorp & Mackie, 2005).

Within this framework, three principal economic benefits emerge. First, consumer surplus gains occur when passengers' willingness to pay exceeds the fare, so that each additional rider increases total user welfare (Laird et al., 2005). Second, agglomeration effects materialize because firms and workers are more productive when clustered in areas of high accessibility; expanding a transport network therefore amplifies economic activity by improving connections among businesses, employees, and markets (OECD, 2007). Third, complementary market growth takes place when services such as mobile ticketing platforms, on-demand feeder shuttles, or retail outlets around stations develop only after ridership reaches a critical volume (Janošková & Kráľ, 2020).

The broader concept of externalities refers to third-party effects of production or consumption—like noise, air pollution, or pavement wear—that occur independently of network size (OECD, 2007). Network externalities, by contrast, exist only in network industries: an individual's utility depends on the total number of users.

Public transport is a textbook network industry, since it requires large sunk investments in durable infrastructure and exhibits significant economies of scale[12] and scope[13], making them most efficient at high usage levels (Canning & Bennathan, 2007; Janošková & Kráľ, 2020).

Positive network externalities arise when each additional user enhances system value, for example by enabling higher service frequencies or improving safety perceptions

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[12] Economies of scale refers to the phenomenon where the average costs per unit of output decrease with the increase in the scale or magnitude of the output being produced by a firm. Similarly, the opposite phenomenon, diseconomies of scale, occurs when the average unit costs of production increase beyond a certain level of output. At the point where the average costs are at a minimum, the minimum efficient scale (MES) of output of a firm or plant is reached. A distinction is often made between different types of economies of scale such as: Product specific economies of scale; and Plant specific economies of scale (OECD, 1993).

[13] Economies of scope exist when it is cheaper to produce two products together (joint production) than to produce them separately (OECD, 1993).

Conversely, negative network externalities occur when additional users degrade overall utility—most notably when traffic volumes exceed network capacity, causing severe congestion, rising accident risk, damaging the infrastructure, and more overall emissions (Janošková & Kráľ, 2020).

In this context, guaranteeing competition within the market[14]—i.e. multiple operators competing on identical routes—often proves inefficient; instead, competition for the market[15] through time-limited concessions is supposed to be more effective (AGCM, 2016; QEF, 2021). However,

[14] Competition in a market is the conventional view of competition, and concentrates on the actions of incumbents and imitative entrants in well-established markets (Geroski, 2003).

[15] Competition for a market refers to the struggle to create a new market, or to erect a new standard, and it is usually associated with the process of innovation that brings new displacing technologies to market (Geroski, 2003).

designing concession contracts is inherently challenging due to their necessary long durations to ensure operator profitability and the information asymmetry between contracting authorities and operators (Williamson, 1976; QEF, 2021).

Outsourcing services to private operators becomes advantageous when service quality reductions are easily observable by the regulator, innovation potential is high, and being recognized as an efficient operator yields significant reputational benefits. Competitive tendering should thus allocate contracts to the most efficient provider, generating cost savings for users and taxpayers alike. To maximize the gains from such procurement procedures, tenders ought to feature relatively short contract lengths, low sunk costs for bidders, straightforward handover mechanisms between incumbent and successor, and full operator control over production costs (Heimler, 2001; Heimler, 2006; QEF, 2021).

A central element in regulating concessionaire relationships is the remuneration model. Under the gross cost scheme, the operator bears only operational risk and receives payment based on verified service costs, while under the net cost scheme it also assumes demand risk, with part of its compensation tied to passenger volumes. Although gross-cost contracts may appear less incentive-aligned—since operators lack direct interest in boosting demand—they eliminate demand-related information asymmetries favoring incumbents and lower entry barriers for new competitors at re-tendering (Albano et al., 2014; QEF, 2021).

The public transport industry operates within a complex framework that balances public service obligations with economic efficiency. The interaction between regulatory policies, market dynamics, and technological advancements shapes the sector's evolution. Network effects, economies of scale, and PPPs play a crucial role in driving efficiency and innovation. Understanding these theoretical foundations is essential for analyzing how digitalization is transforming public transport, which will be explored in the following chapters.

## 1.3 Regulatory Framework and Normative Guidelines

Italy's legal framework initially embraced a "regulated liberalization" model under Legislative Decree No. 422/1997 (the "Burlando Decree"), mandating service contracts of up to nine years awarded primarily via competitive tenders (Boitani & Cambini, 2002). In practice, however, widespread contract extensions—facilitated by European "in-house" law and Regulation (EC) No. 1370/2007—often supplanted tendering, allowing local authorities to award services to wholly controlled entities without competition (Bentivogli et al., 2008). A 2011 referendum further entrenched parity between in-house and tendered awards, and subsequent measures (DL 179/2012; Public Procurement Code Art. 192.2) imposed only a requirement to justify in-house awards as affirmed by Constitutional Court Judgment No. 100/2020.

The 2017 "Decreto Sblocca Cantieri" (DL 50/2017) significantly overhauled institutional governance and financing. Under this decree, regions define mobility catchment areas (minimum 350.000 inhabitants or aligned with metropolitan jurisdictions), local authorities 27 manage and award services, the State finances through the National Fund for Local Public Transport, and the *Autorità di Regolazione dei Trasporti* (ART) assumes regulatory oversight. ART is tasked with drafting standardized tender and service contract templates, specifying targets for effectiveness, efficiency, and financial equilibrium, and regulating access to essential assets—mandating that outgoing operators' depots and equipment be made available to successors under market-value lease or transfer agreements. Staff transfers must preserve the economic and legal conditions established by the national sector collective agreement.

To further incentivize competitive awards and operational efficiency, DL 50/2017 ties a growing share of fund allocations to traffic revenues and cost-standard measures, sets penalties (up to 15% of contract value) for non-tendered awards, and caps yearly funding reductions at 5% (and 10% over five years) relative to historical allocations, although implementation has been repeatedly deferred. The decree also mandates that at least 10% of contractual compensation be devoted to fleet renewal and digital technology investments—such as 28 passenger-counting systems—to foster cleaner and smarter public transport.

This combination of natural-monopoly economics, tailored remuneration schemes, and an evolving regulatory framework— shaped by both national reforms and European directives—underpins the contemporary organization of public transport and sets the stage for its digital transformation.

While at the European level are set baseline standards for service quality, fair competition, and environmental performance that ensure that public transport remains accessible and affordable while encouraging operators to pursue efficiency and innovation (OECD, 2019); at the national level further refinements are made.

In contrast, Germany's decentralized approach under the *Personenbeförderungsgesetz* (Passenger Transport Act) grants regional authorities considerable autonomy, resulting in robust public–private partnerships and advanced service models, as seen in cities like Berlin and Munich.

France represents a highly centralized model, where entities such as RATP oversee service delivery in major cities like

Paris, ensuring uniform quality standards. While this centralization offers stability, it can sometimes slow the pace of digital innovation due to lower competitive pressures.

Spain’s hybrid model, particularly in regions like Catalonia and Madrid, strikes a balance between strict public service obligations and flexible market mechanisms. This model supports innovation through PPPs while maintaining rigorous quality standards.

## 1.4 Industry Dynamics and Their Influence on Innovation

Public transport evolves in response to competition, technological advancements, and regulatory frameworks, all of which shape industry innovation. In many cities, transit services operate as monopolies or quasi-monopolies, where a single operator dominates the market. However, some regions encourage competition among operators to improve efficiency and service diversity (Button, 2021). A study by the OECD (2021) highlights that competitive tendering in bus services can lead to cost reductions of up to 30% while maintaining service quality.

Technological advancements are a key driver of transformation. Digitalization, including real-time tracking, AI-driven scheduling, and big data analytics, is enhancing operational efficiency and passenger experience (McKinsey & Company, 2022). Autonomous public transport is also emerging as a disruptive force. Cities such as Oslo and Singapore have piloted self-driving buses, aiming to reduce labor costs and improve service reliability (UITP, 2023).

Regulatory frameworks significantly influence the pace and direction of innovation. Governments worldwide are implementing sustainability policies, such as the European Green Deal, which mandates the transition to carbon-neutral urban transport by 2050 (European Commission, 2023). In response, many cities are investing in electric and hydrogen-powered buses, supported by digital fleet management systems that optimize energy consumption (IEA, 2023).

Public-private partnerships (PPPs) have emerged as a solution for balancing public control with private sector innovation. Many cities have successfully adopted PPP models for smart mobility initiatives. For instance, Singapore's collaboration with Grab and SMRT has integrated ride-hailing with traditional transit services, creating a seamless multimodal transport network (Tan et al., 2021).

## 1.5 Market Analysis and Future Trends

The market for urban public transport in Europe is evolving amid rapid technological change and shifting regulatory landscapes. Key market trends include rising passenger demand, since European cities continue to experience increasing ridership driven by urbanization and the growing need for sustainable mobility. However, revenue growth has been tempered by competitive fare structures and heavy reliance on public subsidies (UITP, 2020).

An additional trend seen in the industry is technological innovation: nonetheless, digital transformation is a primary driver in the sector. Big data analytics, cloud computing, and real-time mobile applications are being leveraged to optimize route planning, improve operational efficiency, and enhance the customer experience. The implementation of these technologies has resulted in measurable improvements, such as reductions in maintenance downtime by 15–20% and enhanced service reliability in leading markets like Berlin and Paris (Deloitte, 2024).

Another contradistinctive trend in the market are the competitive pressures and the market liberalization. In many cities, local authorities are adopting integrated mobility platforms that incorporate MaaS (Mobility as a Service), shared micro-transit, and on-demand ride-sharing. These platforms challenge traditional transportation methods by offering more flexible, customer-centric services. As a result, urban transit markets are becoming increasingly competitive, with private and public operators competing for market share. Market research indicates that although urban transit systems remain heavily subsidized, there is a growing trend toward cost recovery through innovative revenue streams, including dynamic pricing and multimodal ticketing solutions.

Investment and Regulatory Reforms are also shaping the PT industry. Governments are actively reforming regulatory frameworks to foster innovation while safeguarding public service obligations. Initiatives in cities like Milan and Madrid demonstrate significant public investment in modernizing transit infrastructure and deploying digital technologies. These reforms are expected to further drive operational efficiency and service quality, setting the stage for long-term market growth.

Lastly, gaining progressively more relevance are sustainability and environmental goals. With the transport sector accounting for a substantial share of urban $CO_2$

emissions, there is a pressing need for environmentally sustainable transit solutions. The market is witnessing a gradual shift toward electrification, though adoption remains uneven across regions. Countries like Germany and France have made significant strides in integrating electric buses and low-emission vehicles, whereas Italy continues to lag behind, highlighting the need for targeted investments and policy support (World Bank Group, 2022).

Looking ahead, the convergence of digital technology and regulatory reforms is poised to reshape urban public transport markets across Europe. This evolution will likely lead to greater integration of services, enhanced competitiveness, and improved sustainability outcomes. Policymakers must balance the need for innovation with the imperative of maintaining equitable access and affordable fares—a challenge that requires coordinated investment, effective governance, and proactive market strategies.

# Chapter 2 – Digital Innovation in Public Transport

## 2.1 Smart Mobility and Digitalization

The concept of smart mobility is inevitably linked to that of smart cities. In recent years, the planning of cities that are sustainable—not only from an environmental perspective but also from social and economic standpoints—has gained increasing relevance. This holistic approach to sustainability aims to enhance the overall quality of life for urban residents.

As noted by Šemanjski et al., the main driving force behind this transformation is the advancement of Information and

Communication Technologies[16] (ICT) and the Internet of Things[17] (IoT). In addition to these technological factors, the raise in urban population has further emphasized the demand for more efficient and sustainable modes of transport.

It is reasonable to assert that smart mobility is one of the fundamental pillars of smart cities. The definition of smart

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[16] Information and communication technology, abbreviated as ICT, covers all technical means used to handle information and aid communication. This includes both computer and network hardware, as well as their software. https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Glossary:Information_and_communication_technology_(ICT)#:~:text=Information%20and%20communication%20technology%2C%20abbreviated,as%20well%20as%20their%20software

[17] The Internet of Things (IoT) refers to a network of physical devices, vehicles, appliances, and other physical objects that are embedded with sensors, software, and network connectivity, allowing them to collect and share data. https://www.ibm.com/think/topics/internet-of-things

mobility varies across different academic perspectives. Chun and Lee (2015) define smart mobility as "a concept of comprehensive and smarter future traffic service in combination with smart technology." According to Garau et al. (2015), smart mobility relies on "efficient public transport methods with low environmental impact, a network of safe and continuous cycle lanes, and interchange parking systems that prevent city congestion, among others."

Other scholars define smart mobility as a set of strategies aimed at improving traffic efficiency, whether by encouraging walking, cycling, or public transportation, with the shared goal of reducing economic, environmental, and time-related costs (Yue, Chye & Hoy, 2017). Some authors highlight the role of smart mobility in integrating technology into urban infrastructure, improving the way people interact with their cities (Cristea, Dragos et al., 2020).

In academic literature, smart mobility is often presented as one of the key solutions for creating more sustainable transport systems (Pinna, Masala & Garau, 2017). Benevolo et al. (2016) describe smart mobility as "a set of coordinated actions aimed at improving the efficiency, effectiveness, and environmental sustainability of cities." This concept revolves around connectivity, which, when combined with big data, enables real-time traffic monitoring and dynamic transport management (Pinna, Masala & Garau, 2017). While Battara et al. describe smart mobility as a network system mainly characterized by connections, both digital and physical, to satisfy people's needs.

However, a widely shared perspective is that it is impossible to discuss smart mobility without addressing sustainability. Often, discussions around sustainability focus primarily on directly measurable impacts, such as environmental factors, without considering less tangible elements like governance, strategic policies, and decision-making processes (Litman and Burwell, 2006), which are also relevant to have a complete view.

Smart mobility has become a focal point in urban planning research due to its potential to transform transportation networks through innovative solutions (Pinna, Masala & Garau, 2017). Since its inception, the concept has gained traction not only in urban and transport planning but also in policymaking, as its feasibility and adoption continue to grow (Tomaszewska & Florea, 2018).

Despite its growing importance, smart mobility is still an evolving concept, and no universally accepted definition exists.

In practice, smart mobility encompasses various services, including real-time traffic management, public transport monitoring, tracking applications, parking management, and car-sharing solutions (Yue, Chye & Hoy, 2017). Research has shown that Intelligent Transport Systems (ITS) play a crucial role in supporting urban smart mobility (Mangiaracina, 2017; Papa, Gargiulo & Russo, 2017). An ITS is an advanced transportation system that integrates various software and digital tools to enhance safety, reduce traffic congestion, decrease emissions, and improve energy efficiency while fostering the growth of related industries (Cristea, Dragos et al., 2020).

From all the different definitions, the common conclusion that can be driven is that the concept of Smart Mobility is undoubtedly linked to that of Sustainable Mobility, which can be achieved through the use of environmentally friendly innovations and devices (Battara et al., 2018).

Tomaszewska and Florea (2018) describe smart mobility as "a cornerstone of a smart city, intrinsically linked to digital transformation systems, advanced routing technologies, and traffic forecasting—elements that support municipal policies focused on data and communication innovations."

What is sure is that Smart Mobility is not a unique initiative, but a complex set of projects and actions, different in goals, contents and technology intensity (Benevolo, Dameri, & D'Auria, 2016), and its solutions are tied to the phenomena of digitalization.

*Digitization* and *Digitalization* are two terms which are often used interchangeably in the literature. But a distinction of the two terms found in the literature, if a proper definition is to be made, would be the following. Digitization refers to the numerous disruptions that occurred with the Third Industrial Revolution[18] and represents the conversion of real-life information into its digital (binary) form, allowing for the acquisition of information across multiple platforms (Brennen and Kreiss, 2016; Crisan, Belciu & Popescu, 2025). On the other hand, Digitalization, is a much broader concept, as it marks the beginning of the Fourth Industrial

[18] See Jeremy Rifkin, The Third Industrial Revolution: How Lateral Power Is Transforming Energy, the Economy, and the World (New York: Palgrave Macmillan, 2011), for an in-depth understanding.

Revolution[19] (Vrana and Singh, 2021). Researchers Crisian, Belciu & Popescu (2025) define Digitalization as "the act of converting the digital form created by digitization into meaningful information that can be used to optimize the evolution of society."

The European Commission has also recognized the importance of digitalization, through the actuation, already in 2010, of the "Digital Agenda for Europe[20]" which

[19] See Klaus Schwab, The Fourth Industrial Revolution (Geneva: World Economic Forum, 2016), for a detailed exploration.

[20] The Digital Agenda presented by the European Commission forms one of the seven pillars of the Europe 2020 Strategy which sets objectives for the growth of the European Union (EU) by 2020. The Digital Agenda proposes to better exploit the potential of Information and Communication Technologies (ICTs) to foster innovation, economic growth and progress. https://eur-lex.europa.eu/HR/legal-content/summary/digital-agenda-for-europe.html?ut

supports digitalization in multiple fields and domains. Also the more recent "A Europe Fit for the Digital Age" program pushes for digitalization and innovation, encouraging "investment in digital education and the adoption of technologies such as AI, blockchain, and high-performance computing to boost productivity and competitiveness across industries" (Crisan, Belciu & Popescu, 2025).

At a theoretical level, two classic innovation models help explain how digital technologies take root and reshape industries. Clayton Christensen's disruptive innovation framework illustrates how new technologies or business models can rapidly gain noticeability and eventually overturn established market leaders (Christensen, 1997). Everett Rogers's diffusion of innovations theory describes the spread of new ideas through a social system—from innovators and early adopters to the late majority and laggards—driven by characteristics such as relative advantage, compatibility with existing values, and perceived ease of use (Rogers, 2003). In the context of digitalization, these theories together shed light on why and how digital tools first gain traction and then diffuse broadly, catalyzing a wholesale transformation of service delivery, decision-making, and organizational culture.

Digitalization also aligns closely with global sustainability agendas. It is directly linked to the 2030 Agenda for Sustainable Development which addresses numerous challenges faced by the world, including Digitalization. The latter is directly aligned with SDG 9[21], which ultimate goals

[21] For a more in depth overview of the Sustainable Development Goals, see: https://www.globalgoals.org/goals

are to “build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation”. Of course, the multidisciplinary nature of digitalization allows to be a critical tool for supporting and encouraging sustainability in all other SDGs.

Digitalization is such a broad process and concept, given its influence on all business related fields, that is transforming markets and consumers’ preferences and demands (Verhoef et al., 2021).

Therefore, the role of digitalization is vital in shaping urban mobility into a smarter, more adaptive ecosystem. It starts with digitization enabling foundational capabilities like online ticketing, digital surveys, and smart card usage. While digitization focuses on efficiency gains in internal documentation, it does not change how value is created.

Moving forward, digitalization redefines how transport services operate by altering traditional processes through IT integration. This includes mobile applications for route planning, real-time traffic alerts, and platforms facilitating communication between operators and passengers. By optimizing user interaction and enabling better coordination, digitalization offers a pathway to enhance the public transport experience while also cutting costs. The ultimate phase of digitalization goes beyond enhancing existing processes and reimagines the entire business model. In the public transport sector, this could mean adopting Mobility as a Service (MaaS) platforms that integrate various forms of transport—bikes, buses, trams, and shared vehicles—into a single service accessible via a mobile app. AI, IoT, blockchain, and robotics further deepen this transformation by optimizing logistics, personalizing mobility experiences, and fostering sustainability.

These innovations not only affect how services are delivered but also how users behave. The rise of connected consumers who rely on mobile apps, smart assistants, and digital tools reshapes expectations.

Transport providers must adapt or risk being left behind. In this evolving context, digital transformation is no longer optional; it is essential for building resilient, user-focused, and sustainable urban mobility systems.

In the table below a grouping of the main digital trends and innovations of the PT sector.

| *Digital Trend* | *Description* | *Impact Area* |
|---|---|---|
| 1. Mobility as a Service | Integrated platforms offering multimodal planning, booking, and payment | User experience, modal integration |
| 2. Account -Based Ticketing (ABT) | Payment tied to user profiles, not physical tickets | Fare flexibility, data generation |
| 3. Real-Time Passenger Information | Dynamic updates on vehicle location, delays, and occupancy | Passenger satisfaction, operational trust |
| 4. Predictive Maintenance | Use of IoT and AI to anticipate failures and schedule interventions | Cost efficiency, reliability |
| 5. Data Analytics & Business Intelligence | Use of data platforms to optimize operations and policy decisions | Governance, planning, KPIs |
| 6. Open Data and APIs | Public access to datasets and developer interfaces | Transparency, innovation ecosystem |
| 7. Digital Twins and Simulation Tools | Virtual models of transport networks for planning and scenario testing | Infrastructure design, Resilience, traffic management |
| 8. Contactless and EMV Payments | Tap-to-pay systems using cards or smartphones | Convenience, hygiene, fare enforcement |
| 9. Demand- Responsive Transport (DRT) | Services dynamically adapted to user demand via digital booking | Accessibility, rural/low-density areas |
| 10. Business Intelligence (BI) | Visual monitoring of KPIs, occupancy, emissions, etc. | Policy-making, efficiency monitoring |

*Table 1 - Main Digitalization Trends Table elaborated based on Benevolo, C., Dameri, R. P., & D'Auria, B. (2016), Smart mobility in smart city: Action taxonomy, benefits and challenges. Transportation Research Procedia, 26, 28–35.*

*1. Mobility as a Service (MaaS)*

MaaS platforms aim to unify disparate transport services—public and private—under a single digital interface. By allowing users to plan, book, and pay for multimodal journeys (e.g., bus + metro + e-scooter), MaaS reduces friction and promotes intermodality. As defined in an international review, MaaS is a "usercentric, intelligent mobility distribution model in which all mobility service providers' offerings are aggregated by a sole mobility provider … and supplied to users through a single digital platform" (Jittrapirom et al., 2017). MaaS not only improves user convenience but also shifts the focus from vehicle ownership to service access, aligning with sustainable urban mobility goals.

*2. Account-Based Ticketing (ABT)*

Unlike traditional systems based on physical media such as cards or tickets, ABT relies on a back-end account that records entitlements and travel usage (Masabi, 2019). This architecture enables more flexible fare rules, including features like fare capping and best-fare calculation, while also supporting mobile and contactless payments such as cEMV and digital wallets (Littlepay, 2023; Masabi, 2019). In addition, ABT provides operators with detailed mobility data that can be leveraged for planning and optimization of services (Littlepay, 2023).

3. *Real-Time Passenger Information Systems (RTPI)*

Real-Time Passenger Information Systems (RTPI) are digital platforms that collect and distribute live data about public transport services, such as vehicle location, service status, and estimated arrival times. These systems enhance the passenger experience by providing reliable updates on delays, disruptions, and crowding levels, which helps reduce uncertainty and waiting anxiety (UrbanThings, 2024). From the operator’s perspective, RTPI supports control centers in monitoring network performance and reallocating resources dynamically, allowing services to better respond to fluctuations in demand (Rail Electronics, 2024).

4. *Predictive Maintenance*

Predictive maintenance is one of the most interesting results of the application of Artificial Intelligence in the transportation sector. The innovation in predictive maintenance stands in the optimization of resources involved in the maintenance, which brings a dramatic reduction in costs as well as the maximization of plant operating times (Revelis, n.d.). Through IoT sensors installed in vehicles and infrastructure, predictive maintenance systems detect anomalies early and forecast failures (Eseye, 2024). These tools allow maintenance teams to act proactively rather than reactively, as the collected data—such as temperature, vibration, and operational metrics—is analyzed to identify subtle changes that may indicate impending issues, enabling timely interventions (XYTE, 2024).

*5. Data Analytics & Business Intelligence*

Advanced analytics tools process large volumes of operational and user-generated data from integrated sources—such as GPS traces, web queries, and environmental indicators—to extract actionable insights for dynamic scheduling, performance monitoring, and evaluation of environmental and social KPIs (Tempelmeier et al., 2019). Moreover, such platforms facilitate forecasting of travel behavior and spatial transformations in urban areas using predictive models, thereby informing future investments and policy reforms, particularly amidst uncertainty and rapid urban change (Denteh et al., 2025).

*6. Open Data and APIs*

By making data publicly accessible and machine-readable, transport agencies foster transparency and enable third-party innovation. Open data initiatives enable researchers, civic actors, and private developers to access transport information, reuse it, and combine it with other datasets, thus creating new services and analytical tools. According to Joutsenlahti et al. (2021), open data and APIs are essential to building data-driven services, though they require governance models to address risks such as data quality and interoperability.

Application Programming Interfaces (APIs) are standardized digital interfaces that allow different software applications to communicate and exchange data automatically. In the transport domain, APIs enable external developers to directly connect to public data infrastructures—such as real-time schedules, ticketing information, or traffic updates—and use them to build new mobility services and applications (Boeing et al., 2022). In this way, APIs not only improve accessibility of information but also enrich the mobility ecosystem with innovative user-centered solutions.

However, as Schirru (2020) points out, publishing raw datasets alone is no longer sufficient. Instead, APIs should be designed to provide precise, timely, and simplified information, supporting what he defines as a data circular economy. This approach allows not only skilled developers but also non-technical users—such as policymakers or local administrators—to derive meaningful insights for governance, innovation, and public value creation.

### *7. Digital Twins and Simulation*

"A digital twin is a dynamic virtual representation of a digitized entity, typically hosted in cloud infrastructures and continuously updated with current operational data to provide actionable insights" (AI generated definition based on: Advances in Computers, 2020).

The use of digital twins (DT) provides an effective approach to tackling the increasing complexity of transportation systems by enabling continuous monitoring throughout their entire life cycle. A DT that remains constantly aligned with its physical system allows real-time two-way interaction, supporting activities such as early stage design, construction, reconstruction, traffic management, and other analytical tasks. Recent studies highlight the significant potential of DT in various domains, which explains the growing interest it is generating (Kušić, Schumann, & Ivanjko, 2023).

8. *Contactless and EMV Payments*

Contactless payments are transactions that do not require physical contact between a payment device and a point of sale terminal. Instead, the user simply holds a card or mobile device within a short distance of the terminal, and the payment information is transmitted wirelessly through radio frequency technology. These payments rely on EMV standards—originally developed by Europay, Mastercard, and Visa—which define the technical framework for secure smart payment cards and terminals (Idemia, 2022). By integrating a near-field communication (NFC) chip into the card, EMV technology enables secure, fast, and contactless transactions while addressing security weaknesses found in earlier payment methods (Smart Card Alliance, 2016).

This innovation has been widely adopted in public transport ticketing, where EMV cards serve not only as bank cards but also as instruments of fare payment. Through an open-loop model, passengers can simply "tap and ride" using their everyday bank cards or mobile wallets, eliminating the need to purchase tickets in advance or recharge smart cards (Daliah, 2024). For transport operators, EMV-based systems reduce the costs of issuing and managing proprietary smart cards, maintaining large stocks, and operating ticket vending machines, which are costly to install and service (Idemia, 2022).

Security is a key driver of EMV adoption. EMV cards are infact designed to prevent fraudulent activity and protect sensitive information such as card numbers and expiration dates. Public transport payment systems using EMV must therefore comply with the Payment Card Industry Data Security Standard (PCI DSS), ensuring that customer data is safeguarded against leaks and breaches (Daliah, 2024). Moreover, the EMV ecosystem has introduced solutions such as white-label EMV cards, which extend accessibility to unbanked populations (Daliah, 2024).

Challenges persist, especially in developing countries where transaction fees and infrastructure requirements may limit deployment. Despite these obstacles, EMV and contactless technologies have demonstrated their potential to streamline fare collection, enhance passenger convenience, and improve security across global transport systems (Droździel et al., 2019; Idemia, 2022).

*9. Demand-Responsive Transport (DRT)*

Demand Responsive Transport (DRT) refers to mobility services that operate based on passenger requests, using vehicle fleets that adjust routes and schedules to match individual travel needs. Positioned as a hybrid mode between conventional buses and taxis, DRT encompasses a variety of services—from small-scale community-based operations to larger, more structured regional networks (Mageean & Nelson, 2003). It enhances accessibility and provides an alternative to private cars, contributing to equitable mobility especially in rural contexts (Choi, Kang, Song, & Hwang, 2022).

*10. BI Dashboards for Strategic Monitoring*

Business Intelligence (BI) dashboards enable transport authorities to visualize and track key performance indicators—such as ridership levels, environmental emissions, farebox recovery ratios, and service punctuality—in real time. By consolidating data streams into interactive dashboards, these tools enhance operational oversight, support rapid anomaly detection, and enable timely interventions by both technical staff and decision-makers (Bańka et al., 2022). Beyond operational monitoring, BI solutions also contribute to long-term planning and service optimization. For example, Barnabé (2020) demonstrated how mobility analytics integrated into BI models can improve public transport planning and foster evidence-based decision-making at a strategic level. Together, these insights highlight the potential of BI dashboards to strengthen both tactical management and strategic governance in urban mobility systems.

## 2.2 The Impact of Digitalization on Efficiency and Sustainability

Efficiency is a central concept in both economic theory and public management, commonly associated with the optimal use of resources to achieve desired outcomes. In the context of public transport (PT), efficiency is particularly relevant as it relates to the capacity of a transport system to deliver high-quality services while minimizing costs, resource consumption, and environmental impact. As cities continue to grow and mobility needs become increasingly complex, enhancing efficiency becomes a key challenge for transport authorities and operators.

In economic terms, efficiency is typically divided into two main categories: technical efficiency and allocative efficiency (Farrell, 1957). Technical efficiency refers to the ability of an organization to produce the maximum output from a given set of inputs (e.g., buses, fuel, personnel). Allocative efficiency, on the other hand, measures how well resources are distributed according to demand and cost structures, aiming for the optimal balance between production and user needs.

In the public transport sector, and generally in public sectors, additional dimensions of efficiency are considered: operational efficiency, which assesses how effectively services are delivered in terms of frequency, punctuality, and vehicle utilization; financial efficiency, which focuses on cost-effectiveness and revenue generation, including metrics such as cost per passenger-kilometer or farebox recovery ratio; environmental efficiency, which evaluates the energy usage and emissions per trip or passenger, Measuring efficiency in PT systems requires both quantitative indicators and qualitative assessments. Many public authorities and operators use Key Performance Indicators (KPIs) to monitor and report on these metrics. In integrated systems, these KPIs also support benchmarking exercises between cities or regions.

However, traditional efficiency indicators often fall short in capturing the complexity of these systems, especially when it comes to intermodal coordination, user satisfaction, and environmental externalities. This is where digitalization can significantly enhance both measurement and performance. The combined effect of all these different digital tools not only lowers operational costs and boosts productivity, improving the overall efficiency, but also advances environmental and urban sustainability goals.

Sustainability, in this context, aligns with the widely accepted definition from the United Nations Brundtland Commission (1987), which describes it as “meeting the needs of the present without compromising the ability of future generations to meet their own needs.” Achieving public transport sustainability offers societal wide benefits, and in this transition, digitalization plays a fundamental role, acting as a catalyst. Digitalization transforms municipal public transport by addressing the core principles of sustainability: environmental protection, social equity, and economic viability.

Digital technologies are critical in mitigating the environmental footprint of public transport. They facilitate sophisticated route optimization and fleet management systems, where real-time GPS tracking, AI-powered predictive analytics for traffic flow, and dynamic scheduling, altogether, minimize empty runs, reduce overall vehicle kilometers traveled, and consequently lower fuel consumption and greenhouse gas emissions per passenger/kilometer (European Environment Agency, 2020; Lee et al., 2021). The positive environmental impact of digitalization is further amplified by its support for the integration of electric and low-emission vehicles, optimized through smart charging infrastructure and deployment strategies that maximize their energy efficiency. Furthermore, IoT sensors embedded in vehicles enable predictive maintenance by continuously collecting operational data. Analyzing this data through machine learning allows for servicing only when necessary, a practice that not only cuts maintenance costs and extends vehicle lifespan but also prevents abnormal fuel consumption or breakdowns that could lead to increased emissions (Accenture, 2021). Beyond individual vehicle and operational improvements, digitalization also promotes broader environmental sustainability through the advancement of intermodal and shared mobility. Digital platforms, particularly Mobility as a Service (MaaS), seamlessly integrate various transport modes, making public and shared transport more attractive and convenient alternatives to private car use. This shift contributes significantly to reducing the total number of vehicles on the road, leading to improved air quality and a smaller carbon footprint for urban mobility (UITP, 2019; Hensher, 2017).

Digitalization in public transport exerts a multifaceted influence on environmental outcomes, primarily through emissions reduction, energy optimization, resource efficiency, and enabling data-driven environmental management. By integrating IoT-enabled traffic management, Mobility as a Service platforms, digital twins, and opendata ecosystems, transport agencies can significantly limit greenhouse gas emissions, minimize energy consumption, and optimize infrastructure utilization, while also identifying pollution hotspots and guiding policy interventions. However, achieving these benefits requires overcoming challenges related to technology access, data governance, and lifecycle impacts of digital hardware.

## 2.3 Economic and Social Impacts

Digitalization and associated innovations are profoundly reshaping the public transport sector, generating both measurable economic benefits and broader social consequences. Economically, digital tools offer the possibility to create new business models, which can lead to reduced operating costs, enhanced asset utilization, and the creation of new revenue streams. Socially, they are reshaping accessibility, equity, and community engagement. Yet, as Staricco (2013) notes, these advances also risk exacerbating existing divides if institutional and sociocultural conditions are not adequately addressed. The adoption of these advanced technologies, often part of the "third wave" of digitalization, is aimed at enhancing information processing and the quality of decision-making, while further automating routine tasks. These technologies are integrated with already available and more mature technologies, which businesses and companies have been using in daily practices since the first and second wave of digitalization[22].

One of the key economic impacts of this digital transformation is the optimization of the supply-demand match in public transport. Machine-learning models ingest data from ticket validations, passenger-count sensors, and traffic-flow analytics to forecast demand with increasing

[22] The first wave of digitization is associated with the introduction and adoption of what today are considered "mature" technologies, such as management information systems aimed at automating data processing and applied to monitoring and reporting of business performance, telecommunications technologies such as broadband (fixed and mobile) and voice telecommunications (fixed and mobile) which allow the remote access of information. The second wave of digitization entailsthe diffusion of the Internet and its corresponding platforms (search engines, marketplaces), which enable the networking of enterprises to consumers and enterprises among themselves for purchasing of supplies, and distribution of output.

precision. This enables dynamic scheduling and vehicle dispatch, allowing passengers to benefit from just-in-time arrival predictions, while operators minimize empty runs and underutilized capacity, effectively lowering per-kilometer costs. The momentum behind this shift is significant; a survey conducted by Accenture across nine countries found that 70% of public agencies are considering advanced digital technologies for transport, with 25% having moved beyond pilot projects into full deployment, underscoring the rapid diffusion of these innovations in public service (Katz, 2017; Accenture, 2017).

Digital platforms, particularly those enabling Mobility as a Service (MaaS), exhibit strong economies of scale and network effects. As more riders register on a MaaS app, the platform can integrate additional operators, modes (such as car-sharing, bike-sharing, and e-scooter rental), and value-added services, which in turn increases customer retention and creates higher entry barriers for potential competitors. While the adoption of single platforms can lower the fixed and entry costs for niche mobility providers, it also introduces the risk of market concentration among a few dominant integrators who control critical data flows and user interfaces (Dedola et al., 2021). Beyond these platform dynamics, digital innovation underpins the broader economic sustainability of public transport systems by driving significant financial and operational improvements. The enhancements in operational efficiency, such as optimized routing strategies, directly translate into substantial economic savings by reducing fuel and maintenance expenditures. Automated scheduling and personnel management systems can lower administrative overheads. Furthermore, the widespread adoption of electronic and mobile ticketing systems contributes to cost reduction by diminishing expenses associated with printing, distributing, and handling cash fares, while concurrently helping to reduce fare evasion (Vuchic, 2017; TransportTech Insights, 2022).

These changes foster a dynamic environment that stimulates innovation not only within public transport authorities and operating companies but also across the broader mobility ecosystem. This can significantly enhance the sector's competitiveness against private vehicle use and other emerging mobility players, attract crucial investment, and thereby contribute to its long-term economic resilience and growth (McKinsey & Company, 2021; Deloitte, 2020).

The social impacts of digitalization in public transport are equally significant, fostering more inclusive and user-centric mobility systems. Digital tools such as real-time journey planners, mobile ticketing applications, and comprehensive audio-visual information systems markedly improve the accessibility of public transport for all segments of the population, including the elderly, people with disabilities, and individuals unfamiliar with the local area. This enhancement in accessibility is crucial for promoting social inclusion, ensuring equitable access to employment, education, healthcare, and social activities (World Bank, 2022; ITF, 2020). For instance, account-based and contactless ticketing, especially when combined with offline topup points, can remove significant barriers for tourists, occasional riders, and unbanked users. Moreover, data-driven network planning helps public authorities identify "mobility deserts" and informs the deployment of on-demand feeder services to historically underserved suburbs, thereby improving social inclusion.

Concurrently, digitalization bolsters passenger and staff safety and security. The deployment of on-board and station-based CCTV (Closed Circuit Television) systems, digitally connected emergency alert mechanisms, and AI driven monitoring of driver behavior serves as a deterrent to crime, accelerates emergency responses, and helps prevent accidents. These improvements contribute to both the actual and perceived safety of public transport, thereby encouraging greater ridership (M. Beecroft, 2019; Railway Technology, 2023). The user experience is also substantially enriched through the provision of accurate, real-time information regarding schedules, potential delays, crowding levels, and alternative routes, all readily available via mobile applications and digital displays. This reduces passenger uncertainty and stress. Digital channels for feedback, complaints, and participation in service planning further empower users and cultivate a sense of co-creation, leading to services that are more responsive to community needs (Gössling, 2020; Smith et al., 2019).

Nevertheless, the promise of enhanced social equity through digitalization is limited by the critical challenge of the digital divide. Elderly passengers, low income households, and communities with poor internet connectivity may be excluded from app based booking, payment systems, and real-time information services. Bridging this gap demands parallel investments in ubiquitous connectivity, public Wi-Fi infrastructure, device subsidy schemes, and comprehensive user education initiatives to ensure that the benefits of digital public transport are truly universally accessible.

On the labor front, digitalization induces both displacement and creation effects. Routine tasks such as manual ticket checks, basic fleet monitoring, and timetable coordination are increasingly automated, which can contribute to workforce reductions in high-digital-intensity segments like equipment manufacturing and dispatch operations. Yet, new roles are simultaneously emerging in data science, cybersecurity, software maintenance, and customer-facing digital support. Studies of the Slovak transport sector, for example, reveal that while the manufacturing of other transport equipment (a highly digitalized sub-sector) experienced employment declines, the automotive industry— also digitally advanced but driven by rising market demand—saw job growth. This illustrates that the labor impact of digitalization is contingent on broader market dynamics and sectoral characteristics (Chinoracky et al., 2021). To harness the benefits of digitalization without deepening inequality, policymakers must proactively invest in targeted upskilling programs, promote lifelong learning initiatives, and support the creation of “good jobs” that offer living wages, benefits, and clear career pathways (Dedola et al., 2021).

Finally, the proliferation of passenger data—ranging from trip histories and payment details to real-time location tracking—raises pressing privacy, security, and ethical questions. Comprehensive data-governance frameworks are essential. These frameworks must mandate data anonymization where appropriate, enforce data minimization principles, and ensure transparent consent mechanisms to safeguard passenger trust and comply with stringent regulations such as the GDPR. Cybersecurity protections are equally vital; a breach in real-time signaling systems, operational controls, or fare collection platforms could disrupt entire networks, causing significant economic and social harm. This underscores the critical need for rigorous cybersecurity standards and constant threat monitoring to protect these increasingly complex digital infrastructures.

In sum, digitalization in public transport delivers significant economic efficiencies—through reduced operating costs, enhanced asset utilization, and innovative revenue models—and fosters substantial social benefits by improving access, safety, and engagement. However, to realize its full potential and avoid deepening existing inequities or creating new ones, it is imperative that technological deployment is coupled with thoughtful and targeted digital inclusion strategies, equitable pricing mechanisms, and harmonized regulatory frameworks. Only through such integrated and proactive approaches the public transport sector can evolve into a truly inclusive, efficient, and sustainably modern mobility ecosystem, effectively addressing the core challenges of contemporary urban life. Digitalization is not merely an incremental improvement but a transformative force; its efficiency gains are intrinsically linked to the broader goals of environmental, social, and economic sustainability.

## 2.5 Cities that have implemented smart mobility solutions

The adoption of digital innovations and tools in urban mobility is a critical strategy for addressing contemporary challenges related to environmental degradation, social equity, and economic development. This chapter presents a detailed analysis of smart mobility initiatives in three leading global cities—Singapore, Barcelona, and London—demonstrating their environmental, social, and economic impacts. Following these virtuous case studies, a critical commentary on the situation in Italy will highlight key challenges and opportunities in the national context.

### 2.5.1 Singapore

Singapore, a city-state renowned for its long-term strategic planning, has emerged as a global leader in smart mobility through an integrated and technology-driven approach, embedded within the broader *Smart Nation* vision and the

*Singapore Green Plan 2030* (Smart Nation and Digital Government Office [SNDGO], 2018; Land Transport Authority [LTA], 2022). A cornerstone of its transport system is the Electronic Road Pricing (ERP), a dynamic road pricing mechanism that regulates congestion through real-time tolls based on traffic conditions, enabled by onboard units and digital infrastructure (LTA, 2019a). This is complemented by an efficient public transport system composed of the Mass Rapid Transit (MRT) and an extensive bus network, continuously enhanced with real-time passenger information systems and contactless payment methods to improve the travel experience (LTA, 2019b). Singapore has also been at the forefront of autonomous vehicle testing for public transport and logistics, with the aim of optimizing fleet management and reducing human error (Ministry of Transport [MOT], 2020).

At the same time, the country has committed to a large-scale shift toward clean energy vehicles, supported by incentives and infrastructure expansion: from 2030, all new registrations must be cleaner-energy vehicles, and by 2040 all taxis and buses are expected to be fully electric (LTA, 2020). These strategies converge in the development of *Mobility as a Service (MaaS)*, designed to integrate various transport modes into a single digital platform, enhancing accessibility and connectivity (LTA, 2022).

The environmental outcomes of these measures are noteworthy. The ERP has helped alleviate peak-hour congestion, leading to a reduction in vehicle emissions and improved air quality (LTA, 2019a). Electrification of high-emission fleets, particularly taxis, is crucial since an average taxi emits seven times more $CO_2$ than a private car, according to LTA (2020). Fleet electrification is therefore a fundamental step in achieving Singapore's target of net-zero emissions by 2050 (Ministry of Sustainability and the Environment [MSE], 2021). Socially, McKinsey & Company's report *Elements of Success: Urban Transportation Systems of 24 Global Cities* (Knupfer, Pokotilo, & Woetzel, 2018), claims Singapore's policies enhance inclusivity: its transport system is the world's best in terms of availability, efficiency, affordability, and sustainability. Broad public transport access ensures equitable mobility for work, education, and services, while innovations such as electric buses with accessibility features promote social integration (LTA, 2020). Economically, congestion reduction increases productivity by facilitating the movement of goods and people, while investments in electric vehicle infrastructure foster green economy opportunities. Additionally, revenues from ERP are reinvested in improving transport infrastructure, generating a virtuous cycle of innovation and growth (LTA, 2019).

### 2.5.2 Barcelona

Barcelona has positioned itself as a pioneer in sustainable urban mobility through policies that integrate digital technology, sustainable transport, and urban planning. The *Urban Mobility Plan (Pla de Mobilitat Urbana, PMU)* 2019–2024 outlines a comprehensive strategy aimed at reducing private car usage, cutting $CO_2$ emissions, and promoting active transport modes such as cycling and walking (Ajuntament de Barcelona, 2019). The introduction of *superblocks (superilles)* has redefined urban space by restricting car traffic within designated areas, prioritizing pedestrians, cyclists, and public transit, and significantly improving air quality and livability (Rueda et al., 2020). Barcelona has also invested heavily in electric mobility, expanding charging infrastructure and electrifying parts of its municipal fleet, while enhancing digital platforms for integrated ticketing and real-time information (Autoritat del Transport Metropolità [ATM], 2020).

The environmental impact of these initiatives is considerable. According to Ajuntament de Barcelona (2019), the full implementation of superblocks could reduce $NO_2$ levels by up to 24% and $CO_2$ emissions by 23%. Additionally, the expansion of bicycle lanes and the public bike-sharing scheme *Bicing* promotes sustainable commuting and reduces reliance on motorized transport. Socially, Barcelona's mobility policies foster inclusiveness by creating safer, healthier, and more accessible urban spaces. The superblock model reduces noise pollution and traffic accidents, enhancing the quality of life in densely populated neighborhoods (Rueda et al., 2020). Furthermore, investments in low-emission zones ensure cleaner air, directly improving public health outcomes (European Environment Agency [EEA], 2021). From an economic perspective, Barcelona's policies stimulate the local green economy by supporting sectors related to electric mobility, urban redesign, and technological services for transport (ATM, 2020). These measures illustrate a holistic approach that balances environmental sustainability with social well-being and economic development.

### 2.5.3 London

London represents another leading case in the adoption of smart mobility solutions, with a strong emphasis on congestion management, electrification, and digital innovation. A central pillar is the *Congestion Charge Zone*, introduced in 2003, which applies a fee to vehicles entering central London, thereby reducing traffic volumes and encouraging the use of public transport (Transport for London [TfL], 2021a). Building on this, the *Ultra Low Emission Zone (ULEZ)* was launched in 2019 and expanded in 2021, imposing stricter emission standards on vehicles and significantly reducing air pollution levels (TfL, 2021b). London is also a frontrunner in electrification, with targets to phase out diesel buses and electrify its entire bus fleet by 2037, supported by widespread charging infrastructure (Mayor of London, 2020). The city has additionally invested in digital platforms such as the *TfL Oyster and Contactless system*, which integrates various modes of transport into a seamless ticketing solution (TfL, 2021c).

The environmental benefits of London's strategy are tangible. TfL (2021b) reports that the ULEZ contributed to a 44% reduction in roadside $NO_2$ concentrations within its boundaries, while the Congestion Charge has consistently curbed traffic levels in central areas (TfL, 2021a). Socially, these policies promote equitable access to clean transport options and improve public health by reducing exposure to harmful pollutants. The integration of cycling infrastructure and shared mobility services further broadens sustainable travel choices (Mayor of London, 2020). From an economic standpoint, congestion and emission charges generate significant revenues, which are reinvested in upgrading public transport services and supporting low-carbon initiatives (TfL, 2021a). London's smart mobility policies therefore illustrate how regulatory, technological, and financial measures can be effectively combined to advance environmental sustainability, social equity, and economic resilience in a major metropolitan context.

### 2.5.4 The Situation in Italy

While the aforementioned cities—Singapore, Barcelona, and London—demonstrate significant steps forward in smart mobility, Italy presents a more varied and often challenging landscape. The country's progress in adopting digital innovations and tools for sustainable transport is characterized by a notable geographical divide and persistent environmental concerns, suggesting a need for more unified and comprehensive strategies at national level.

One of the most pressing challenges in Italy is the persistent issue of air quality. Despite various efforts, none of the 102 Italian cities analyzed in the Legambiente Mal'Aria (2022) report currently fall within the parameters set by the World

Health Organization (WHO) for fine particulate matter and nitrogen dioxide. This indicates a systemic problem with urban air quality, directly linked to prevailing transportation patterns and highlighting that current smart mobility implementations may not yet be sufficient in scale or integration to overcome these high pollution levels.

Furthermore, Italy exhibits a clear north-south divide in smart city and smart mobility adoption. While cities in the North and Centre, such as Florence, Milan, Bologna, and Rome, are more actively engaged in advancing green and digital transitions—with Milan, for instance, ranking highly in global smart city indices and expanding its cycling infrastructure and public transport—southern regions generally lag behind. This disparity can lead to unequal access to smart mobility benefits and exacerbate existing social and economic inequalities across the country (Battarra, F., et al., 2025).

A significant obstacle to widespread smart mobility adoption is the pervasive lack of adequate infrastructure. This includes comprehensive bicycle lanes, which remain underdeveloped in many regions, and an insufficient network of charging stations for electric vehicles, particularly in southern regions such as Calabria, Sicily, and Basilicata (European Union, 2022; Anariev, 2024). While there is growing interest in shared mobility and micromobility, the deeply ingrained reliance on private car ownership remains a substantial barrier. Without robust infrastructure to support sustainable modes, the adoption of digital innovations in mobility will inevitably remain limited in its overall impact. The complexity of implementing smart mobility solutions at scale also poses a challenge, requiring significant public engagement, substantial infrastructure changes, and adaptation from residents and businesses, often complicated by bureaucratic hurdles and varying local administrative capacities (Battarra et al., 2025). Despite these significant challenges, Italy has substantial potential for advancing smart mobility solutions. The country is well positioned to leverage support from European funding under the Next Generation EU program for post-COVID recovery, which can be strategically directed towards smart and sustainable urban planning initiatives (FBK, 2025). Moreover, there is a growing awareness and interest in sustainable solutions, particularly among younger generations; surveys indicate a willingness to use public transport if it is punctual, safe, and frequent, and interest in micromobility is growing. Cities like Milan and Bologna are taking significant steps in improving public transportation and urban green spaces, and Naples is also showing improvements in municipal apps and green mobility (POLIS Network, 2025). These local successes can serve as valuable models for wider adoption. Finally, the promotion of open innovation by government agencies and the refinement of public-private partnerships could significantly accelerate the diffusion of innovative services, drawing lessons from virtuous cities like Copenhagen and Amsterdam (Battarra et al., 2025).

In conclusion, Italy's journey towards comprehensive smart mobility is undeniably in progress but faces significant hurdles that necessitate a more unified, integrated, and equitable national strategy. This strategy must prioritize robust infrastructure development, actively incentivize shifts away from private car dependency, and ensure that the benefits of digital innovations are accessible across all regions. Overcoming sustainability issues and bridging the regional gap will require investments, strong political will, and proactive citizen engagement, ultimately paving the way for more sustainable, livable, and economically vibrant Italian cities (Battarra et al., 2025; Anariev, 2024; FBK, 2025; European Union, 2022; POLIS Network, 2025).

# Chapter 3 – ANM Case Study and Future Perspectives

This chapter builds on the hands-on experience gained during my curricular internship at Azienda Napoletana Mobilità (ANM), which provided direct access to internal sources and key figures driving the company's digitalization and innovation efforts. In this study, informal dialogues with Cinzia Barba (Head of the Integrated Management System), Felice Mondo (Head of Technological Innovations), Pierpaolo Martino (Director of Surface Transport and Funiculars) and Alfonso Cirillo (Management of Maintenance Activities) form the empirical foundation for analyzing whether and how digitalization is transforming municipal public transport and what environmental, social, and economic impacts ANM's innovations are generating.

## 3.1 The History of ANM and the Neapolitan Mobility Context

Azienda Napoletana Mobilità (ANM) is deeply rooted in the history of public transport in Naples, a journey that began long before its formal establishment. The company's origins trace back to 1875, when the Municipality of Naples granted the Società Anonima dei Tramways Napolitains (S.A.T.N.), based in Brussels, the right to build and 82 operate the city's first horse-drawn tram network. This pioneering phase marked the beginning of an evolution that would see Neapolitan public transport adapt to technological and societal changes.

Throughout the 20th century, the development of public transport in Naples continued with the introduction of new forms of mobility. In 1947, ATAN (Azienda Tranvie Autofilovie Napoli) was founded, inheriting and developing surface services, including trams and trolleybuses, becoming a cornerstone of urban mobility. The 1990s marked another fundamental stage: in 1995, ATAN transformed into a Special Company, adopting the name Azienda Napoletana Mobilità (ANM). Subsequently, on March 30, 2001, ANM became a Joint Stock Company, under the control of Napoli Holding S.r.l., wholly owned by the Municipality of Naples. This corporate structure allowed for greater flexibility in management and investments.

In 2013, ANM further expanded its scope, incorporating Metronapoli and Napolipark, entities that managed rail transport (metro and funiculars) and parking respectively. This merger process consolidated ANM as the primary integrated public transport and mobility services operator in Naples, managing not only buses, trams, and trolleybuses, but also the two metro lines (Line 1 and Line 6) and the four urban funiculars (Chiaia, Centrale, Mergellina, Montesanto), in addition to interchange parking and paid street parking.

The "Mobility Charter" (Carta della Mobilità), a fundamental document regularly published by ANM, embodies the company's commitment to its citizens. This instrument defines the guiding principles for service provision – including equality, impartiality, continuity, freedom of choice, participation, and efficiency – and provides detailed information on the services offered, quality standards, annual objectives, and achievements. The Charter represents a pact between the company and its users, renewed year by year to meet the evolving needs of customers and to monitor quality objectives, reflecting an approach geared towards continuous improvement and transparency. Within this historical and operational context, ANM now faces the challenge and opportunity of digitalization, a process that is redefining the very way public transport operates and interacts with citizens.

Digital transformation is not merely a technological upgrade, but a profound rethinking of operational strategies and user relationships, with significant environmental, social, and economic impacts.

## 3.2 Digital Transformation at ANM

Digitalization is permeating every aspect of ANM's activities, from ticketing to operational management, deeply influencing the quality of service offered and its overall impact on the city of Naples. Interviews conducted with ANM personnel reveal a clear direction towards innovation, although not without challenges and internal considerations.

### 3.2.1 The Evolution of Ticketing and Payment Systems

One area where digitalization has had an immediate and tangible impact is ticketing and payment systems. ANM, as part of the Unico Campania consortium, has embarked on a journey to move beyond traditional magnetic and electronic ticketing, although these represented an initial level of computerization. There is a progressive shift away from these older technologies in favor of more modern and integrated solutions.

The introduction of dynamic QR Code ticketing has represented a significant leap in quality. Through mobile applications, users can purchase and activate travel tickets, which are then validated in realtime by validators communicating with a central server. This system not only simplifies the user experience, allowing access to services with a simple tap on a smartphone, but also enhances security, reducing the risk of counterfeiting due to the dynamic nature of the code.

Even more revolutionary has been the implementation of EMV (Europay, Mastercard, Visa) contactless payments directly on validators. This technology, inspired by solutions implemented in cities like London, allows passengers to use their existing contactless credit or debit card to access transport, eliminating the need to purchase a physical ticket or use a specific application. The system, while processing payment transactions offline, reconciles with a central system that ensures security and, crucially for users, automatically calculates the "best fare" based on the journey undertaken. This offers unprecedented convenience and promotes the adoption of electronic payments, as evidenced by the growing percentage of purchases made by card. The "tap-in/tap-out" logic becomes essential to ensure correct fare application, especially for extra-urban routes. The future vision includes the introduction of a "Chip for payment" for ticketing, which will make tickets neutral and un-pre-valued until valorized at the point of sale, thereby reducing distribution costs and risks associated with cash management.

The installation of Automatic Vending Machines (AVMs) in an increasing number of stations and strategic points (funiculars, metro, airport) further supports the transition towards cashless transactions, offering an automated alternative to traditional purchases and encouraging the use of electronic money. The direction is clear: ANM is transitioning towards an account-based ticketing system, where the intelligence resides in the central system rather than in the individual ticket. This paves the way for post-payment logic and greater tariff flexibility, as already experimented with the electronic identification of Carabinieri cards for free transit.

### 3.2.2 Mobility Integration: Smart Mobility and MaaS

Digitalization is not limited to payment systems but extends to the broader vision of urban mobility. ANM actively participates in the "MaaS for Italy" project, funded by the PNRR (National Recovery and Resilience Plan), a national initiative aimed at realizing true "Mobility as a Service" (MaaS). This paradigm places the user at the center, offering a fluid and integrated travel experience across different transport modes.

MaaS pursues the objective of providing users with easy and unified access to all necessary information for their journeys – schedules, fares, routes – and tools for planning and purchasing multimodal trips. The government initiative has created a B2B platform (DSFRS) that acts as a marketplace for mobility services, integrating static and dynamic data from a plurality of operators. This approach simplifies the offering for new operators, such as startups developing mobility apps, by providing standardized data and clear integration rules. Unlike private MaaS initiatives, the "MaaS for Italy" project aims to be a public and national platform to remove access barriers even for smaller entities.

### 3.2.3 Internal Digitalization and Data Management

Beyond the user interface, digitalization is also transforming ANM's internal operations, leading to greater efficiency and more intelligent data management.

A significant example is the use of satellite detectors on buses, which allows for real-time tracking of vehicles and more effective service management. This data, previously unavailable, is now an asset that ANM makes accessible to the public via electronic displays at stops and multimedia applications, providing real-time information on vehicle arrivals. This transparency is crucial, especially in areas with less regular service, enabling users to better organize their movements.

Maintenance management is also becoming increasingly digital, with dedicated software for planning ordinary and extraordinary maintenance schedules for rolling stock, with the intention of extending it to funiculars. Similarly, the management of transport service applications allows for monitoring planned versus actual routes and kilometers, providing more rigorous control, although the complexity of urban traffic makes efficiency measurement more challenging for road-based transport.


All validation data, millions every day, converge into a centralized "Data Lake." While ANM uses business intelligence tools for analysis, the absence of in-house data scientists and indirect access to the Unico Campania consortium's databases still represent a limitation.

The push towards electronic document management, digital signatures, and integrated management systems (such as software for audit processes and document version control) reflects the ambition to unify and harmonize information across different company departments, reducing reliance on paper and improving administrative processes.

## 3.3 Impacts of Digitalization at ANM: Environmental, Social, and Economic

The ongoing digital transformation at ANM is yielding diverse impacts across economic, social, and environmental dimensions, demonstrating a clear shift in how the company operates and serves its users.

Environmentally, digitalization is intrinsically linked to ANM's broader environmental sustainability objectives. ANM is investing approximately **€180 million**—of which **€145 million** is allocated to the procurement of 253 electric buses and €35 million to the deployment of charging infrastructure. By 2025, 37 electric buses are already in operation, with expectations that electric vehicles will comprise 50% of the total fleet by 2026. These changes are projected to lead to a reduction in $CO_2$ emissions by over 5,000 tons per year, as well as significant cuts in local particulate and NOx emissions (Martini, Bezzini, Longo, 2024). Digital monitoring systems are expected to track these environmental metrics more accurately through integrated fleet management and diagnostic platforms. This represents a tangible step towards reducing polluting emissions and noise pollution within the city of Naples.

However, this initiative also prompts critical reflection on operational effectiveness; for instance, the chosen "overnight charging" strategy for these buses raises questions regarding its optimality in the absence of advanced digitalization and sophisticated SCADA (Supervisory Control and Data Acquisition) systems for dynamic charge management. Indeed, some internal perspectives suggest that more innovative solutions, such as "flash charging"—which allows for rapid charging at designated stops during service—could prove more effective in the long run. This highlights an ongoing discussion within ANM about the importance of embracing "courage in innovation" and avoiding the mere replication of solutions adopted by other transport authorities without critical adaptation to local needs.

Beyond fleet electrification, digitalization is proving fundamental for the systematic collection and certification of data required for comprehensive sustainability reporting, particularly in compliance with the Corporate Sustainability Reporting Directive (CSRD). This represents a necessary evolution from current manual data collection practices, often reliant on tools like Excel, which are acknowledged as not scalable for the robust reporting demands of the future.

The social impacts of ANM's digitalization efforts are mainly tied to substantial improvements in user experience and overall service accessibility (Rämänen, J., Riihiaho, S., Erkkilä, M., Seppälä, A., 2011). The introduction of contactless payment systems, such as EMV technology, and the strategic integration with MaaS platforms significantly simplify access to public transport, rendering it more intuitive and less cumbersome for a wide range of users.

In 2021, during the pandemic, app sales exceeded 1.3 million. In the first 4 months in 2022, there was a growth of 300%. Since September 2021, the UnicoCampania platform and the app have hosted over 120,000 free season pass for students of the Campania Region (UITP, *Ticketing in Mobility as a Service, 2022)*.

The capability for passengers to use their existing bank cards or smartphones for fare payment effectively eliminates the prerequisite of purchasing a physical ticket in advance, a development that particularly benefits casual users and tourists unfamiliar with local ticketing modalities. Furthermore, the provision of readily available, updated information regarding vehicle locations and estimated waiting times, disseminated through mobile applications and digital displays at stops, directly addresses a fundamental user need. This allows passengers to better plan their journeys and serves to reduce the anxiety often associated with service uncertainty (Zhang Kennedy et al., 2023), a factor of relevance within a complex and dynamic urban context like Naples.

Additionally, ANM has also expanded its customer service points and introduced 70+ new TVMs, enhancing convenience and ensuring that the service remains accessible even outside traditional retail operational hours.

On the employment front, the transition to electric and digital systems has generated new specialized job positions, including roles for SCADA monitoring, IT maintenance, and

EV diagnostics, alongside upskilling programs for over 150 existing employees.

From an economic standpoint, digitalization is also yielding tangible benefits for ANM, contributing to both revenue enhancement and cost efficiencies. The transition towards predominantly electronic payment systems, for example, significantly reduced costs and inherent risks associated with extensive cash handling by an estimate of 15–20%, freeing up internal resources for investment in innovation and safety. The adoption of these new payment systems has already demonstrated positive economic outcomes, with a notable and increasing percentage of ANM's revenue now being generated through diverse electronic channels. As of 2025, over one third (33%) of total fare revenue is collected via digital channels. EMV contactless payments currently account for 9% of all revenue, while sales through modern TVMs represent 18%, and the Unicocampania mobile application contributes a further 6%.

Beyond revenue, the digitalization of maintenance schedules and service management processes allows for more precise resource allocation and more accurate performance monitoring, which led to greater operational efficiency overall lowering vehicle downtime by 12% (Comune di Napoli). While data analysis capabilities are still evolving within the organization, the insights derived from collected data are increasingly valuable for optimizing business strategies and service planning.

Finally, ANM's strategic integration into the promising MaaS ecosystem opens new avenues for collaboration with other mobility providers and service expansion, potentially generating novel revenue streams and consolidating ANM's central position within the integrated mobility landscape of the region.

## 3.4 Challenges and Strategic Outlook

Despite the significant progress achieved in its digitalization efforts, ANM confronts several persistent challenges that shape its innovation journey. Resource constraints present a notable hurdle, with shortages of drivers and the advanced age of certain segments of the vehicle fleet impacting service delivery reliability and the capacity to fully leverage new technological capabilities. The high frequency of vehicle breakdowns further exacerbates these operational strains. A crucial, non-technical challenge lies in fostering cultural change and achieving deep organizational integration. Overcoming siloed operational mentalities and cultivating a culture of cohesive collaboration is essential, particularly for the successful implementation of complex, cross-cutting projects like the new ERP system and the comprehensive integrated management systems. As highlighted by Cinzia Barba, the company must learn to "reason as a system", a sentiment echoed by PierPaolo Martino who emphasized the need for courage to innovate proactively rather than merely replicating solutions adopted by other entities. Effective data management and ensuring genuine interoperability also remain areas of ongoing development; while ANM collects vast quantities of data, ensuring its consistent quality, widespread accessibility, and effective utilization across diverse departments is a work in progress that the new ERP aims to address. The imperative for continuous innovation requires sustained financial investment, which is often dependent on the availability of public funding from municipal or regional bodies. Finally, ANM's operations are heavily influenced by external factors beyond its direct control, such as pervasive traffic congestion, unexpected road closures, and other unpredictable urban dynamics, all of which can significantly affect operational efficiency, irrespective of the sophistication of the technological tools deployed. The rapid pace of technological evolution also means that systems can face obsolescence relatively quickly, making decisions on long-term investments, such as the choice of charging infrastructure for electric buses, strategically critical. Looking towards the future, ANM's strategy appears to be concentrated on several key interconnected areas. First is the completion of its ticketing modernization program, which involves phasing out the remaining magnetic tickets and replacing them with "Chip for Payment" technology, while also continuing to explore and develop account-based ticketing solutions. Second, the implementation of the new integrated ERP system stands as a cornerstone project, pivotal for enhancing internal efficiency, achieving robust data integration, and supporting more agile decision-making. Third, ANM plans to deepen its involvement in MaaS initiatives, notably through its continued participation in the "MaaS for Italy" project, aiming to foster more user-centric and seamless multimodal travel experiences. Fourth, there is a strong commitment to strengthening sustainability practices across the organization, a drive significantly influenced by CSRD compliance requirements and the planned expansion of ISO certifications. This includes a particular focus on ensuring the certification of data used for sustainability reporting. Fifth, enhancing operational resilience remains a priority, to be achieved through continued investment in fleet renewal, particularly with more electric buses, and by further refining operational control mechanisms through the synergistic use of technology and skilled personnel. Lastly, there is an underlying objective to foster a more pervasive innovative culture within ANM, encouraging the proactive adoption of new solutions and embedding data-driven management principles, as evidenced by the expressed desire for benchmarking against other cities and learning from their experiences. The case study of ANM reveals that digitalization within a large municipal public transport operator is not a singular event but rather a complex, continuous, and multifaceted undertaking. It represents an ongoing series of interconnected transformations that span technology deployment, operational methodologies, customer interaction strategies, and internal organizational culture.

## Conclusions

This thesis aimed to explore the transformative power of digitalization within municipal public transport, guided by the central research questions: *If and how is digitalization transforming municipal public transport? What are the environmental, social, and economic impacts of these innovations?*

The investigation, drawing upon a robust theoretical framework, international case studies, and an in-depth analysis of Azienda Napoletana Mobilità (ANM), confirms that digitalization is not merely an incremental upgrade but a fundamental reshaping of the sector.

Digitalization is unequivocally and profoundly transforming municipal public transport. The transformation is occurring through the adoption of integrated digital platforms, data-driven decision-making, the dematerialization of fare media, enhanced real-time communication with users, and the automation of operational and maintenance processes. It is shifting the paradigm from a service-delivery model to a more dynamic, responsive, and user-centric mobility ecosystem.

The *environmental* impacts, while promising, are contingent on strategic implementation. Digital tools enable the optimization of routes, support the integration of cleaner fleets like electric buses, and are vital for robust environmental monitoring and reporting. However, realizing their full potential requires overcoming challenges related to charging infrastructure, data completeness, and ensuring that digital systems themselves are energy efficient.

The *social* impacts are largely positive, centering on enhanced user experience, improved accessibility, and greater service transparency. Digital tools empower passengers and can make public transport more inclusive. Nevertheless, a critical consideration remains the digital divide, which, if unaddressed, could exacerbate existing inequalities by excluding those without access to or proficiency with digital technologies.

The *economic* impacts are complex. Digitalization drives operational efficiencies, reduces specific costs and opens avenues for new revenue streams and business models. However, it also necessitates significant upfront and ongoing investment in technology, infrastructure, and skilled personnel, posing challenges for often resource constrained public operators.

This research underscores that while the technological capacity for transforming public transport is largely available, its successful and equitable implementation is a complex matter. The journey towards smart mobility is not only a technological race but a socio-technical process requiring strategic vision, supportive and adaptive regulatory frameworks, substantial investment, organizational and cultural change within transport authorities and municipalities, and a persistent commitment to inclusivity.

The ANM case study, in particular, highlights the real-world tension between ambitious digitalization goals and the operational, financial, and cultural hurdles faced by a large public entity. The "courage to innovate," as articulated by ANM management, is crucial, but must be balanced with pragmatic strategies for resource allocation, workforce upskilling, and ensuring that digital solutions are robust, secure, and genuinely meet user needs across diverse demographics.

The approach adopted in this thesis reflects a trust in innovation and digital technologies as powerful levers to make public transport in large urban centers more sustainable, efficient, and socially acceptable, reinforcing the conviction that technological progress, when strategically guided, can serve the public good.

The promise of digitalization—smarter, greener, more efficient, and user-friendly public transport—is compelling. Yet, its fulfillment demands a holistic approach. Public authorities and operators must move beyond fragmentary adoption of technologies towards integrated strategies that consider the entire mobility ecosystem. This includes fostering interoperability between systems, promoting open data initiatives where appropriate, investing in digital literacy, and ensuring that the benefits of innovation are shared broadly, rather than creating new forms of exclusion.

The path forward requires continuous learning, adaptation, and a collaborative effort between public entities, private sector innovators, and the communities they serve, ensuring that the digital future of public transport is not only smart but also sustainable and equitable for all.

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