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Key performance and value indicators for enhancing sustainable and intelligent Mobility as a Service solutions

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A me stessa, che ho spesso dubitato delle mie capacità, ma ho imparato che ogni sfida superata è una dimostrazione di forza.
A mia madre. Sarò per sempre in debito con te.

Abstract

Mobility as a Service (MaaS) represents the integration of different transportation services into a unified framework aimed at revolutionizing urban mobility by offering integrated, user-centered, and sustainable travel solutions. This thesis focuses on examining and analyzing key performance indicators (KPIs) and key value indicators (KVIs) crucial for developing and optimizing sustainable and intelligent MaaS systems. By assessing metrics such as service efficiency, user satisfaction, environmental impact, congestion reduction, minimization of arrival times, and cost-effectiveness, this research aims to identify the indicators that reinforce the successful and effective implementation and operation of MaaS platforms. Through an in-depth examination of these indicators, this study proposes objective functions that prioritize achieving an equitable and optimized MaaS ecosystem.

Sommario

La Mobility as a Service (MaaS) rappresenta l'integrazione di diversi servizi di trasporto in un quadro unificato mirato a rivoluzionare la mobilità urbana offrendo soluzioni di viaggio integrate, centrate sull'utente e sostenibili. Questa tesi si concentra sull'esaminare e analizzare gli indicatori chiave di performance (KPI) e gli indicatori chiave di valore (KVI) cruciali per lo sviluppo e l'ottimizzazione di sistemi MaaS sostenibili e intelligenti. Attraverso la valutazione di metriche come l'efficienza del servizio, la soddisfazione dell'utente, l'impatto ambientale, la riduzione della congestione, la minimizzazione dei tempi di arrivo e la convenienza economica, questa ricerca mira a identificare gli indicatori che rafforzano l'implementazione e il funzionamento efficace delle piattaforme MaaS. Attraverso un'analisi approfondita di questi indicatori, questo studio propone funzioni obiettivo che prioritizzano il raggiungimento di un ecosistema MaaS equo e ottimizzato.

Contents

Listing of figures

Listing of tables

Listing of acronyms

Automatic Vehicle Location (AVL)
Connected, Cooperative, and Automated Mobility (CCAM)
Connecting Europe Facility (CEF)
Coordination of Network Descriptions for Urban Intelligent Transport System (CONDUITS)
Collaborative Vehicle Routing Problem (CVRP)
Customer Satisfaction Score (CSS)
Dial-a-Ride Problem (DARP)
Stop-based Deviation Index (DIS)
Demand-Responsive Transport (DRT)
Department of Digital Transformation (DTD)
Electric Vehicles (EVs)
Feeder Vehicle Routing Problem (FVRP)
Flexible Transport System (FTS)
Greenhouse Gases (GHG)
Geographic Information System (GIS)
Global Positioning System (GPS)
International Civil Aviation Organization (ICAO)
Information and Communication Technologies (ICT)
International Maritime Organization (IMO)
Internet of Things (IOT)
Intelligent Transport System (ITS)
Key Performance Indicators (KPIs)
Key Value Indicators (KVIs)
MaaS Inclusion Index (MAASINI)
Mobility as a Service (MaaS)
Mixed Integer Linear Programming (MILP)
Ministry of Infrastructure and Sustainable Mobility (MIMS)
Ministry for Technological Innovation and Digital Transition (MITD)
MaaS Maturity Index (MMI)
Centro Nazionale per la Mobilità Sostenibile (MOST)
Marginal Personal Cost (MPC)
Micromobility Sharing Systems (MSS)
Marginal Social Cost (MSC)
Net Promoter Score (NPS)
Orienteering Problem (OP)

Operational Research (OR)
On-Time Performance (OTP)
Orienteering Shuttle Routing Problem (OSRP)
Pay-As-You-Go (PAYG)
Route-based Deviation Index (PIR)
National Recovery Resilience Plan (PNRR)
Public Transport (PT)
Quality of Life (QOL)
Real-Time Information (RTI)
Real-Time Vehicle Routing Problem (RTVRP)
Shared Autonomous Vehicles (SAVs)
School Bus Routing Problem (SBRP)
Short Message Service (SMS)
Stated Preferences (SP)
Total Cost of Ownership (TCO)
Travelling-Salesman Problem (TSP)
User Experience (UX)
Vulnerable Social Groups (VSGs)
Willing to Pay (WTP)

1
Introduction

MaaS, or mobility as a service, is a ground-breaking framework that offers a wide range of multimodal transportation options while maintaining a focus on the demands of the user. MaaS unites several mobility services into a single, integrated digital platform that provides a wealth of information, booking possibilities, ticket kinds, payment methods (pay-as-you-go or subscription plans), and customer feedback systems. The purpose of this integration is to increase traveler participation generally and the ways of achieving sustainable objectives. Regardless of public sector subsidies, the MaaS structure is really flexible, working at several geographical scales (urban, regional, or global) and including a wide range of services, including private automobile usage and parking. It is important to mark that MaaS is extremely distinct from traditional travel planners, versatile transport services, or exclusive shared transport solutions.

The birth of MaaS was driven by the need to deal with critical urban transportation challenges including bottleneck, environmental pollution, and the inefficient systems offered by conventional transport modes. By increasing the role of public transport and incorporating a diverse array of mobility services (such as taxis, car-sharing, ride-sharing, and ride-hailing) MaaS attempt to promote more sustainable travel behaviors. The primary goal of MaaS is indeed to boost the efficiency of the mobility system, making car-based transportation less desirable and more impractical.

The idea of MaaS started coming together with a 2011 study called "The Flexible Passenger" [74] which looked at the project of creating an all-in-one transportation service in cities. This research assign the groundwork for UbiGo, the first commercial MaaS trial, launched in

Gothenburg, Sweden, in 2013-14.

Instead of just focusing on individual modes of transport or reducing fossil fuel use, UbiGo tried to incorporate various public and private transport options into one service, very easy to use. The goal was to make travel simpler for individuals and families by harmonizing different transport activities. Yet, many MaaS projects have remained small and focused on specific areas, with limited studies on how well they run. UbiGo, for instance, faced challenges in moving from a pilot phase to a fully commercial service, particularly due to rules that made it difficult to resell public transport tickets. These issues highlight how elaborated it can be to integrate different transport services and get all stakeholders on the same page.

In the description of Maas, Sochor et al. [41] introduced its topology, categorizing different levels of integration in mobility services from Level 0 to Level 4, each of it representing a new degree of integration and associated value for customers, societal effects, and business potential.

- Level 0: at this level, there is no integration of services, with each transport mode operating independently.
- Level 1: information integration. This level provides users with centralized access to travel information, like multimodal travel planners or assistants. The focus here is on helping users find the best travel options. It is typically funded by ads or taxpayers. Even though operators do not oversee service quality, they must ensure that the information provided is accurate and user-friendly to maintain engagement.
- Level 2: integration of booking and payment. Users can book and pay for different transport modes through a single app at this level, contributing convenience for those using multiple forms of transport. While this integration simplifies the travel experience, it may not significantly impact car ownership. Revenue is typically generated through commissions and brokerage fees, but challenges include high integration costs and slim profit margins.
- Level 3: service integration. This level bundles numerous transport services into one comprehensive package, providing an alternative to car ownership. Here, the MaaS operator takes on the responsibility of managing both the service and the relationship between customers and service providers. This level offers greater profit potential through negotiated deals and customized service packages.
- Level 4: societal integration. The focal point at this level is on aligning mobility services with larger societal goals, such as reducing private car ownership and improving urban livability. It involves cooperation between public authorities and MaaS operators, incorporating public policies and incentives to encourage sustainable transportation choices. This level emphasizes the combination of mobility services with the aim of achieving long-term societal benefits.

MaaS is crucial for solving urban transportation issues, especially congestion and environmental topics. Traditional traffic management strategies, such as road construction and jam control measures, have run out of steam as cities get denser. The increasing needs of urban mobility, particularly in the context of smart cities, frequently cause these policy based solutions to fall behind at the same rate of advancement. In fact, big data analytics, extensive IoT sensor networks, and information technology are only a few of the cutting-edge technologies that smart cities use to transform mobility planning. The integration of MaaS into smart city architecture opens the door to offering citizens more sustainable, flexible, and efficient mobility options. Under those circumstances, MaaS boost the benefit of public transportation and other shared mobility services. This allow to make them more attractive alternatives to private car use.

1.1 Thesis Goals

In order to help MaaS systems proliferate and grow, this thesis looks into and assesses Key Performance Indicators (KPIs) and Key Value Indicators (KVIs). KPIs are benchmarks that businesses use to assess and improve their performance in reaching predetermined objectives. They are essential for evaluating the efficacy of business operations and cover both non-financial and financial factors [80]. On the other hand, KVIs go beyond conventional performance measurements by emphasizing the value produced by certain organizational activities or procedures. KVIs emphasize value creation over simple performance tracking by offering insights into the efficacy and impact of various initiatives. In contrast to KPIs, KVIs frequently call for original thinking and thorough conversations in order to discover and measure [59].

Relevant KPIs and KVIs in the MaaS context are: cost-effectiveness; multimodal trip utilization; modal share; environmental impact; arrival time minimization; service efficiency; user happiness; and cost variation per user or trip. This thesis will take a close look at these indicators, evaluating their definitions, approaches, and potential uses in the MaaS space. Finding the KPIs and KVIs that maximize the performance and value of MaaS systems is, in fact, the main objective of this thesis. Italy hasn't given KVIs much thought, therefore with this thesis, we hope to draw attention to how important these values are. We will also discuss the reasons behind the development of MaaS, including its historical background, its relationship to smart cities, and a particularly divisive contradiction. Even though policies are still being developed and MaaS initiatives are still being implemented locally, the research will also look at the legal framework for developing KPIs and KVIs within the MaaS approach. A case study will offer a thorough examination on how well different algorithmic techniques, such as greedy heuristics and Mixed-Integer Linear Programming (MILP), maximize user pickups while reducing service impact. We shall also assess the trade-offs between KVIs and KPIs in order to decide which should come first for the best results. This will include determining the effects of giving one priority over the other and how this will affect performance as a whole.

1.2 Thesis Outline

The remainder of this thesis unfolds as follows. Chapter 2 introduces the motivations for the creation of MaaS, including its origins in history, environmental exigencies, balancing KPIs and KVIs, its connection to smart cities, the need for fair service and a particularly contentious paradox. Chapter 3 examines the regulatory landscape surrounding KPIs and KVIs within the European Union and Italy, focusing on the limitations of Italian legislation in addressing KVIs. Chapter 4 discusses about different KPIs relevant for MaaS, such as modal share, variation in service utilization rates due to MaaS, bus-route oriented trips ratio, multimodal trips ratio, average cost per user and per trip, average MaaS revenue odds, Co2 emissions before and after the introduction of MaaS, efficiency, operational cost-effectiveness, accessibility and availability, KPIs in the MOST context. Chapter 5 analyzes several KVIs that are essential for understanding the impacts of MaaS, like social inclusion, user experience, community impact, behavioral change, innovative solutions and flexibility. Chapter 6 illustrates different optimization strategies for urban shuttle services. Here we compare a greedy heuristic with a novel algorithm formalized through mixed-integer linear programming. Lastly, Chapter 7 offers concluding remarks and a brief discussion on the future directions.

2

Motivations

Understanding the rationale for measuring KPIs and KVIs in the MaaS architecture is essential given the rapid advancement of urban mobility. These reasons go beyond straightforward technical ones and represent more general goals like increasing social justice, encouraging sustainable development, and improving policy efficacy. This chapter begins by exploring the historical underpinnings that have shaped the evolution of MaaS, offering vital context for understanding its progress. After that, it looks at the underlying motivations, emphasizing the need to strike a careful balance between quantitative metrics and qualitative values. Lastly, special attention is placed on the peculiar circumstances surrounding smart cities and the environmental imperatives propelling the development of MaaS. We can better appreciate how KPIs and KVIs fit with the overarching objectives of developing more sustainable, fair, and effective urban settings by being aware of these variables.

2.1 Historical foundations in MaaS

For a number of decades, a major focus of both urban planning and logistics management has been the movement toward more environmentally friendly and effective transportation networks. Due to this requirement, a number of vehicle routing issues and their solutions have been developed, laying the groundwork for modern MaaS techniques. MaaS has its roots in the early work on vehicle route optimization, starting with the Vehicle Routing Problem (VRP). Introduced by Dantzig and Ramser in 1959 as the "Truck Dispatching Problem" [17], that may be considered as the generalization of the Travelling-Salesman Problem (TSP). The VRP's primary goal was to minimize the operating expenses associated with delivering products. However, as the issue developed, further limitations and goals were added, such lessening the influence on the environment, boosting consumer pleasure, and strengthening service dependability. These advancements influenced not just the manner that contemporary MaaS platforms handle transportation but also set important technological benchmarks.

MaaS solutions are fundamentally a merging of various routing problems like VRP, the Orienteering Problem (OP), the School Bus Routing Problem (SBRP), and the Dial-a-Ride Problem (DARP). Every one of these problems conveys different aspects of routing challenges, from optimizing delivery routes under time constraints to managing on-demand, real-time transportation services.

Metrics like route efficiency, customer happiness, service dependability, and environmental effect are examples of KPIs in the context of MaaS and have their origins in the original VRP and its variations. For example, the multi-vehicle routing methods presented by Clarke and Wright in 1964 [32] directly informs the sort of efficiency KPIs required in MaaS, where various modes of transport must be coordinated flawlessly.

The term "Orienteering Problem" was first introduced by Golden et al. in 1987 [9]. To maximize the overall score gathered from the visited (chosen) nodes, it entails choosing nodes and figuring out the shortest path between them. In this case, a limited time budget prevents visiting every reachable node. As a result, the Knapsack Problem and the TSP are two well-known combinatorial problems that are combined to form the OP.

Furthermore, modern MaaS systems benefit from the developments in real-time dynamic routing, such as the Real-Time Vehicle Routing Problem (RTVRP). This has facilitated the creation of KPIs that track real-time system responsiveness, adaptability to traffic conditions, and dynamic demand management, which are essential for maintaining a high level of service quality in an on-demand environment.

By tracing the development of routing problems such as VRP, OP, SBRP, DARP, and RTVRP, we gain a deeper understanding of the challenges and opportunities that MaaS presents. These historical perspectives are instrumental in pinpointing key areas where KPIs and KVIs can be effectively manipulated to ensure MaaS solutions achieve not just operational efficiency but also substantial user value.

2.2 The balance between quantitative metrics and qualitative values

First, the efficacy of the laws and rules governing MaaS is critical to its successful implementation. Evaluating whether these policies are successful and theoretically sound in the real world is one of the main reasons for doing this examination. Indeed, KPIs are used as a common instrument to assess how well MaaS projects are doing. These metrics offer a quantitative assessment of a number of variables, including operational effectiveness, user adoption, and service dependability. However, there's more at play here than just keeping tabs on the figures. Ensuring that these KPIs are relevant, all-inclusive, and accurately represent the broad objectives of MaaS, including minimizing carbon emissions and traffic congestion, is the main concern. Ensuring that these KPIs are precisely defined and consistently used in many situations, such as smart cities, is the difficulty, and hence the driving force. This calls for a critical evaluation of the current KPIs, the identification of any weaknesses or potential shortfalls, and the proposal of improvements that are in line with the changing requirements of urban mobility. For this reason, we will examine KPIs in detail in Chapter 4. However, it is important to recognize that KPIs have intrinsic limits in spite of their critical role in offering quantifiable insights into MaaS effectiveness. Not every facet of smart city development and urban mobility can be fully encapsulated in data and quantitative analysis. This brings us to the concept of KVIs, which represent qualitative aspects that are equally important in evaluating the success of MaaS initiatives. For instance, user experience is a crucial component that KPIs might not be able to adequately measure. The motivation here is to advocate for a balanced approach that integrates both KPIs and KVIs. While KPIs offer the necessary quantitative benchmarks, KVIs ensure that the evaluation process remains aligned with the core values of society. This dual strategy allows for a more comprehensive assessment, capturing both the measurable outcomes and the qualitative benefits that define the success of MaaS initiatives.

2.3 The context of Smart cities

The identification that smart cities are not homogeneous and that they vary significantly in terms of size, basis, population density, and socio-economic states is, first and foremost, a key motivation for the clarification of KPIs and KVIs inside the MaaS background. This contextualization is necessary to ensure that the indicators used are not only pertinent but also adaptable to the dynamic and multifaceted nature of urban environments. Smart cities represent complex ecosystems where technology, policy, and community interests converge. Besides, as new technology, practices, and social dynamics emerge throughout time, smart cities continue to evolve. The incentive here is to ensure that the KPIs and KVIs used are not static but are continuously reviewed and updated to reflect these alterations. In order to improve the indicators and make them more receptive to the demands of the city and its citizens, this compromises the inclusion of new data sources, such as user assessment and real-time mobility data. Furthermore, another main contextual contemplation is the role of fairness and inclusivity in smart city development. More focus is being placed on making sure that all citizens benefit from technology advancements, particularly those pertaining to mobility, as cities strive to become smarter. Encouraging KPIs and KVIs that reflect not just overall performance but also benefit distribution across various social groups is the goal here. Creating metrics to assess the availability of MaaS services in underserved sections of the city or their accessibility for low-income citizens may be necessary to achieve this. Specifically, that is covered in Chapter 5.

Last but not least, integrating MaaS with the broader smart city ecosystem is an important consideration. MaaS is interconnected with other elements of urban infrastructure, including electricity grids, communication networks, and city planning systems; it does not function in an isolated space. Creating KPIs and KVIs that represent these interdependencies is the driving force behind this, since it guarantees that MaaS helps to the universal efficiency, sustainability, and resilience of the smart city.

2.3.1 The emerging need for fair services

In the context of mobility services, fairness refers to the idea that people from different demographic groups should have equal access to resources, such as shared bikes or scooters. This belief stems from the universal idea of group fairness in machine learning by Dwork et al in 2012 [21], which aims to ensure that both advantaged and disadvantaged groups receive similar predicted results. In the context of transportation, this idea agrees with the notion of vertical equity, which suggests that policies should be designed to be in favor of disadvantaged groups (Delbosc and Currie, 2011) [52]. Vertical equity is focused on redistributing resources to help those with fewer advantages, ensuring that they have better access to essential services, including transportation. The uneven distribution of micromobility services poses significant obstacles for underprivileged populations. According to research, Micromobility Sharing Systems (MSS) are more common in affluent, central locations, whereas access is restricted in impoverished, suburban places. As a result, those living in underprivileged areas, who stand to gain the most from accessible transportation, are frequently left out. Furthermore, financial obstacles like expensive subscription fees make social exclusion worse. Fairness in MSS is necessary since mobility inequity has larger societal ramifications. Inadequate access to transportation can prevent people from getting essential services like work, education, and healthcare, which can prolong cycles of poverty and social isolation. Demographic considerations exacerbate this problem even further because minority populations and disadvantaged areas often overlap, exacerbating racial and socioeconomic marginalization. In order to address fairness in MSS, a fundamental change in design and operation is necessary, not only a readjustment of vehicle availability. This is akin to machine learning fairness issues, where biased datasets provide different results. Even though this method is less economical, MSS operators must give priority to spatial fairness in order to guarantee that shared cars are available in every area. Ultimately, the growing public desire for inclusion in urban transportation is reflected in the need for equitable services. Finding a balance between efficiency and justice will be critical as MSS become more and more important for cities. Realizing the full potential of MSS will depend on making sure that these services are available to everyone, not just a select few with privileged access [13].

2.4 Environmental motivations for MaaS adoption

The pressing need to discuss environmental issues, especially those related to excessive greenhouse gas (GHG) emissions, is driving the development of MaaS. The transportation industry is a major contributor to world emissions, with road transport alone accounting for 11.9% of global GHG emissions, according to Marco Giusti's "L'urgenza di agire" [33]. This significant environmental impact emphasizes how urgently structural adjustments to the optimization and management of urban transportation are needed.

Current consumption habits have created a worldwide ecological imbalance, which is one of the strongest arguments for acquiring MaaS. The rate at which our earth is depleting its resources is 1.7 times faster than its capacity for sustainable regeneration. Action must be taken right now to curb this abuse, particularly in industries with the potential to reduce emissions like transportation.

However, increasing vehicle economy alone is insufficient. Increases in energy efficiency, such those found in more efficient diesel engines, can paradoxically result in higher overall energy consumption, as the Jevons Paradox [2] illustrates (see Subsection 2.4.1). This occurs because these developments may make it feasible to manufacture bigger, more energy-intensive automobiles, such as SUVs, which would counteract the advantages of higher efficiency. Because of this, MaaS advocates for systemic changes in travel behaviors, such as supporting public transit, carpooling, and remote work, in addition to technical advancements.

A variety of deliberate actions are required in order to minimize emissions successfully. These include promoting electric cars (EVs) and quickly phase-out of gasoline and diesel automobiles. Transportation electrification offers the potential to cut energy use by up to 75%, but this transformation requires proper planning. For example, strategic placement of EV charging stations and deliberate urban planning are essential to avoiding traffic jams and guaranteeing effective resource use. Since the current rate of EV adoption is not fast enough to fulfill global climate targets, legislative action is required to hasten the replacement of internal combustion engine cars. In this case, MaaS may act as a change agent by providing a viable substitute for traditional automobile ownership and encouraging the use of greener modes of transportation. In conclusion, creating a more environmentally friendly and effective urban transportation system is a major reason for implementing MaaS. This necessitates gauging the success of MaaS efforts using KPIs and KVIs. KPIs offer measurable criteria for assessing the effectiveness of MaaS, like decreased emissions, greater usage of public transportation, and overall energy efficiency. KVIs, meanwhile, make sure that the assessment procedure stays in line with the larger social principles, such inclusion and equity.

There is a clear worldwide need to incorporate MaaS into everyday life. However, it is as important to guarantee that the laws and rules governing MaaS are faithfully upheld. This means that in order to ensure that MaaS not only contributes to reducing environmental impact but also aligns with and advances the broader objectives of sustainable urban development.

2.4.1 The Jevons' Paradox

Jevons' Paradox investigates the paradoxical link between efficiency gains in technology, especially in the use of materials and energy, and their usually unanticipated side effects. Efficiency is a notion that quantifies how well resources are employed to get a certain result. In contemporary circumstances, efficiency is typically discussed in relation to lowering energy consumption or pollution. As an illustration, increasing energy efficiency may help lessen the impact on the environment by requiring less energy to produce the same amount of output. Intensity is the opposite concept of efficiency [70]. The intensity of energy usage can be determined, for example, by measuring the amount of energy consumed per unit of output. Greater efficiency is correlated with lower intensity.

The English economist named William Stanley Jevons detailed this conundrum in detail in 1865. "The Coal Question" is the title of his book [42]. Contrary to popular belief, Jevons observed that increasing the efficiency of coal utilization preferred to lead to a paradoxical rise in coal use rather than a decrease in total coal consumption. This is because higher efficiency led to lower costs and easier access to coal, which in turn drove up demand for coal-powered technology and industries.

The paradox can be split into three steps:

- First of all, advances in technology reduce the amount of energy or resources needed to get the same result. There is a chance for large savings as a result. Efficiency usually results in lower costs associated with the use of a certain resource or technology. Therefore, because these advancements reduce the cost of production, the finished goods or services are more affordable. Costs are coming down, which raises demand and increases consumption.

- In certain cases, this can potentially negate the energy savings that the original efficiency boost produced. This is known as the "rebound effect". This effect occurs in two ways: first, the direct rebound effect refers to the increase in consumption of the particular product that has become more efficient, such as driving a car that uses less fuel; second, the indirect rebound effect describes how savings from using one product can be used to purchase other goods and services, which increases overall economic consumption.

- In certain instances, when the rebound effect is especially powerful, universal consumption not only doesn't fall but rather rises above the pre-efficiency adoption levels. The boomerang effect or backfire are terms used to describe this phenomena. The main premise behind the Jevons' Paradox is that higher efficiency in the use of coal actually leads to increased profitability and increased industrial capacity, which in turn increases the use of coal.

Although Jevons developed his case in relation to coal, it is applicable to a variety of resource uses. Jevons said that increases in income and population were made possible by technical advancements. This brings us to the paradox: the world might not be able to maintain as many people or be as wealthy if we hadn't increased efficiency, yet since we did, we now utilize considerably more resources.

Certain opponents point out that as technology advances, costs drop, which might reduce overall consumption. Jevons counters that individuals frequently end up utilizing more of a resource when prices decline. It seems like more people would drive if fuel were more affordable. Reducing consumption doesn't always come from efficiency alone. Jevons further illustrated his idea using the example of labor efficiency. Although the introduction of machines enhanced worker productivity, they frequently raised demand for labor since more people could now buy the products, rather than decreasing the need for labor. Similarly, increased energy efficiency results in increased energy consumption rather than decreased energy consumption.

Furthermore, discussions concerning sustainability and energy efficiency, in particular, still make Jevons' Paradox important. There are others who contend that enhancing energy efficiency will lessen our ecological footprint. However, if Jevons is correct, efficiency may not be beneficial as it promotes more consumption. Instead, it could be required to directly regulate consumption by measures like rationing, limitations on the extraction and use of resources, or emissions. Efficiency and adaptability must coexist in balance for human growth to be sustainable and to prevent advancements in one from undermining advancements in the other. A deeper comprehension of the interactions between various forms of efficiency and adaptation, as well as deliberate policy decisions, are necessary to achieve this balance in order to solve the long-term problems of sustainability.

Jevons concluded, at last, that population expansion and consumption are driven by technical advancements, especially energy efficiency, which exacerbates environmental stress. In order to keep consumption in control, we need harsher restrictions like rationing or resource usage limits. In order to combat the Jevons Paradox, it could be necessary to utilize other measures, such taxes or higher expenses or design incentives based on specific KPIs and KVIs.

3

European and Italian legislation about MaaS

This chapter looks at how changing legal frameworks in Italy and Europe are affecting the creation and use of MaaS. Now that we have established the fundamental effects of transportation on the environment, significant initiatives such as the European Green Deal and the Net Zero Emissions commitment are essential milestones in combating global warming and promoting sustainable development. These initiatives show how crucial it is to include MaaS into more comprehensive environmental strategies in order to guarantee a future of transportation that is both efficient and ecologically benign. These landmark agreements highlight the urgent need for environmentally conscious integrated mobility solutions that support ambitious targets, opening the door for the creation of practical KPIs and KVIs that are critical to MaaS success. In order to make the European Union the first continent to achieve carbon neutrality by 2050, the European Commission unveiled the European Green Deal, an innovative action plan. Numerous initiatives are included in this extensive plan with the goals of lowering greenhouse gas emissions, encouraging sustainable growth, and protecting the environment. One of its main objectives is to decarbonize the transportation industry, which is a major source of carbon emissions. MaaS is crucial to achieving this goal because of its capacity to decrease reliance on personal automobiles, cut emissions, and improve transport networks. Furthermore, this commitment is extended internationally by the Net Zero Emissions target, which highlights the need for all industries, including transportation, to achieve net-zero greenhouse gas emissions by the middle of the century. Innovative technologies like MaaS need both a strong legislative framework and supporting policies in order to achieve these ambitious goals. The development and deployment of KPIs to assess how well MaaS laws are being applied, as well as KVIs to strike a balance between these quantitative measurements and the qualitative ideals that MaaS seeks to advance, should be part of this framework.

This chapter will look into how laws in Europe and Italy are changing to facilitate the production of these meaningful measures and the integration of MaaS. This chapter attempts to provide a comprehensive picture of how regulatory frameworks are being built to ensure MaaS contributes effectively to a sustainable and efficient transportation future by integrating the reasons behind MaaS with the legislative efforts to establish and execute KPIs and KVIs.

3.1 EU legislation

The relevant EU legislation will be examined in this section, with particular attention paid to important points like the function of the Directorate-General for Mobility and Transport, the Directive 2010/40/EU on the framework for the deployment of ITS, and the important mobility-related communication from the European Commission. This research will offer a thorough grasp of how European directives and policies influence the creation and use of MaaS in each member state.

3.1.1 DG Move

Developing mobility and transport policy for the European Union is the responsibility of the Directorate-General for Mobility and Transport (DG MOVE) [64]. Nearly all European Union Member States, the European Parliament, European business, citizens, social partners, and other stakeholders are involved in DG MOVE's activity. The International Maritime Organization (IMO) and the International Civil Aviation Organization (ICAO) are two international organizations with which it collaborates. Five of the six Commission headline aspirations outlined by President von der Leyen in her Political Guidelines are addressed by DG MOVE in the investigation to guarantee that transportation in Europe is sustainable, safe, smart, dependable, efficient, and affordable: European Green Deal: a digitally-savvy Europe, a people-centered economy, a more powerful Europe globally, advocating our European way of life.

To advance its policies and achieve its specific goals, a number of indicators are outlined in the annex.

The key performance indicators include:

1. the term "Share of CEF Transport investment in sustainable modes" alludes to the percentage of funds allocated by Connecting Europe Facility (CEF) for Transport that are invested in sustainable transportation methods. The point is to carry environmentally-friendly transport solutions, promote healthier and cleaner mobility options, and increase the use of sustainable fuels across different transport modes in Europe and globally.
2. The rate at which new transportation rules and regulations are enacted and put into effect is known as the "transposition rate". The objective is to establish a well-run transportation sector with uniformly enforced regulations that promotes economic recovery.
3. Estimated risk at closure: this entails making sure that initiatives are adequately funded. They will oversee budget execution, arrange required funding, and guarantee adherence to financial regulations. The VIGIE system will assist in monitoring budget use throughout the year and providing management and pertinent authorities with financial performance reports.

3.1.2 Directive 2010/40/EU

The European Parliament's Directive 2010/40/EU is utilized to facilitate the implementation of intelligent transport systems (ITS) in road transportation and to facilitate interactions with other modes of transportation [26]. To ensure optimal performance and efficiency, it is crucial to consider certain fundamental principles while formulating regulations and selecting technology for ITS. The following guidelines can also be used as KPIs and KVIs to assess how well ITS deployments are doing.

- Effectiveness: the main transportation issues facing Europe should be heavily discussed in ITS initiatives. These issues include minimizing traffic jams, cutting emissions, stepping up energy conservation, and improving safety, especially for vulnerable road users.
- Cost-efficiency: by weighing the expenses against the goals and advantages, ITS solutions should be disposed of in a way that maximizes return on investment.
- Proportionality: services must to be designed to offer different deployment and quality levels according to particular local, regional, national, and European demands.
- Service continuity: in order to meet the various requirements of the transport networks that link nations, regions, and cities, ITS must guarantee uniform service throughout the European Union, especially on the trans-European network and its external borders.

- Interoperability: systems must be built to efficiently share and exchange data in order to guarantee smooth service delivery across various ITS platforms.
- Backward compatibility: new ITS systems must be able to work seamlessly with pre-existing, similarly-purposed systems without impeding technical progress.
- Respect for current infrastructure: when implementing ITS, countries should take into account the features of their current transportation networks, such as traffic patterns and meteorological conditions.
- Equality of access: ITS services ought to be freely available to all users, even those who utilize the roads more vulnerably.
- Maturity: after a careful risk assessment, innovative ITS systems must show resilience and dependability through sufficient technological advancement and practical application.
- Timing and positioning quality: to guarantee accuracy and dependability, ITS applications needing accurate timing and positioning should make use of satellite-based technologies or comparable systems.
- Intermodality facilitation: to improve overall transportation efficiency, ITS should facilitate the coordination of various modes of transportation when appropriate.
- Respect for coherence: new advancements in ITS should be in line with current regulations, policies, and standardization initiatives of the European Union.

3.1.3 Communication from the European Commission

"Sustainable and Smart Mobility Strategy – Putting European Transport on Track for the Future" [14] is a communication from the Commission to the European Parliament, the Council, and the European Economic and Social Committee of the Regions.

The main goal of the European Commission's 2030 and beyond plan is to transform the transportation industry to make it healthier, more intelligent, and environmentally friendly. It outlines many crucial tactics intended to accomplish the next objectives.

- Multimodal system: the goal of a multimodal system is to create a superior transportation network that links clean aircraft, high-speed rail, and other environmentally friendly choices. Digital solutions will be pushed to validate smooth multimodal transportation and shared mobility services in order to achieve this. The extension of contemporary mobility systems will be facilitated by the integration of Connected, Cooperative, and Automated Mobility (CCAM) technologies. Furthermore, to make travel simpler and more effective for all users, efforts will be directed at improving multimodal travel information, ticket types, and payment methods.

- Eco-friendly mobility: the EU calls for the promotion of sustainable city mobility plans that prioritize the expansion of bicycle infrastructure and the accomplishment of zero-emission targets. This undermines the promotion of freight solutions with zero emissions, such automated delivery and cargo bikes. Furthermore, in an effort to promote more environmentally friendly choices among the general public and corporate sector, the European Union will make transparent the environmental effects of various transportation options.

- Modal shift: in order to improve efficiency and sustainability in the transportation sector, a sizable amount of road freight is directed toward rail and inland waterways. Redesigning the intermodal transport framework will be necessary to better integrate various forms of transportation, resulting in more seamless transitions and improved logistics chain efficiency.

- Smart solutions: in order to guarantee smooth, safe, and effective mobility, the EU intends to make use of digital solutions and ITS. This involves promoting cutting-edge mobility innovations including electric transportation options, driverless cars, and drones. There will be an agile regulatory structure in place to facilitate experimentation and innovation. Important EU financing initiatives like Digital Europe and Horizon Europe will be crucial in advancing sustainable technology research and application. AI and 5G-enabled enhanced digital infrastructure are essential to the development of transportation networks. The availability of data and a strong digital infrastructure will be the main priorities. With a focus on privacy and competitiveness, a common mobility data area for Europe will be developed to facilitate data exchange and improve mobility services.

- Affordability and accessibility: it is important to draw attention to the high cost of transportation, especially for the poor, the disabled, and those living in rural areas. It is critical to enhance working conditions in the transportation sector and extend public transit connections to rural and impoverished areas in order to mitigate labor shortages exacerbated by the COVID-19 pandemic. Maintaining social standards and promoting moral work practices are also essential for all modes of transportation. It is also crucial to support gender equality, the inclusion of individuals with disabilities in transportation laws, and the rise in the number of women working in the transportation sector in order to create a more fair and inclusive transportation system.

- Safety and security: keeping the EU at the forefront of transportation safety and aiming for zero deaths are top goals. This entails tackling important traffic safety concerns including intoxication, speeding, and distracted driving. To combat cyber threats, strengthening the security framework is also crucial. Improving cybersecurity legislation and looking into possibilities for quick alert systems at the EU level are crucial steps in protecting the transportation industry.

3.1.4 CONDUITS

The Coordination of Network Descriptors for Urban Intelligent Transport Systems[1] instituted the report "Key Performance Indicators for Traffic Management and Intelligent Transport Systems", which aims to generate a unified evaluation framework for measuring the successfulness of traffic administration and ITS through a detailed set of KPIs [39]. This project, which lasted from May 2009 to June 2011, was funded by the 7^{th} Framework Program of the European Commission's Directorate-General for Mobility and Transport. The KPIs and KVIs are arranged into four main categories: traffic efficiency, traffic safety, pollution reduction, and social inclusion and land use.

Traffic efficiency is divided into four subcategories:

- Mobility index: measures the average travel time to various destinations within highway and public transport networks, normalized by the distance to those destinations.
- Reliability index: focuses on system efficiency from the perspective of service providers, emphasizing efforts to reduce congestion and enhance mobility.
- Operational efficiency index: assesses how well resources are organized to produce an acceptable level of transport output.
- System condition and performance index: evaluates the physical condition of transport infrastructure and equipment. It may focus on the condition of the system itself (e.g., roadways with poor ride quality) or on the efficiency of transport programs (e.g., the cost of maintaining roadways). Common metrics include the condition and age of roadways and bridges, as well as maintenance by their managing organizations.

Traffic safety is divided into six subcategories:

[1] The CONDUITS project is dedicated to developing Key Performance and Value Indicators that support European municipalities in making well-informed decisions regarding ITS projects. It also encourages the exchange of best practices among municipalities based on their involvement with ITS.

- Traffic accident index: evaluates the safety level of a transport network. Over the decades, a vastness of measures have been instituted to reduce traffic accidents, including in-vehicle features (seatbelts, airbags, etc.) and on-road engineering results (pedestrian crossings, traffic calming measures). ITS plays a significant part in both areas (e.g., collision control, variable speed warning signs).
- Applications with direct safety impact index: measures the number of system interventions, with a higher number indicating a lower safety level due to more frequent interactions between road users that could lead to critical situations or accidents.
- Applications with indirect safety impact in urban environments index: focuses on reducing or avoiding situations with negative impacts, including safety. In complex urban environments, it is challenging to attribute safety impacts solely to traffic management and ITS applications.
- Applications with indirect safety impact on urban motorways index: targets traffic management and ITS applications that harmonize traffic and prevent congestion on urban motorways. While these measures generally improve safety by stabilizing traffic conditions, there are cases where safety might decrease due to conflicts with fixed system components (e.g., the use of the hard shoulder at motorway intersections).
- Car-to-infrastructure communication-related applications index: assesses systems that directly warn drivers of dangerous situations. These warnings, provided by the infrastructure operator, can be either link-based (e.g., warning of congestion, accidents, or weather conditions) or junction-based (e.g., warning of possible conflicts or red-light violations).
- Total traffic safety index: provides a comprehensive assessment of safety-related performance across various application categories. This differentiation is crucial for experts and policymakers, as it allows for targeted evaluations of the systems.

Pollution reduction is categorized into three subgroups:

- Emissions from motor vehicles index: reflects the impact of traffic management and ITS on vehicle fleet emissions, typically influenced by changes in traffic conditions and driving routes. Traffic conditions are often described by a typical driving cycle, which includes factors such as average speed, maximum speed, number of stops, and maximum acceleration/deceleration. Driving route parameters include length and topography.
- Emissions from electric vehicles index: special considerations are required when assessing the impact of EVs on total fleet emissions. While EVs have zero tailpipe emissions, they may affect urban air quality due to increased emissions from electricity production. However, if the number of EVs in the fleet is minimal, their impact on emissions can be considered negligible.

- Total pollution reduction index: aggregates emissions data from the vehicle fleet before and after the implementation of traffic management or ITS measures to provide a synthetic indicator of pollution reduction. This index serves as a tool for evaluating the environmental impact of different solutions.

Social inclusion and land use indices are divided into four subcategories:

- Accessibility index: assesses the spatial accessibility of activities by calculating the opportunities for specific activities reachable from a given zone using a particular transport mode. This method relies on predefined spatial zones, their structural data, and the quality of the transport system.
- Social mobility of special groups index: focuses on improving mobility for specific population groups, such as people with disabilities, the elderly, and the economically disadvantaged. The goal is to enhance their mobility options, creating a more inclusive transport system where all citizens have similar mobility patterns on average.
- Public transport usage of special groups index: measures the effectiveness of traffic management and ITS applications in empowering special population groups, particularly those with mobility impairments, to use public transport. Unlike the general population, these groups have different modal choices, so the assessment compares potential public transport demand with actual usage.
- Land use index: evaluates the impact of traffic management and ITS on land use, acknowledging the different reaction times of both elements. While traffic management and ITS seek short-term improvements, land use changes occur over the long term. Some applications aim to enhance existing infrastructure, potentially reducing the need for new developments. This index demonstrates the proportionality of the covered area at a macroscopic level.

3.2 Italian Legislation

We will look at how MaaS and the creation of KPIs and KVIs are addressed by Italian law in this part. We will specifically look at important projects like the "MaaS for Italy" project, the "Towards a New Model of Local Sustainable Mobility" study, and a thorough examination of the "National Shared Mobility Observatory". The way Italy approaches MaaS closely follows European guidelines. For example, the "MaaS for Italy" program aims to improve accessibility and efficiency of transportation by integrating various mobility services onto a single platform.

In order to improve city mobility and inform policy choices, the National Shared Mobility Observatory collects and analyzes data, which is a crucial component of this endeavor.

However, Italy has to make the best use of its financial resources if it is to achieve the full potential of these projects. By doing this, the nation can ensure that MaaS initiatives provide the greatest possible benefits to society and the environment by stepping up their practical implementation. This will call for a coordinated approach that takes into account the demands for infrastructure and technology while also promoting cooperation between public and commercial partners in order to create a more integrated and sustainable transportation system.

3.2.1 MaaS for Italy

The National Recovery and Resilience Plan (PNRR) sub-Investment 1.4.6 was introduced in 2021 by the Ministry for Technological Innovation and Digital Transition (MITD), in collaboration with the Department for Digital Transformation (DTD), the Presidency of the Council of Ministers, and the Ministry of Infrastructure and Sustainable Mobility (MIMS). This project, called "Mobility as a Service for Italy", is funded by the European Union under the Next Generation EU program and is a component of Mission 1-Component 1 of the PNRR. The strategy is to provide fresh mobility services based on the MaaS architecture [61]. Another key player in the context of MaaS is the MOST (Centro Nazionale per la Mobilità Sostenibile), which aims to advance sustainable mobility solutions in Italy.

Alongside the project's detailed description, including the application architecture, mission, and development of pilot projects, the initiative aims to refine and test the project by formulating and applying certain KPIs. These indicators were designed to measure

- the effectiveness of the data sharing and service repository facilities;
- the scope and completeness of the technological advancement within MaaS;
- the estimation of the effectiveness, efficiency, and quality of the transport system resulting from the specific MaaS experiments implemented;
- the evaluation of the socio-economic effects resulting from the specific MaaS experiments implemented;
- the analysis of the cultural and behavioral impact (habits and attitudes) resulting from the introduction of the specific MaaS experiments implemented;
- a rate of the expected environmental impact;

- an assessment of the expected energy impact.

As we can see, Italian MaaS law continues to place insufficient emphasis on KVIs. Acknowledging the significance of benefits to society, this thesis seeks to define shared values in detail, emphasizing the necessity of KVIs in addition to KPIs. For a comprehensive explanation of KVIs, see the chapter 5.

3.2.2 Towards a new model of local sustainable mobility

The present situation of local transportation in Italy is described in the MIMS study "Verso un nuovo modello di mobilità locale sostenibile" [19]. It looks at communal and public transportation systems, provides a number of steps to accomplish these goals, and suggests possible benchmarks for measuring and evaluating public investments and reform programs. The goal is to improve local mobility in Italy in a way that is sustainable from an economic, social, and environmental standpoint. Modernizing the local transportation network requires a robust public transportation system. The report contains a number of KPIs pertaining to public transportation. Both governmental and private operators in charge of local transportation can work together more successfully to decide on the best course of action by setting quantifiable objectives. This strategy will help align Italy with European standards and fulfill the sustainable development goals described in international agreements.

One of the tables presented in the report lists the following indicators:

- Travel times and congestion indices: commute times for work-related travel in metropolitan areas should decrease by 1%, with the goal of nearly eliminating commutes longer than one hour. Additionally, congestion indices, such as hours lost in traffic per capita, should be reduced by 5%.

- Ratio of revenues (or passengers) to public costs: efficiency optimizations should also apply to service management, with a rise in the revenue-to-cost ratio, particularly for areas starting from lower levels (below 35%).

- Public transportation accessibility indices: in 2019, more than 1.2% of Italian families reported having substantial trouble using the system, with rates significantly higher in cities, especially in the suburbs, than in major European nations (about 0.3%). Reducing the proportion of individuals experiencing access issues by around 0.5 percentage points might lead to the objective of halving this difference. Reducing architectural and other barriers for vulnerable and underprivileged groups should be a priority in the ongoing efforts to increase accessibility.

- Objective quality metrics and satisfaction indices: in addition to enhancing accessibility, public transportation services should be of a higher caliber. This may be accomplished by encouraging the broad use of modern technologies, such as electronic ticketing and infomobility systems, which should cover at least all provincial capitals and cities with populations over 100,000, and completely replacing the most polluting cars (those that fall short of Euro 5 requirements). Furthermore, the objective is to cut in half the difference between Italy and the most developed European nations in the proportion of the population that expresses dissatisfaction with local public transportation in relation to service frequency and punctuality, vehicle and stop comfort, intermodal connectivity, commercial speed, service cost, and other aspects.

- The proportion of sustainable mobility and motorization rates: it is crucial to consider that Italy has a five percentage point higher private car usage rate than the average of major European cities when establishing goals. It is reasonable to strive for a 10 percentage point modal shift towards sustainable transportation by 2030, considering the growth of shared mobility, the construction of bike lanes, and the extension of tram and metro networks. A decrease in the motorization rate to align it with other top European nations should go hand in hand with this objective. Compared to France, Spain, and Germany, Italy had 66 cars per 100 people in 2019, an increase of 18, 15, and 10 percentage points. Reducing the dependence on road transportation and raising the number of seats available per square kilometer are two ways to meet these objectives on the supply side. Due to both their growth and a decline in road transportation, the modal share of trams and subways has increased by more than 5 percentage points during the last five years. The objective may be to raise the total seat-kilometers provided by public transportation by 10% by 2030, in addition to increasing the modal share of trams and subways.

- Air quality indicators and CO_2 emission levels: achieving these targets will significantly reduce CO_2 emissions and air pollution.

3.2.3 A National Shared Mobility Observatory

Launched in September 2015, the Ministry of Environment and Energy Security, the Ministry of Infrastructure and Transport, and the Foundation for Sustainable Development all support the Italian National Shared Mobility Observatory (INSMO). The effort aims to create a joint platform that unites providers of shared mobility, public and corporate organizations, and the academic community to oversee, facilitate, and promote the growth of shared mobility in Italy.

The National Report on Shared Mobility and other publications released throughout the year, along with other documents, use the data gathered to create indicators, according to the document “Monitoring of Sharing Mobility Services - Definition, Classification, and Methodology of the National Shared Mobility Observatory” [58]. Using historical data, simple and composite indicators are used to assess service performance at particular times or over long periods of time, as well as to look at shared mobility across different territorial levels (national, regional, and local). Comparing other cities and services is also made possible by these metrics. Basic metrics (such the annual number of shared cars) aggregate information from several cities and/or services to describe the industry’s present situation. Conversely, composite indicators combine a number of characteristics to evaluate the effectiveness of a service and provide operational insights.

Every year, the INSMO updates a number of important indicators and tracks how they evolve over time. Reliable analysis requires that the definitions and measures of these indicators remain consistent from year to year.

These metrics include the quantity of shared mobility services, which indicates the amount of services that are available, and the kinds of services that are provided, which illustrates the diversity of the industry. These services’ distribution and accessibility are shown by how they are located throughout Italy, broken down by city size and geographic region. Furthermore, the overall fleet size and the degree of electric car acquisition may be inferred from the number of shared vehicles as well as the percentage of electric vehicles. The fleet’s average vehicle weight, expressed in kilos, provides details on the normal size of the vehicles in use. The number of people signing up for shared mobility services indicates how engaged users are, and the age and gender distribution of users’ demographic data offers a picture of the typical service user. Patterns in usage may be found by combining the total number of trips made utilizing these services with the breakdown of trips by distance and duration categories. Additionally, the breakdown of failed trips by day of the week and time of day reveals the peak usage hours for certain services. The fleet’s average age aids in assessing its overall health, and the distribution of cars according to Euro emission standards shows how each vehicle affects the environment. The distribution of fuel types across the car-sharing fleet illustrates the variety of fuels utilized, while the average annual number of rentals per user indicates user activity. Furthermore, the relatively low number of kilometers driven per year per car and the number of automobiles per 1,000 people provide insights on the availability and use of vehicles worldwide. Lastly, a more thorough knowledge of the consumers of these services is provided by the demographic segmentation of users based on their age and gender.

4
Key Performance Indicators

It is crucial to evaluate quantitatively the impact and effectiveness of MaaS. Critical insights into how MaaS alters mobility patterns, service consumption, environmental effect, and economic viability are offered by Key Performance Indicators (KPIs).
Firstly, this chapter will look at the many kinds of transportation that have developed over time and how they might work together. We shall assess the average cost per trip or per user. Then we are going to evaluate how these new and combined modes affect the financial performance of transport operators, including changes in revenue streams. Furthermore, we shall analyze the environmental impact of these transportation modes, focusing on how they contribute to or reduce emissions. Next, we shall explore strategies to ensure that transportation systems remain efficient, optimizing routes and reducing delays. Afterwards, we shall assess how well these modes provide access to various populations. Finally, we will look at how cost-effective it is to run various transit systems, taking into account factors like infrastructure, maintenance, and overall financial sustainability.

4.1 Modal Share

A crucial and commonly used KPI in the context of MaaS is the modal share. This metric computes the percentage distribution of various modes of transportation used in a given area, whether it a city, region, or nation. Modal share sheds light on people's travel preferences by showing the relative usage of different modes of transportation, such as private vehicles,

public transportation, bicycles, and walking. Various criteria can be taken into account in the computation, including the percentage of travelers who use a certain mode, the number of trips that are completed, and the distance that each mode covers [71].
The European Commission defines modal share as a critical metric for understanding how various transport modes contribute to mobility and achieving sustainable transport goals [27].
This KPI highlights the diverse distribution of transport modes within a given area and allows for the identification of the most efficient and suitable transport mode for specific needs. The most 'competent' modes for a given job may be identified by evaluating modal share, which takes into consideration real boundary circumstances including transport volume, available modes, capacity restrictions, demand regularity, and geography [75].

4.1.1 Benefits

Cities have started implementing modal share objectives in an effort to promote a more sustainable and equitable mix of transportation alternatives in recent years. By doing so, they aim to:

- encouraging the adoption of ecologically good transportation alternatives: reaching a balanced modal share supports the adoption of environmentally friendly transportation options, which improves air quality and lowers carbon emissions. Cities may contribute to a cleaner and healthier urban environment by encouraging the use of public transportation, bicycles, walking, and other sustainable modes [40].
- alleviating traffic congestion: redirecting a sizable portion of travels to public transit, cycling, and walking can help reduce traffic congestion [1] The traffic congestion can be calculated using a level of service rate, average traffic speed, and average congestion delay compared with free-flowing traffic and improve bottleneck. These alternative modes help reduce the number of vehicles on the road, easing traffic flow and decreasing travel times. This reduction in congestion not only enhances the efficiency of the overall transportation network but also leads to lower stress levels for commuters and contributes to a more pleasant urban environment [54].
- decreasing energy usage: encouraging the use of non-motorized options, as electric vehicles, and public transportation results in lower energy consumption and reduced CO_2 emissions. Even thought these options are not yet a global phenomenon.

[1] The extra expenses brought on by traffic congestion are known as road user interference's effects. These impacts are most significant down urban-peak circumstances when traffic volumes approach a road's capacity. As a result, there is less mobility and more stress on drivers, higher car expenses, and pollution.

4.1.2 Measurement methodologies

Effective mobility and transport planning necessitate an understanding of the current situation and an analysis of travel characteristics, along with the absolute and relative performance of various transport modes, such as passenger numbers, passenger kilometers, and modal share percentages. To gather data on modal share it is also important to investigate the types of transport modes utilized by passengers. Different modes of transportation are included in the concept of "modal share", such as road transportation, public transportation, cycling, and bike-sharing programs. E-bikes have recently been added to the range of transportation options for suburban and urban travel [5].
Besides, some companies have proposed shared dockless e-scooters as a new option for urban mobility [37].

4.1.3 Challenges

One of the main challenges is the lack of reliable data sources, regardless of whether the analysis is conducted at the national, regional, or local level [75]. Because there are many different types of data sources and their successful integration can be difficult to achieve, collecting data across different modes of transportation accurately can be difficult. Data gaps and discrepancies may result from inconsistent data collecting and reporting among various areas and municipalities. Ensuring data accuracy and fair representation of each transport mode presents another significant challenge. Different modes of transport have varying levels of data availability and accuracy, which can distort the results. For instance, while road transport data may be more readily accessible and precise, data on pedestrian and cycling modes might be less comprehensive, potentially leading to an under-representation of these modes in the modal share calculations.
Assessing the extent of walking as a significant mode of transport presents challenges and raises methodological issues. Questions such as how to categorize walking as a distinct mode of transport, given its integration with other modes during access and egress trips, remain unresolved.
In addition, there is no universally accepted framework for addressing new and growing transport modes like micro-mobility [2], electro-mobility, and shared mobility, which are

[2]In the ITF report "Safe Micromobility" (ITF, 2020) [31], micro-mobility is defined as: "the use of micro-vehicles: vehicles with a mass of no more than 350 kg and a design speed no higher than 45 km/h. The vehicle's kinetic energy is limited by this definition to 27 kJ, which is 100 times less than the kinetic energy that a small

becoming increasingly important in urban transportation.

4.1.4 Technological Tools

Technological progresses like mobile tracking apps, Geographic Information Systems (GIS) [3], and big data analytics facilitate the collection and analysis of modal share data, providing more accurate and real-time insights. In situations where more and more new devices have their own data recording and processing systems, and moreover, they can communicate with IT systems, which, in turn, can make the acquired information resources available to wide area networks. This type of solutions is based, among others, on Internet of Things. In turn, such solutions can be widely used in the implementation of the Smart City concept and, as a consequence, in Smart Mobility.

4.1.5 Future Trends

There are notable emerging trends in urban transportation, such as the increasing popularity of e-mobility and the introduction of shared autonomous vehicles [83]. Understanding these patterns is crucial for modifying policy to accommodate future transportation demands and the modal share of these new modes of transportation. E-mobility is the use of EVs and other electric-powered means of transportation. In order to optimize energy efficiency, it integrates a variety of electric vehicles, such as automobiles, buses, and bikes, and it interacts with smart power networks. Reduced running costs, more fuel-efficient cars, and adherence to carbon emission regulations are some advantages of e-mobility, all of which help to lower pollution levels worldwide. Shared autonomous vehicles, or SAVs, are self-driving cars meant to be used by several individuals. They do away with the necessity for individual car ownership. SAVs are expected to transform urban transportation by providing effective, adaptable, and environmentally friendly mobility options. They might reduce pollutants, relieve traffic congestion, and improve the effectiveness of transportation as a whole. Significant improvements in infrastructure, vehicle technology, and regulatory framework are necessary

automobile can achieve at its fastest speed." Bicycles are a typical human-driven micro-vehicle, in addition to the more recent electrically powered models like e-scooters and e-bikes.

[3] GIS is a technology that is used to create, manage, analyze, and map all types of data. GIS links information to a map by fusing location data, which tells us where things are, with various kinds of descriptive information (which tells us what those things look like). This provides a foundation for mapping and research that is used in almost all corporate and academic domains. Users may better grasp linkages, patterns, and spatial context with the aid of GIS. The benefits include improved communication, efficiency, management, and decision-making.

for the deployment of SAVs.[4]

4.1.6 Considerations

Environmental KPIs may benefit from a shift in mobility patterns toward more environmentally friendly options like walking, bicycling, and public transportation, which can reduce pollution and carbon emissions. A successful modal shift can lead to improved service quality and higher user satisfaction if public transport systems are enhanced to accommodate increased demand efficiently. By lowering healthcare expenditures, increasing quality of life, and improving public health outcomes, switching to active transportation options like walking and cycling can have a favorable impact on KPIs that measure public health and welfare. By giving marginalized groups more mobility alternatives and having an influence on social equity KPIs, expanding access to reasonably priced and dependable public transit can promote social equality.

4.2 Variation in service utilization rates due to MaaS

MaaS has combined several modes of transportation, including buses and trains, with shared or private choices, like bike and vehicle sharing, into a single, easy-to-use system. MaaS streamlines the transportation process by enabling consumers to plan, schedule, and pay for all of their travel requirements on a single platform. This convenience encourages more people to use these integrated services, as they can easily compare options and choose the most efficient mode of transport for each journey [72]. As a result, the introduction of MaaS has significantly increased the usage rates of various transportation services. In term, this promotes a seamless travel experience, making it more appealing for people to rely on a mix of transportation modes instead of solely using private cars.

4.2.1 Impact on public transportation

MaaS significantly influences public transportation by enhancing accessibility and user experience. The MaaS experience is delivered via applications, which centralize the booking and payment process and give real-time data on schedules, route costs, car position and availability, and traffic conditions. By integrating schedules, providing real-time updates, and

[4] ibidem

streamlining payment processes, MaaS encourages greater use of buses, trains, and trams. Furthermore, it can optimize routes based on demand, resulting in more efficient resource allocation and potentially increased service frequency on high-demand routes. The integration of real-time updates and payment processes makes public transport more reliable and user-friendly, potentially increasing user satisfaction and ridership. Optimizing routes based on demand ensures that resources are allocated efficiently, addressing peak times and popular routes, which can enhance service frequency and reliability. MaaS provides users with simple access to a variety of mobility services, increasing their options and comfort levels. It provides consolidated information about all mobility services, facilitating travel and enabling users to choose their preferred mode of transportation with more ease, including ticket purchases.

4.2.2 Impact on Ride-Sharing and Car-Sharing

MaaS provides useful substitutes for private vehicle ownership, which has impacted ride- and car-sharing significantly. By consolidating several transportation providers into a single, easily navigable platform, MaaS promotes users to select shared mobility solutions. This modification can mitigate the negative environmental consequences of traffic congestion by lowering the number of private autos on the road. It can also encourage the shared economy in transportation. Ride-sharing can be defined as the shared use of transport vehicles, typically arranged dynamically and available on short notice, anywhere from a few hours to a few minutes before departure. It is based on cost-sharing, where all participants share the travel costs, ensuring that no one pays more than they would if traveling alone. Importantly, the financial benefit for the driver is limited to less than the total travel costs to prevent the service from being profit-driven. Ride-sharing often involves offering occasional rides over short distances and includes participants who may not know each other beforehand [25]. The concept of shared vehicle use dates back to 1948 in Zurich, Switzerland, driven by economic needs. However, early public car-sharing systems struggled to succeed. The 1980s saw the emergence of a number of successful car-sharing programs, which gained popularity in the early 1990s as a result of rising public awareness and the expansion of information and communication technologies (ICT). The extensive use of mobile services in the 2000s fueled these programs' expansion even further. Community members' mobility is increased by car sharing, which gives them access to places they may not otherwise be able to go by walking, bicycling, or public transportation. It also contributes to more sustainable urban areas by increasing awareness of the negative social and environmental effects of driving a private vehicle. Typically, car-sharing programs utilize fuel-efficient automobiles, which lowers urban pollutants and relieves traffic in cities [68]. BlaBlaCar provides long-distance trips, while Uber offers short-distance, taxi-like services. These are two examples of ride-sharing and car-sharing services.

4.2.3 Impact on Bike-Sharing and E-Scooter services

MaaS provides efficient solutions for both the beginning and end of a trip, which greatly increases the utilization of e-scooter and bike-sharing services. This lessens reliance on private vehicles and enhances public transit. By incorporating these services into MaaS systems, the availability and awareness of e-scooter and bike-sharing choices are improved, which has a significant positive impact on utilization. When it comes to filling in the gaps in public transit, first and last-mile connection is most important. This helps lessen the need for private automobiles for quick travels and promotes sustainable urban transportation. The results of a survey carried out in Shanghai [55] indicate that bike sharing has resulted in fuel savings of 8358 tons. This led the decreasing of carbon dioxide and nitrogen oxide gas emissions and improved air quality [86].
In addition to the environmental benefits of bike-sharing, increased physical activity can have a positive impact on public health.
Shared mobility and micro-mobility systems have been continuously evolving in cities all over the world for over 15 years, as part of a change in mobility patterns and lifestyle [51]. The electric scooter, often known as an e-scooter, is a creative and environmentally friendly mode of transportation that may be privately owned or shared. It can enhance community ties, lessen traffic and air pollution, and offer an effective substitute for cars in metropolitan areas [45]. When "Bird" in Santa Monica, California, presented the first dockless service in 2017, e-scooter sharing systems were first introduced in the USA as an alternate form of urban shared micro-mobility.

4.2.4 Impact on walking

Walking is not typically considered a transport service like other modes, and it often tends to be overlooked by MaaS operators in their quest for innovation [24].
Data from MaaS can assist city planners in improving walking infrastructure by identifying popular routes and distinguish areas needing development. This can promote walking,

particularly for short distances. MaaS can encourage walking by seamlessly connecting pedestrian routes with other transport services, making it a more inviting option for users. An improved infrastructure for walking encourages a more sustainable and healthful way of living. The UK government released "Future of Mobility: Urban Strategy", their approach to innovation in urban transportation, in March 2019 [30]. This lays out nine guidelines for encouraging urban mobility that must to be adhered to wherever feasible. Principle number three is that "Walking, cycling and active travel must remain the best options for short urban journeys".

4.2.5 Impact on car usage

People may use less own cars as a result of MaaS's cost and convenience, as they are becoming more and more interested in flexible and sustainable transportation choices.
This shift has the potential to reduce emissions, ease traffic congestion, and improve the sustainability of the urban environment. MaaS systems that encourage carpooling can increase vehicle occupancy rates and decrease the number of automobiles on the road to further these advantages [8].
Offering services such as public transportation, shared (e-)bikes, and ride-sharing at fixed prices can attract to travelers, who may be more responsive to bundled pricing than the long-term cost associated with owning a private vehicle. Research indicates that MaaS has the potential to decrease private vehicle ownership [53].
Despite that, for people to consider giving up their private cars, MaaS must offer significant improvements and reliable services. A major renovate of mobility services and the implementation of travel demand management strategies are necessary to reduce private vehicle ownership. It is particularly challenging to reduce the use of private vehicles for spare activities. The perceived costs of driving vary significantly between peak-time commuters and non-commuters. According to Hörcher and Graham (2020) [38] congestion can motivate the shift from private car ownership to other mobility services, though reducing car ownership might not always be the best policy objective. Instead, the focus should be on encouraging the use of high-occupancy vehicles such as buses and trains, shared mobility options, and active travel modes. Pricing strategies for MaaS bundles need to be carefully considered to support this shift. Also, while a decline in car ownership can free up parking space and impact vehicle-related tax revenues, these effects are complex and not fully quantified in this context due to a lack of reliable data.

4.3 Bus-route-oriented trips ratio

Understanding the utilization patterns of the different modes used in MaaS is critical for optimizing service delivery and improving urban mobility. This part introduces the concept of the *bus-route-oriented trips ratio*, intended as the number of trips with, at least, a bus route over total number of trips sold through the MaaS (e.g., driving + bus or walking + bus). This ratio is a key indicator of bus route utilization and provides insights into user preferences and behavior. The current trend is to create laws that encourage people to switch from using private to public transportation in an effort to lessen traffic in metropolitan areas and create a sustainable traffic environment. When users shift to public decrease consequently and this saves more energy and resource.

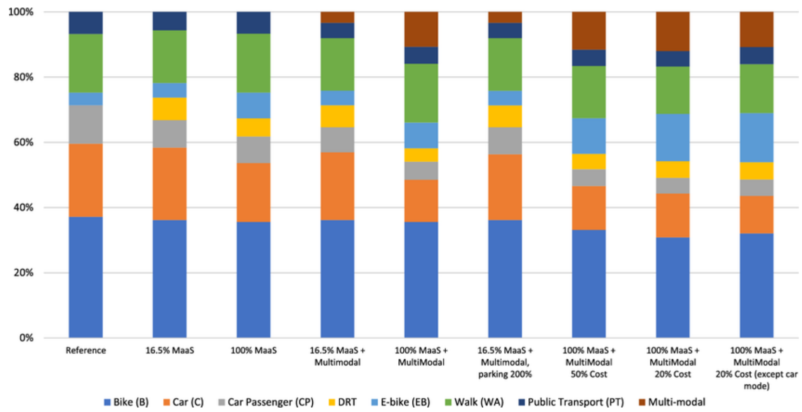

Figure 4.1: Modal split in different scenarios. Sharing and non-sharing trips are aggregated, and multi-modal mode trips are aggregated [66]

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This phenomenon can be appreciated by looking at Figure 4.1. Each bar in the chart shows the percentage of trips taken by different modes of transportation for different scenarios, which are compared to a reference scenario (such a reference represents the baseline scenario without any modifications). The first one is MaaS adopted by 16.5% of the population. The second bar represents the full adoption of MaaS. The third the 16.5% MaaS adoption with a multimodal approach. The fourth describes the 100% MaaS with a multimodal approach. The next one shows the % MaaS adoption + multimodal and parking costs increased by 200%. The sixth portray the full MaaS adoption with a multimodal approach and costs reduced by 50%. The following one shows 100% MaaS adoption with a multimodal approach and costs

reduced by 20%. 1the last one describe the full MaaS adoption with a multimodal approach, costs reduced by 20% except for car mode.
The most crucial idea that will be covered is Demand-Responsive Transport (DRT), which is so critical in the context of MaaS that it deserves a thorough explanation. DRT is an adaptable public transportation option that is in between taxis and conventional bus services. It utilizes small to medium-sized vehicles with routes that are dynamically adjusted according to customer demand. Typically, passengers schedule their trips in advance, specifying the origin, destination, and preferred times. DRT is often subsidized by local authorities to serve areas with low transportation demand or to provide specialized services, such as paratransit for the elderly or disabled. As well, DRT's popularity is growing due to the shortcomings of conventional transport systems and advancements in technology. However, it is often criticized for its high operating costs, limited flexibility, and difficulties in handling high demand. Currently, most DRT services operate on a small scale, primarily in areas with low demand. The potential for large-scale DRT systems is significant, especially in urban areas where they could compete with private cars by offering environmentally friendly, flexible, and cost-effective transportation options. On the other hand, challenges such as maintaining reliability, managing pre-booking requirements, and addressing the inherent advantages of private cars present significant obstacles. Despite these challenges, further exploration of large-scale DRT systems is necessary, particularly in congested urban areas where the use of private cars may become increasingly impractical [36].
In the reference scenario we can see the high percentage of bike and car usage, and the low public transport (PT) usage.

- In the 16.5 % of MaaS there is slight shift from cars to other modes. There is a decreasing in PT usage with respect to the reference scenario. It is also introduced the DRT.
- In the 100 % MaaS we have significant reduction in car usage, increase in public transport, and other modes.
- In 16.5 % MaaS + multimodal there is a moderate grow of multimodality.
- In a full 100 % MaaS adoption with multimodal we can find a further reduction in car usage and increase in public transport and multimodal options.
- In the 16.5 % MaaS + multimodal, parking 200 % situation, of course increasing parking costs we significantly reduce car usage.

- In the full MaaS adoption, multimodal and 50 % Cost we increase the usage of multimodal and public transport options.
- In the 100 % MaaS + multimodal 20 ‰ Cost this enhances the trend from the previous scenario.
- In the full MaaS + multimodal 20 % Cost (except car mode): maintaining higher costs for car mode while reducing costs for other modes further shifts trips from car usage to other modes.

4.3.1 Accessibility and user behavior

This example highlights the percentage of use of each transport mode, corresponding to the level of MaaS integration in the urban situation. In comparison to other transport modes, PT has a low percentage of use, which can be attributed to the accessibility of this type of transport and the influence of user behavior on mode choice. PT usage is higher in a multimodal situation because its accessibility increases for a larger population when integrated with walking, biking (or e-bikes). Additionally, increasing the cost of parking and reducing the cost of MaaS can lead to better PT usage.
Since accessibility depends not only on the costs of the mode but also on the urban context. It is essential to consider and enhance access in rural and suburban areas as well. The user behavior, as 4.1 shows, tends to favor car usage. This can be changed, for instance, by increasing the cost of parking spots and making MaaS more affordable for the majority of the population.

4.3.2 Considerations

After all, it is difficult to determine precisely the number of trips that include a bus route within the MaaS framework. Yet, integrating bus routes into a multimodal transportation system can significantly improve their usage. This improvement can be further enhanced by considering the current social situation. For example, making buses part of a seamless travel experience that includes walking, biking, or e-bikes can increase their attractiveness and accessibility. Plus, addressing social factors such as affordability, convenience, and the overall user experience can further encourage people to choose bus routes as part of their daily commutes.

We can also consider the benefits of incorporating DRT (e.g. minibuses). DRT offers numerous environmental benefits as these vehicles typically pick up and drop off passengers based on their specific needs. This service can also cover areas that are not well-served by regular public transportation.

4.4 Multimodal trips ratio

Multimodality in the context of MaaS refers to the integration and seamless coordination of multiple modes of transportation within a single service or platform. The term "multimodality" describes the practice of utilizing many modes of transportation throughout a single trip or duration. Promoting multimodality may be a useful way to lower CO_2 emissions, decrease the number of cars on the road, and encourage modal changes toward environmentally friendly transportation [87]. This section present the idea of *multimodal trips ratio*, which is defined as the number of multimodal trips over the total number of trips. The utilization of integrated modes, such as shared bikes, public transportation, and others, is becoming more and more relevant in the future, and MaaS may play a significant part in this. A crucial concept to understand is that multimodal trips are always counted as fewer than single-mode trips for each transportation mode. This is because multiple modes trip is recorded as a single journey, regardless of whether the user employs two or three different modes of transportation. In contrast, single-mode trips are counted individually for each trip made. In other words, a multimodal journey that involves multiple segments across different modes (e.g., walking, bus, and train) is still considered one trip. Contrarily, single-mode trips, where the user relies just on one mode of transportation, result in multiple individual trip counts. Therefore, the aggregate number of trips for each mode will inherently be higher in single-mode transportation than in multimodal travel. Examples of multimodal journal planners app and public transit app can be Google Maps, Moovit, Citymapper.

4.4.1 Benefits

By understanding how users combine different modes, MaaS providers can optimize journey planning features and improve the user interface [76].
Numerous research look at the impact that travel habits and attitudes, the built environment, and socio-demographics have within a given time period on the adoption of multimodality. Discrete choice modeling was used in other research to predict people's travel preferences

based on stated preferences (SP) in hypothetical scenarios or disclosed observations in real life. Transport operators can adjust their services to better meet the needs of users who rely on multimodal trips. The goal is to coordinate services of different modalities in order to effectively allow a smooth switch between them. In the literature this is defined under the name of "Synchromodality" [4]. The others objectives are to minimizing delays, reduce dead times, and disruptions [67].
This data may be used by legislators and city planners to assist the construction of multimodal hubs and integrated ticketing systems, two infrastructural advancements that facilitate multimodal transportation. The political objective of creating a sustainable transportation strategy as well as the general enhancement of public transportation can both benefit from the adoption of smart ticketing systems throughout Europe.

4.4.2 Integration with others KPI

Multimodal trips serve as a key performance indicator that is intricately linked with several other KPIs, including modal shift, environmental impact, and user satisfaction. An increase in multimodal trips often indicates a successful modal shift. This is due to the fact that more people are choosing to combine many means of transportation (like biking and public transportation) rather than depending only on one, like driving a vehicle. When combined, eco-friendly means of transportation such as walking, cycling, and public transportation lessen the environmental effect of single-mode automobile trips. Multimodal transportation generally incorporates these modes. By offering flexible and effective travel alternatives, the availability and integration of numerous transportation modes may improve consumer satisfaction. Satisfied users are more likely to adopt and consistently use multimodal transportation.

4.5 Average cost variation per user and per trip

Although owning a car might save time and provide a high degree of comfort, many individuals find it to be costly and unpleasant owing to the associated expenses and obligations. Taxis and rental vehicles can offer comparable comfort and flexibility with less waiting time, but they are sometimes too expensive to be a regular mode of transportation. On the contrary, public transportation like buses and trains is more affordable but requires passengers to adhere to fixed schedules, regardless of varying demand, which can be less convenient for spontaneous travel. The trade-off between adopting MaaS or maintaining vehicle ownership expenses is taken into account while making short-term daily decisions (trip selections) and longer-term decisions (car ownership and MaaS subscription choices).

4.5.1 Average Cost Variation per User

The cost variation per user depends on different factors, such as: type of transportation included in the MaaS. As Anna-Maria Feneri [29] demonstrated, the type and the amount of mobility services included in a plan are more significant factors than the actual price of specific modes included the plan. The subscription plan, for example: monthly or annual subscription plans offering discounted rates for frequent users can affect cost variation. It also depends on frequency, distance, and mode of trips taken by users. The objective is the user satisfaction. If the average cost variation per user suggest that MaaS might be too expensive for users, policymakers and service providers may provide adjustments in service offerings or pricing strategies to improve service efficiency and affordability. In the research in Ioannis Tsouros [78] revealed that, for most of the mobility services, the willing to pay (WTP) estimation was higher for bundles than for stand-alone services, which indicated a higher valuation in the MaaS bundle.

4.5.2 Observations

The cost performance has been evaluated and studied and the distribution of costs was estimated.

In Figure 4.2 the horizontal axis represents the price, with values ranging from 0.00 to 15.00. The vertical axis shows the percentage of MaaS users, with values ranging from 0% to 40%. Several data points are marked on the graph, meaning the number of Maas users for a specific price.

This diagram showing a decrease in the percentage of MaaS users as the price increases, how sensitive users are to price changes. A rapid decline in the percentage of users with increasing price suggests that users are highly price-sensitive. This means that as the price increases, fewer users are willing to pay for the service.

The data can help identify an optimal price range for maximizing user base. For example, if a significant drop in users is observed beyond a certain price point, it might be beneficial to keep prices below this threshold to hold on a larger user base. By understanding the user drop-off rate at different prices, businesses can estimate potential revenue changes. While a

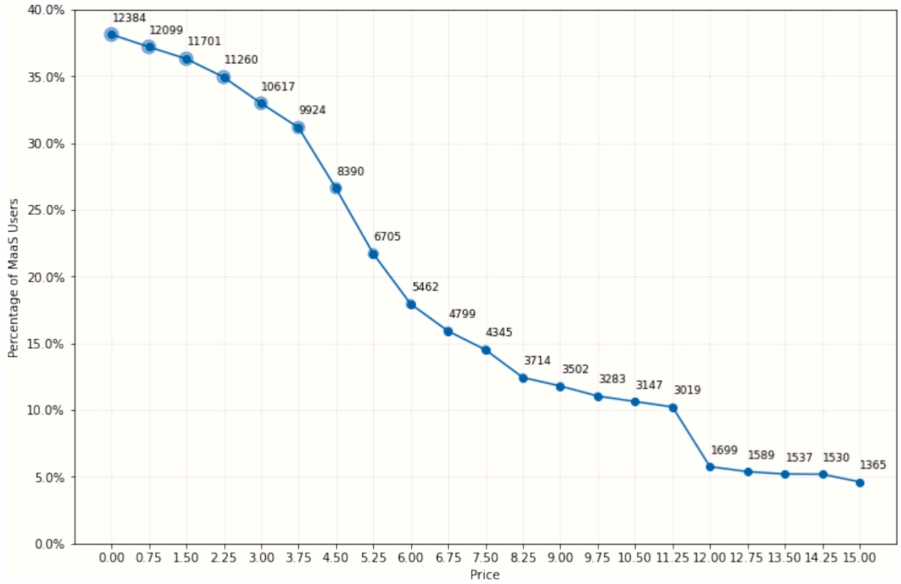

Figure 4.2: Percentage of MaaS members across MaaS Fee scenarios [81].

lower price may draw more users but result in lower revenue per user, a higher price may result in fewer users but more revenue per user.

Also, this diagram reflects the affordability of MaaS for different user segments. A large user base at lower prices suggests that many users find the service affordable only at those price points. Data can assist in market segmentation. If there are distinct drops at certain price points, it may indicate different market segments that value the service differently. This can help adapting marketing strategies for different segments.

4.5.3 Average Cost Variation per Trip

Naturally, the cost variation depends on different factors, such as the type of transportation used in the trip. For example there are differences between a public transport, or a bike and a taxi, which for sure has an higher cost-level. As for the average cost variation per user, the subscription play a fundamental role. Definitely multiple trips have their benefits.

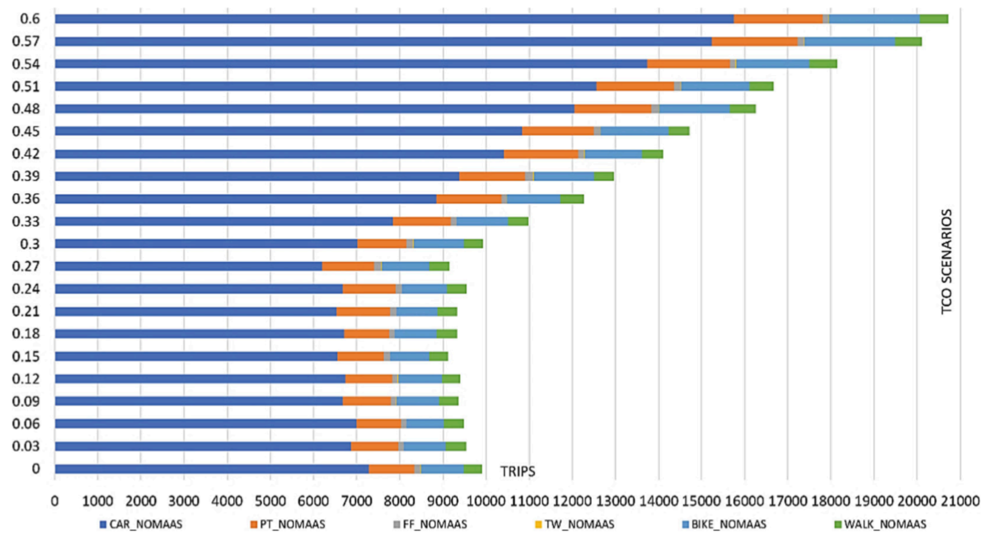

Figure 4.3: MaaS members trips distribution across TCO scenarios in No MaaS scenario [12].

Figure 4.3 represents the average usage per trip mode depending on the Total Cost of Ownership (TCO) in a No MaaS scenario. In the horizontal axis we can find the number of trips per type of mode. The vertical axis shows several TCO scenarios. Car is the dominant mode in nearly all TCO scenarios, especially in higher TCO scenarios, indicating a high reliance on cars when MaaS options are not available. Public transport is significant but less dominant compared to car transport. As the TCO decreases, there is an observable increase in the proportion of PT trips. Similar to Figure 4.4, as the TCO decreases, there is a gradual increase in the usage of other transport modes such as Fast/Flexible transport, two-wheeler transport, bike and walk.

Instead, lower TCO scenarios show a diversification in transport mode usage, with a notable increase in walking and biking, which are the most cost-effective and sustainable options. In these scenarios, car usage is predominant, leading to higher average costs per trip due to higher vehicle operating costs, maintenance, insurance, and other expenses associated with car ownership. As TCO decreases, there's a shift towards more economical transportation modes such as PT, walking, and biking. This diversification reduces the average cost per trip as these modes are generally less expensive compared to car travel.

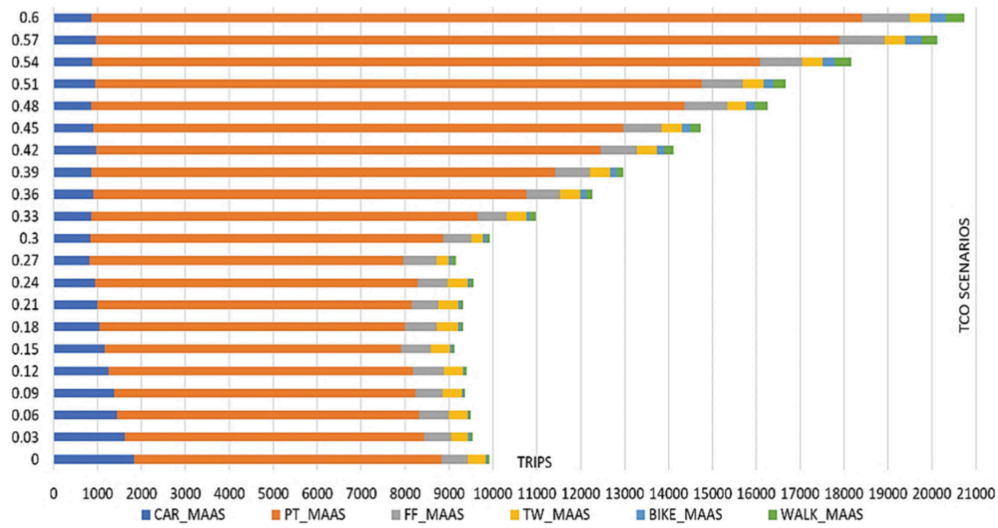

Figure 4.4: MaaS members trips distribution across TCO scenarios [12].

In the Figure 4.4 each bar indicates the total number of trips for a particular TCO scenario, each segment represents the proportion of trips made using each MaaS option. In most TCO scenarios PT constitutes the largest portion of trips, indicating that public transport is a widely used option across different cost scenarios. As the cost per trip decreases, the presence of other MaaS options increases. This indicates a shift towards more affordable and possibly more sustainable modes of transport in lower TCO scenarios. The trend suggests that as TCO decreases, travelers tend to prefer more economical and environmentally friendly modes of transport. Better accessibility, lower environmental impact, or economic savings might be the cause of this.

4.5.4 Comparison

A larger percentage of journeys are performed by PT, and the distribution of trips across modes is more evenly distributed in Figure 4.4. MaaS seems to encourage the use of diversified and often more sustainable transport modes, potentially lowering the average cost per trip compared to the No MaaS scenarios. Also, without MaaS, there is a heavier reliance on car usage, particularly in higher TCO scenarios, leading to higher average costs per trip.

4.6 Average MaaS revenue odds

Traditional transport services operate independently, often without integration or optimization across different modes. This can lead to fragmented services, inefficiencies and higher costs for users. Without MaaS, transport operators do not have a central platform to optimize demand and supply. This can lead to overcrowding on certain services while others operate below capacity. Passengers also do not benefit from real-time information on transport options, which can guide to optimal travel choices and increased no satisfaction during disruptions or peak times.

Without a MaaS provider acting as an aggregator, individual transport operators may struggle to reach a broader audience. This limits their ability to expand their market share and attract new customers who might prefer a more integrated travel solution. Traditional systems may not provide effectively to different social groups with varied financial capabilities, as they lack the flexibility and inclusivity that a MaaS platform can provide through tailored services and payment options. With No MaaS provider's ability to shift demand and optimize capacity, transport operators might miss out on potential revenue opportunities. Peak times may lead to lost revenue due to overcapacity, while off-peak times might see underutilized services. Thus, the inability to manage demand dynamically can lead to dissatisfaction among passengers who face overcrowded services or long waits, potentially driving them away from public transport options. In a No MaaS system, there is less incentive for transport operators to improve their services. The absence of a competitive, integrated platform means that operators do not have to continuously innovate and enhance the quality of their offerings to attract and retain customers. Without the drive for competition fostered by a MaaS ecosystem, the overall quality and efficiency of mobility services may remain stagnant, not keeping pace with evolving customer expectations and technological advancements. Traditional transport systems might still rely on outdated ticketing methods, lacking the convenience of account-based ticketing and smartphone-readable solutions that MaaS platforms can provide. The absence of modern sensor-based services and smart data usage means that traditional systems are less capable of providing seamless, user-friendly experiences that adapt to real-time conditions and user needs.

In this segment we shall define the meaning defined as the ratio between the average revenues for transport operators for MaaS services and the average revenues for transport operators for no MaaS services. Transport operators are key suppliers to the MaaS provider, holding a central role within the centre business ecosystem. They sell their services to MaaS operators and provide openness and access to their data through secure APIs (Application Programming Interfaces). To fully permit the MaaS concept by offering the necessary data, transport operators should ideally provide their services with sensors and apply account-based ticketing systems that accept smartphone readings.

The MaaS provider generates value for transport operators in multiple ways. In the first place, transport operators, through the MaaS provider, can reach a wider demand and expand their market share. Moreover, the MaaS operator can optimize the request and supply by having real-time insights into the demand and capacity of transport operators. This is particularly beneficial during peak hours when some transport operators are at full capacity. The MaaS provider can thus shift demand to other transport operators, thereby preventing passenger dissatisfaction. As a result, transport operators can grow their revenue by reaching previously inaccessible customer markets and enhance customer satisfaction. This can also be done taking in consideration different social groups and so different possibility to pay. As well, the MaaS provider fosters competition among participating transport operators, leading to improved mobility services.

4.6.1 Considerations

The diagram in Figure 4.5 displays a comparison of total revenue and earnings from public transportation in Berlin over the period from 2005 to 2020. The x-axis represents time, while the y-axis represents monthly revenue/earnings in euros (€). The black line represents the revenue, and the red line represents the earnings. Revenue and earnings closely follow each other, indicating a strong correlation between the two metrics. However, the earnings exhibit more pronounced seasonal peaks compared to revenue.

To analyze the impact of the introduction of MaaS, we would need to know the specific year or period when MaaS was introduced in Berlin. Assuming MaaS was introduced around 2015, we can observe the trends before and after this period. Before MaaS (2005-2015) both revenue and earnings show steady growth with seasonal variations. The growth rate is relatively consistent. After MaaS (2015-2020): post-2015, the growth in both revenue and earnings appears to accelerate. The seasonal peaks in earnings become more pronounced, and the overall climbing trend is sharper.

Before the introduction of MaaS, the revenue and earnings growth was steady, and seasonal variations were present but relatively moderate. After MaaS introduction, there is a

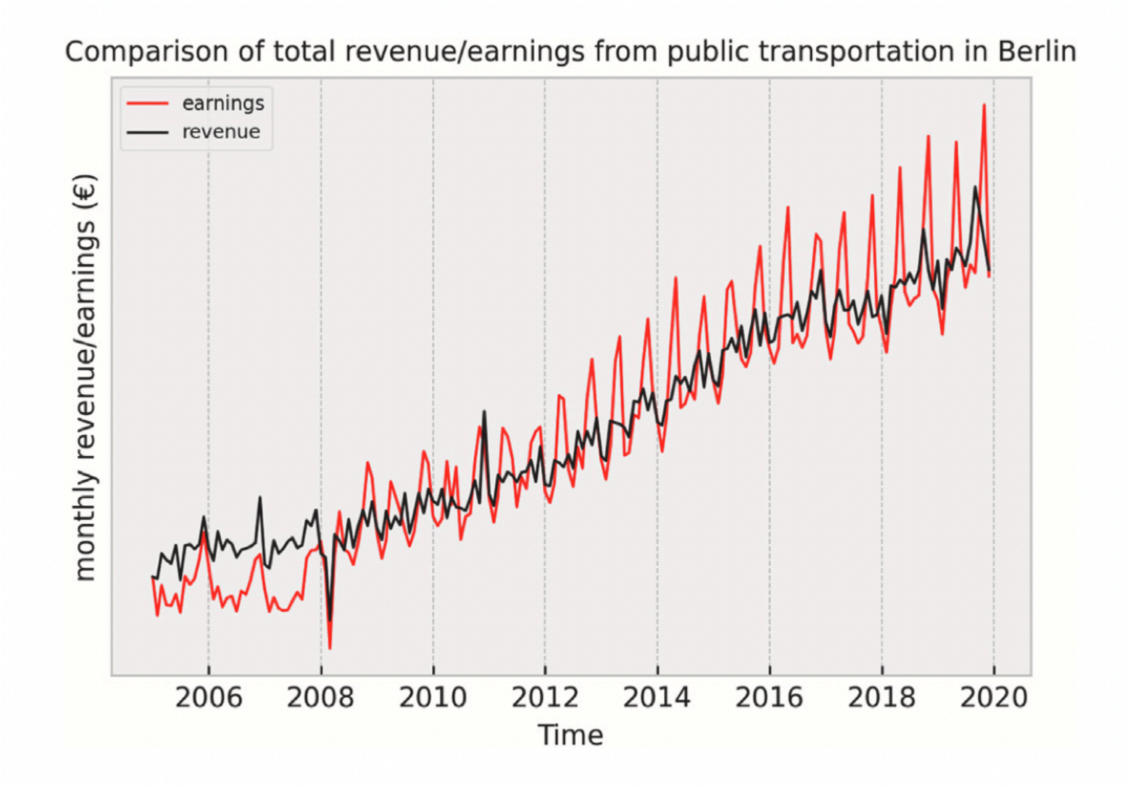

Figure 4.5: Comparison of the time series of the total revenue and earnings for public transportation in Berlin [84].

noticeable increase in the amplitude of seasonal variations, especially in earnings. This could indicate that MaaS has led to higher demand during peak times, resulting in more significant fluctuations.

4.7 Co2 emissions before and after the introduction of MaaS

In figure 4.5, the period following the potential introduction of MaaS in Berlin, around 2015, exhibits increased seasonal fluctuations in earnings. This pattern might indicate a corresponding rise in transport demand and usage, particularly during certain times of the year or specific events. In keeping with environmental objectives like those described in the Net Zero Emissions by 2050 Scenario, this increasing demand may have a beneficial effect on CO_2 emissions if it represents a shift towards increased usage of public transportation.
The overall trend in profits and revenue over the last 15 years indicates a consistent upward

tendency, which supports the growing popularity and financial success of Berlin's public transportation system. The notable seasonal variation that was seen, along with sporadic peaks, may have resulted from variations in the demand for public transportation, which may have been caused by seasonal events, tourists, or shifts in commuting habits.
These trends imply that the MaaS initiative might have played a role in boosting public transport usage, especially during peak periods. As PT generally results in lower CO_2 emissions per passenger compared to private cars, this shift could contribute to a reduction in overall transport-related emissions, supporting broader climate goals. This is especially crucial since, between 1990 and 2022, the average annual rate of increase in transport emissions was 1.7%, outpacing the growth of emissions from all other end-use sectors except industry. In light of this trend, it will be necessary to reduce CO_2 emissions from the transportation sector by more than 3% yearly through 2030 in order to achieve the Net Zero Emissions by 2050 Scenario.
Specifically, road transportation is a major factor in this problem. With 24% of Europe's total CO_2 emissions in 2020, it is the main transportation sector contributor to climate change. These emissions are commonly expressed in grams of CO_2 per passenger kilometer and account for a sizeable amount of the world's greenhouse gas emissions. This metric reflects the efficiency and environmental impact of various transport modes, emphasizing the need for more sustainable alternatives. Studies like Carroll's [10] show that switching from private to shared transportation may result in major drops in CO_2, NO_x, and $PM_{2.5}$ emissions. This change emphasizes how crucial MaaS initiatives are to encouraging more environmentally friendly transportation practices and lowering the transportation sector's carbon footprint.

4.7.1 Impact of different Road Transport

The average carbon dioxide emissions related to different forms of transportation are shown in Figure 4.6. According to the research, conventional gasoline and diesel vehicles have the most carbon emissions out of all the modes listed; thus, they are the most ecologically friendly choice. In contrast, modes such as walking, biking, light rail, e-bikes, e-scooters, and e-buses exhibit significantly lower carbon emissions. This highlights the minimal environmental impact of electric and non-motorized transport options, emphasizing their advantages in reducing overall carbon footprints. However, motorbikes, scooters, trains, and buses show relatively high environmental impacts compared to electric modes. While trains and buses are generally more efficient than cars in terms of emissions per passenger, they still contribute

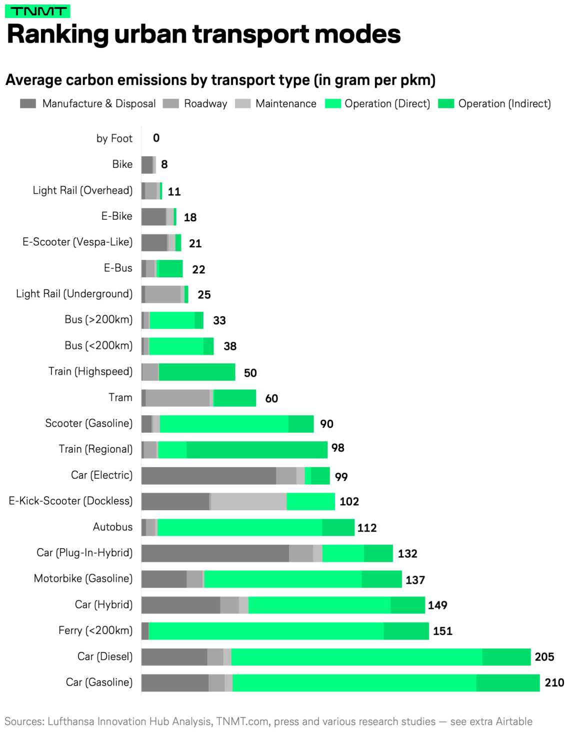

Figure 4.6: Average carbon emissions by transport type [77].

more to CO2 emissions than the least impactful transport modes, such as walking and cycling.

From 1990 to 2020, the greenhouse gas emissions of several transport services are shown in Figure 4.7. Throughout the whole time, there is a clear pattern of rising emissions. One noteworthy finding is that the bulk of these emissions are constantly attributed to vehicle transportation. Nonetheless, 2020 sees a significant drop in emissions, mostly as a result of the COVID-19 pandemic's reduction in transportation-related activities.
These emissions have a significant negative impact on the environment, which emphasizes the urgent need for new policies to meet our climate targets. The use and optimization of MaaS is a crucial tactic in this transition. Although MaaS's effect on emissions is not yet entirely apparent, there are a lot of potential advantages.
By minimizing the number of cars on the road, which lowers total greenhouse gas emissions, maximizing the implementation of MaaS may have a major positive impact on the environment. Furthermore, by lowering air pollution and encouraging active transportation choices like bicycling and walking, MaaS can enhance public health. Furthermore, MaaS may promote a culture that values and gives priority to environmental health by raising society

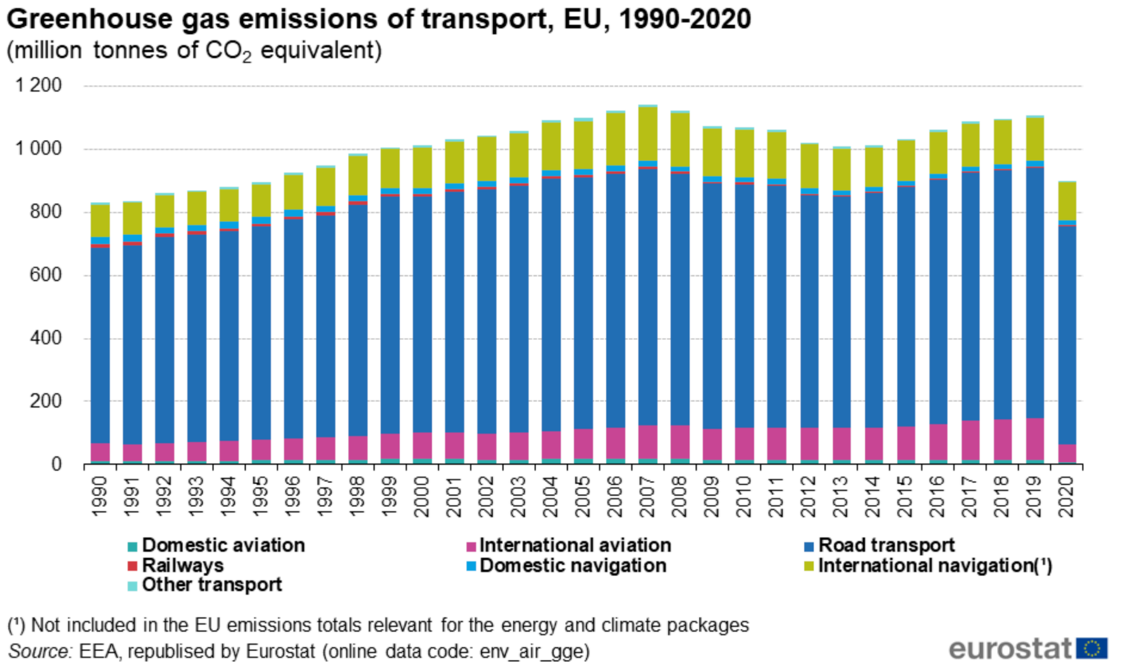

Figure 4.7: Greenhouse gas emissions of transport, UE, 1990-2020 [28].

knowledge of and sensitivity to sustainable mobility behaviors.

4.7.2 Implications on other KPIs

MaaS can encourage consumers to switch from more polluting modes (like private automobiles) to more environmentally friendly ones (like public transportation and shared mobility). Specifically, a decrease in carbon dioxide emissions after MaaS deployment suggests favorable environmental effects, bolstering efforts to mitigate climate change. This is in line with regional governmental efforts to lower carbon footprints and international environmental goals. Changes in modal share may be analyzed to provide insights about user preferences. For instance, MaaS shows successful service integration and effective behavioral nudges if it dramatically boosts the use of public transportation while decreasing the number of trips taken in private vehicles. MaaS systems' operational effectiveness can result in increased occupancy rates for shared mobility and public transportation, which further lowers emissions. This illustrates how integrating technology may maximize the use of available resources. The case for legislative measures promoting the growth of MaaS can be strengthened by demonstrating substantial drops in CO_2 emissions. It can also draw expenditures meant to improve the infrastructure of public transportation and increase available mobility alternatives. Adoption of MaaS has the ability to change the trends in urban transportation, which might result in less traffic and better air quality. Cities may promote sustainable transportation options and aim toward being carbon neutral.

4.8 Efficiency

Enhancing the travel experience by enhancing the smoothness, convenience, and sustainability of transportation is one of MaaS's main objectives. At the heart of this objective lies the chasing of efficiency. This is an essential measure of how well the transportation system performs in delivering reliable and timely services to users.

Efficiency in MaaS encompasses multiple dimensions, all aimed at enhancing the total effectiveness of transportation solutions. Efficiency, according to E. S. Savas in 2015 [73], is a crucial performance indicator that shows how effectively a system satisfies user demands and expectations. Efficiency in the context of MaaS includes not just cutting travel times but also enhancing customer pleasure, timeliness, and service reliability.

One of the central metrics for assessing service efficiency is the average trip time. This metric gauges the typical duration of travel between a source and a destination. To measure this, route-based methods are employed, which involve determining a specific travel route and then aggregating the time required for each segment based on historical data. Although, measuring average trip time presents challenges, primarily related to the reliability of travel times. The likelihood that a trip will be finished within the projected time range, including for variations brought on by weather, traffic, and other circumstances, is known as travel-time reliability. Shortening the average trip duration lessens the impact on the environment and traffic jams associated with each trip. In addition to making driving less frustrating, improved traffic flow increases safety by lowering the likelihood of accidents. Additionally, fewer traffic bottlenecks improve public transportation systems by increasing commuter attraction and reliability for buses and trams.

Public transportation punctuality has a direct influence on customer happiness and faith in the system, making it a crucial system efficiency indicator. For public transportation to function as efficiently as possible and to increase user happiness, it must run on time. A poor user experience might result from cascading problems like lost connections and crowds caused by delays. Therefore, monitoring and improving On-time Performance (OTP) is essential. OTP is a commonly recognized metric for assessing the punctuality of various

modes of public transportation. It offers a standardized way to evaluate and compare how effectively different service providers adhere to their published schedules.
OTP is measured in two main ways:

- Timely departures: the percentage of trips that start within the designated pickup window provided to the rider when they booked their trip.

- Timely arrivals: the percentage of trips that are completed before or by the rider's requested drop-off time.

Trips that are marked as "missed trip" might result in fines for operators and cause schedule disruptions for passengers. A crucial component of transportation is reliability, which shows how effectively a service keeps to its scheduled timetable. This entails leaving on time, or making timely departures, and arriving at destinations on time, or making timely arrivals. When a service is reliable, riders can depend on it to follow the timetable consistently. OTP deals with headway consistency, which is the ability to maintain regular intervals between vehicles. For instance, if buses on a particular route are supposed to arrive every 10 minutes, reliability ensures that the time between buses remains consistent, without significant gaps. The travel time between the origin and destination has to remain predictable. Riders should be able to expect similar travel duration for the same trip at different times, barring unusual circumstances.
Several indices are used to assess punctuality and reliability in public transportation systems:
• Route-based Punctuality Index (PIR): this measures the chance of a bus arriving at its terminals within a specified time frame.
• Stop-based Deviation Index (DIS): this assesses the ability to maintain consistent headways and reduce average passenger wait times at stops.
• Stop-based Evenness Index (EIS): this measures the uniformity and consistency of headways between vehicles.
These metrics provide valuable insights into the performance of public transit systems, helping to identify areas for improvement and ensure more reliable and punctual services [85].
<u>Example: punctuality index</u>
P_I is an index indicating the magnitude of the time gap between actual arrival time and scheduled arrival time [56].

$$P_I = \frac{S_I^2}{h_t^2} \tag{4.1}$$

$$S_I^2 = \frac{1}{I}\sum_{i=1}^{I}(t_i - \tau_i)^2$$

where:

h_t : Scheduled headways

I : Number of operations

t_i : Actual arrival time of i-th bus

τ_i Scheduled arrival time of i-th bus

S_I : Standard deviation

P_I : Punctuality index

The Punctuality Index in (4.1) is calculated by dividing the variance of arrival times S_I^2 by the square of the scheduled headway h_t^2. Normalized by the scheduled headways, this index measures the degree of disarray between the actual arrival timings and the scheduled times. Higher P_I indicates greater variability in arrival times, suggesting less punctual service. Lower P_I indicates lower variability, suggesting more punctual service. The variance S_I^2 formula computes the squared difference average between the scheduled and actual arrival times. This provides an indication of the degree to which the scheduled arrival timings and actual arrival times differ.

4.8.1 Benefits

Service punctuality and dependability increase customer satisfaction. Users are more likely to think favorably of a service when visits are shorter and prompt service is provided. Users will have more spare time when journey times are reduced. Because users may spend more time on personal or professional pursuits and less time commuting, this can enhance overall quality of life. Reliable and dependable transportation can also lessen the stress that comes with commuting. Delays and ambiguity are less likely to cause users to get frustrated. Reduced travel times may result in a more economical use of resources. Cars have more capacity and can do more journeys in the same amount of time, which lowers operating expenses. Higher usage rates might result from more consumers being drawn to services that are more dependable and efficient. This may increase profitability and provide justification for more service and infrastructure spending. The MaaS provider's reputation is enhanced by timely and effective services. Positive customer feedback and word-of-mouth can spur expansion and boost market share. Reduced fuel usage and wear and tear on vehicles can result in cheaper operating and maintenance expenses when routing and scheduling are done effectively. Providers may improve scheduling, fleet management, and resource allocation, which will result in more efficient service delivery, by using accurate data on trip times and punctuality. In conclusion, well-managed and punctual services may better spread travel demand, and efficient journey times can help alleviate traffic congestion. Reduced emissions and fuel consumption may be achieved by taking shorter and more efficient routes, which can support environmental sustainability. Enhancing timeliness and efficiency can also improve the network's overall connection, which will facilitate users' transitions between different forms of transportation.

4.9 Operational Cost-Effectiveness

Operational cost-effectiveness is a fundamental point for MaaS, reflecting the system's capability to deliver transportation services in an efficient manner while keeping costs low and maintaining or improving service quality. This concept involves a multi-faceted approach that integrates resource optimization, technology utilization, and strategic pricing, all while ensuring high standards of service.

Resource optimization is fundamental to achieving cost-effectiveness in MaaS. Effective management of vehicles and team is crucial for reducing operational costs. This not only cuts costs but also improves service reliability. Drivers and support staff are planned according to actual service demand when labor expenses are in line with effective people management. Furthermore, combining different forms of transportation, like bikes, cars, buses, trains, and car-sharing services, into a single MaaS platform improves system performance overall and offers passengers multimodal trips that are reasonably priced.

Technology use is essential to improving operational cost-effectiveness. Implementing advanced technologies like GPS tracking, data analytics, and artificial intelligence enables better route planning and operational optimization. According to research on AI's application in transportation modeling and planning, real-time traffic light management, route and parking modification, and other tasks can be handled by AI. For MaaS systems, there are two types of data that must be gathered and combined:

- Historical (conventional) data: survey data, GIS data, schedules.
- Dynamic data (big data): includes information from social media, GPS, mobile phones, public transportation cards, and built-in sensors in roads and traffic signals.

These technologies help in reducing operational costs by improving efficiency and user experience. Additionally, employing dynamic pricing strategies can balance demand and supply, thereby maintaining profitability while adapting to real-time data and demand fluctuations.
Pricing strategy is another critical component of cost-effectiveness. The optimal fare for public transport should be set by balancing the net marginal social cost (MSC) and the marginal personal cost (MPC). The MSC includes factors such as crowding discomfort and delays, while the MPC covers access costs, waiting time, and in-vehicle travel time. Pricing strategies must account for outside influences as well, such as the benefits of responsive capacity management, which can lead to reduced waiting times and operational cost savings. Conversely, factors like crowding and delays impose negative externalities that need to be addressed in fare calculations.

4.9.1 Considerations

Integrating these elements with other KPIs is essential for maintaining the service quality. High standards of service, including punctuality, safety, and customer support, are crucial for user satisfaction. Balancing cost efficiency with these service standards ensures that efforts to reduce costs do not adversely affect the user experience. Furthermore, manipulating detailed data from user travel preferences and profiles can lead to personalized services and competitive pricing, enhancing both service quality and operational efficiency.
Finally, incorporating environmentally friendly practices into MaaS operations can further contribute to cost-effectiveness. For example, adopting electric vehicles or promoting shared mobility reduces the environmental impact and potentially lowers costs related to emissions and fuel.

4.10 Accessibility and availability

In the context of MaaS, accessibility and availability are fundamental to ensuring that users can effectively utilize transportation options. These concepts are crucial for delivering equitable and efficient transit services, impacting how users interact with and benefit from the MaaS system. This KPI differ from the KVI Social Inclusion because it focuses on how well the service promotes inclusivity, accessibility, and equity for all members of society, particularly those who might be marginalized or deprived. This perspective is more concerned with ensuring that everyone, regardless of their social or economic status, has equal opportunities to benefit from the service.

4.10.1 Service Coverage Area

This is a key element of accessibility in MaaS. It defines the geographical region where MaaS services are provided and significantly influences how easily users can access transportation options. The extent of service coverage can vary widely:

- partial coverage: this occurs when MaaS services are available only in specific areas, such as a city center or particular rural zones. While partial coverage can meet the needs of some users, it may leave gaps in accessibility for those in less serviced areas.
- full coverage: full coverage implies that MaaS services are accessible across an entire city, region, or even country. Such extensive coverage enhances social equity by providing broader access to essential services, including employment and education.

<u>Different urban situations:</u>

1. In urban environments, MaaS aims to reduce the ownership and use of private cars, which will alleviate traffic, cut emissions, reduce parking issues, and improve urban planning. MaaS services in urban areas usually make use of the current public transit networks, complemented by car-, bike-, and parking facilities.
2. In suburban regions, MaaS seeks to diminish the necessity for a second car and to boost car capacity utilization. Characteristic services in these areas include on-demand options, park and ride, shared services, and first- and last-mile solutions integrated with urban MaaS systems.
3. In rural areas, where populations are sparse and multiple car ownership is common due to long distances, the focus of MaaS is on enhancing overall efficiency and utilization rates. The goal is to maintain adequate service levels despite the low number of travelers and to ensure necessary accessibility. Services in rural areas prioritize on-demand options, taxis, buses, sharing services, and first- and last-mile connections to long-distance transportation [1].

The service frequency and hours of operation further affect service availability. Service frequency refers to how often a transit service is available within an hour, considering the walking distance from stops and user preferences. Additionally, hours of operation measure the total time during the day when transit services are active along a route or segment. Comprehensive service coverage ensures that transit services are provided throughout the day and within reasonable walking distance, enhancing overall accessibility.

4.10.2 Real-Time Information

Availability of real-time information (RTI) is another crucial aspect that affects the effectiveness of MaaS. RTI systems enable users to make informed decisions by providing current data about transportation services. This includes information such as vehicle locations, upcoming stops, expected arrival times, and occupancy rates. RTI systems often utilize technologies like Automatic Vehicle Location (AVL) and GPS to deliver accurate updates through various platforms, including smartphone apps and digital displays [11]. [5] Real-time information changes customers' opinions about how reliable the service is and makes travel planning easier. When and when passengers choose to travel, accurate and timely information encourages them to choose public transportation instead of driving their own automobiles. Additionally, it satisfies the requirements of various socioeconomic and demographic groups by offering particular information that closes coverage gaps. Understanding users' perceptions of RTI across various socioeconomic and demographic backgrounds is essential for improving MaaS services. Variations in how different groups perceive and use information technologies can highlight areas where service improvements are needed, particularly in regions with insufficient public transport coverage.

4.11 KPIs in the MOST context

The MOST (Centro Nazionale per la Mobilità Sostenibile) is a research organization whose mission is to promote and assist the creation of revolutionary, sustainable, and inclusive solutions for the entire nation through partnerships with 24 universities, the Italian National Research Center, and 24 significant corporations. It covers a wide range of topics and sectors, including rail, maritime transportation, air mobility, light vehicles and active mobility, and novel fuels. The MOST seeks to reduce accidents through digital systems, create a more inclusive and accessible mobility model, and employ more efficient public transportation and logistics strategies. It also hopes to make the mobility system "greener" globally and more "digital" in its management. According to the MOST, an effective MaaS system must address

[5] AVL systems allow companies to track and manage their vehicle fleets in real-time. Originally designed for fleet management and vehicle tracking, AVL software often integrates with GIS to provide detailed location data. Although AVL systems are based on GIS, they commonly use Short Message Service (SMS) technology for communication. This means that while the underlying system is sophisticated and GIS-based, the actual transmission of data between vehicles and the central management system often relies on simple text messaging technology for updates and coordination.

a number of important factors that together dictate how well the system functions, satisfies user demands, and benefits the community. These domains encompass a variety of MaaS ecosystem elements, including technology, community benefits, economic viability, organizational effectiveness, user experience, and the wider system operating environment. We may link certain KPIs to each of these dimensions, and they should be observed in order to evaluate a MaaS system's performance.

4.11.1 Technical Dimension

The technical dimension evaluates a MaaS system's technological features, such as data management, third-party service integration, platform scalability, and general design. It considers the system's capacity to facilitate secure, effective, and seamless service delivery. To guarantee a MaaS system's efficacy and user happiness, a number of crucial factors need to be taken into account while defining it technically. The following are some crucial elements that the MOST has determined:

- Data management: refers to the system's capacity to manage, store, and safeguard operational and user data. It also includes privacy/security safeguards and real-time data exchange.
- Service integration: how well different modes of transportation and outside services are integrated inside the MaaS system (e.g., public transportation, bike sharing, ride-hailing).
- Availability and application of standardized APIs: to facilitate smooth data transfer and communication with other platforms or service providers is known as API compatibility.
- Scalability: the system's capacity to accommodate growing user, service, and data volumes without experiencing a drop in performance.
- Platform design (UX): refers to the total usefulness and quality of the system's user interface, including functionality and simplicity of navigation.
- Real-Time Information: the delivery of precise and current data on service availability, traffic patterns, and itinerary preparation.
- Software update and maintenance: the regularity and dependability of software updates and maintenance procedures, which guarantee ongoing enhancements and bug patches.

- Geographic coverage: how much of each region is covered by the MaaS system (e.g., citywide, regional, national).

In order to implement the technical efficacy of a Maas, the MOST determined several KPIs, some of which are as follows: the percentage of mobility services that share real-time data; compliance with data protection regulations; the presence of data analytics capabilities; the presence of standardized data formats across services; the number of fully integrated third-party services; the average user rating of the app in app stores; the number of regions or cities that the service covers; the numbers of available payment methods; and the percentage of system uptime.

4.11.2 Organizational Dimension

The governance frameworks and organizational structures used in MaaS projects are the main topics of the organizational dimension. It looks at how well partnerships work together, how clearly roles and duties are defined, and how well cooperation works while providing effective services.

A MaaS system's organizational dimension is examined to reveal numerous important factors that govern the system's functionality and evolution.

- Governance structure: the framework that outlines the obligations of both public and private parties as well as the general procedure for making decisions.
- Partnerships and collaboration: the quantity and kind of partnerships, as well as the efficacy of collaboration, with third-party service providers, municipal governments, and mobility suppliers.
- Management structure: the MaaS system's internal organizational structure and the way various departments and stakeholders collaborate with one another.
- Innovation and adaptability: the capacity of the company to develop new ideas and adjust to rules, laws, and consumer expectations.

To execute the organizational aspect of a Maas, the MOST identified many KPIs, some of which are listed in the following: the stakeholders' diversity index; total number of current collaborations with technology companies, mobility providers, and other pertinent parties; percentage of partners (based on surveys) who say they are happy with the partnership; number of collaborative efforts or projects started with partners; percentage growth in the organization's service offerings or service regions.

4.11.3 Economic and Financial Dimension

The MaaS system's business model and the initiative's commercial and financial sustainability are the main topics of the economic and financial dimension.
A number of crucial elements need to be taken into account in order to fully comprehend the feasibility and sustainability of a MaaS system while examining its financial and economic elements.

- Value proposition: the service's increased value in relation to competitors.
- Revenue streams: the many revenue streams for the MaaS system, including advertising, pay-per-use charges, partnerships, subscriptions, and government financing.
- Pricing strategy: the method of setting prices, including pay-as-you-go, subscription pricing, bundling services, and demand-driven pricing.
- Funding: the sources and arrangements of financial support, such as grants from the government, private investments, and public-private partnerships (PPP).
- Investments: the sum allocated to both technology advancements (such as platform updates and data analytics) and physical infrastructure (such as stations and cars).

KPIs must be tracked in order to evaluate the financial viability of MaaS solution. The pertinent KPIs identified by the MOST and their importance are listed as follows: diversity of revenue streams; average cost per user; Earnings Before Interest, Taxes, Depreciation, and Amortization (EBITDA) and Earnings Before Interest and Taxes (EBIT); Return on Investment (ROI), Return on Assets (ROA), Return on Equity (ROE); customer lifetime value; Capital Expenditures (CapEx); market share.

4.11.4 User Dimension

The user dimension focuses on the MaaS system's end users. The system's ability to comprehend and fulfill users' wants and preferences, impact their travel behavior, and deliver a flawless travel experience is evaluated.
A few fundamental components should be taken into account in order to explain how MaaS system communicates with and fulfills the needs of its users:

- Customer segments: the suppliers' intended market customer.

- Satisfaction and feedback: how well customer input is gathered and used to enhance services and guarantee that user needs are consistently satisfied.
- User happiness: the general level of user happiness with the MaaS system, sometimes ascertained by app ratings or surveys.
- User retention and loyalty: long-term user loyalty is indicated by the percentage of users that stick with the MaaS system over time.
- User preferences and personalization: how much the MaaS system customizes travel options based on user behavior, preferences, and past usage patterns.
- User trust and data privacy: how much users trust the system to protect their money and personal information.
- User involvement in development: the part users play in the system's ongoing progress, as demonstrated by community involvement initiatives, feedback loops, and beta testing.
- User travel habits: how much the MaaS service affects and modifies users' travel habits, such as switching from driving a private vehicle to using public transportation or shared mobility choices.

The MOST suggests that the following KPIs be taken into account in order to efficiently monitor a MaaS system's user dimension: variability in user groups; monthly count of newly registered users; average user happiness based on reviews in the app store or surveys; percentage of consumers that stay on the service for more than one month; percentage of new users that sign up for the service as a result of recommendations from current users; average time to book a reservation from beginning to end; percentage of active users that use the platform often; how many people switch to premium or paid services.

4.11.5 Community Dimension

The community dimension takes into account the MaaS system's wider implications on the community, specifically with regard to its consequences on the environment, society, and economy. It measures the system's contributions to lowering environmental effect, advancing social justice, and bolstering regional economic growth.
A MaaS system's community dimension should be monitored using a number of KPIs, all of which should be taken into account. These KPIs aid in evaluating how the system affects the neighborhood and how it advances more general social and environmental objectives:

reduction of carbon emissions from transportation-related activities as a result of the MaaS system's implementation; reduction in the quantity of single-occupancy vehicle journeys; an increase in Air Quality Index (AQI) ratings; total amount spent on MaaS system-related municipal infrastructure development and transportation; percentage reduction in the amount of traffic congestion in MaaS-served locations; measurement of the distribution of MaaS services' equity among various demographic groupings.

4.11.6 Context Dimension

The local and regional factors that might have an impact on the acceptance and deployment of MaaS systems are considered in the context dimension. Urban development, regulatory frameworks, cultural aspects, policy frameworks, and transportation infrastructure are all included in this.
In order to conduct a thorough analysis of the contextual dimension of MaaS system, it is necessary to take into account a multitude of factors that influence the system's deployment and operating surroundings.

- Legal and regulatory environment: the set of rules, laws, and guidelines that control how the MaaS system is put into place and run.
- Cultural and social context: the population's cultural norms, attitudes, and behaviors that might have an impact on the MaaS system's acceptance and use.
- Existing transport infrastructure: how well the MaaS system connects with or complements the existing transportation infrastructure, such as roads, public transit, and bike lanes, as well as its availability and quality.
- Technological infrastructure: the condition of the digital infrastructure that underpins the MaaS platform's operation, such as the availability of real-time data systems, smartphone diffusion, and internet coverage.
- Economic conditions: the region's economic background, encompassing employment rates, income distribution, and the general affordability of MaaS services for consumers.

In order to determine the MaaS system's efficacy in the contextual dimension, it is recommended that numerous KPIs be monitored. The MOST selected ones are: observance of regulations; the quantity and worth of government incentives offered to promote the service; the proportion of the intended audience that has embraced the MaaS system; number of public awareness efforts aimed at promoting MaaS advantages; the extent of MaaS integration with current public transit systems; amount spent on enhancing or growing the infrastructure needed to enable MaaS; corporate sustainability reporting directive integration.

5
Key Value Indicators

Key Value Indicators (KVIs) provide a framework for involving stakeholders and innovators in a collaborative process to identify shared values and defined objectives for societal benefits. They help turn these targets into specific design and development needs and assess both the targets and the innovation based on societal values. The ultimate goal is to encourage the widespread adoption of the solutions that result from this process.

"KVIs: quantitative or qualitative indicators for gauging effects on values as outcomes. The purpose of KVIs is to gauge the impact from the execution of a use case in terms of economic, social and/or ecological benefits (gain) or detriments (loss). KVIs are here defined as metrics, either on a qualitative scale (good-bad, etc.), or when possible on a quantitative scale (high- low, etc.)" [1]

KVIs differ from KPIs in that they provide greater understanding into human-related factors and can require conversations and creativity to emerge [69].

In this thesis we shall focus on six KVIs: social inclusion, user experience, community impact, behavioral change, innovative solutions, and flexibility. These indicators have been chosen for their relevance in capturing the diverse dimensions of value that innovations can offer.

[1] p.8 in [59]

5.1 Social Inclusion

First of all, MaaS greatly influences transportation services by combining different mobility options and experiences, supplying to a variety of social groups. Providing equitable access to social and economic opportunities is one of the primary objective of the transportation system. It is critical to comprehend who gains from transportation services and if the expenses and benefits are distributed fairly across various demographic groups. However, the adoption of MaaS can escalate transport disadvantages and digital inequalities if different social groups are unwilling or unable to utilize these services.
Nima Dadashzadeh's [16] research nominated the MaaS Inclusion Index (MaaSINI), designed to evaluate inclusion inside MaaS services. This index focuses on the needs of vulnerable social groups (VSGs) at a service level rather than a city or area level. The MaaSINI harmonize with the United Nations Sustainable Development goal 11, which emphasize the importance of inclusive, safe, resilient, and sustainable transportation systems. Ensuring public transportation accessibility is crucial to achieving this goal.
VSGs are identified as:

1. Elderly people (ELD): individuals who are 65 years old and above, including people of all genders and income ranges.
2. Persons with disabilities (PwDs): individuals of any age, gender, and income level with disabilities.
3. Low-income people (LIP): individuals who have a low income, regardless of their age, disability status, or gender.

These groups have unique travel behaviors and have particular transportation requirements. Meeting these needs is crucial for promoting fairness in transportation and reaching inclusive mobility solutions through MaaS.
According to Lucas K. [23], accessibility can be evaluated using either a location-based approach, which targets on geographical distances between places, or a person-centered approach that takes in consideration individual characteristics, resources, capabilities, and time constraints.
Individuals who have a driving license and no physical or cognitive disabilities can be offered mobility plans that include both car-sharing and public transportation options. Contrarily, for those without a driving license, mobility plans should focus on alternative solutions and

exclude car-sharing options. For persons with disabilities who face physical or cognitive challenges that prevent them from using PT, the plans should exclude public transportation, particularly where it is not accessible. Besides, while some MaaS providers have introduced discounted packages, such as those for students, it is also crucial to consider low-income individuals. These individuals often rely on affordable transportation options like PT, and for this reason, their needs should be taken into account during the design of mobility packages.

The integration of factors such as possession of a driving license, physical or cognitive abilities, and income levels significantly influences users' intentions to subscribe to MaaS services [10].

Kamargianni and Matyas [57] present the following findings: there is considerable variety in users' attitudes towards MaaS plans based on their socio-demographic characteristics and travel habits. Less expensive plans that include public transportation and bike-sharing options tend to attract students, retired individuals, and middle-income people who are more price-sensitive. In contrast, more expensive plans that also include taxi and car-sharing options are more appealing to high-income individuals.

The least likely demographics to sign up for MaaS programs include those who are old, have limited incomes, or solely utilize one mode of transportation. Nonetheless, younger individuals are more likely to subscribe, particularly those in their 20s and 30s.

VSGs encounter distinct challenges and have specific needs when using transportation services and mostly using technologies. To effectively address these challenges, several key accommodations are necessary. Firstly, a MaaS app designed for VSGs should prioritize accessibility features. This includes adjustable text and icon sizes, as well as color adjustments to assist individuals with visual or hearing impairments. Additionally, providing real-time information is crucial, such as data on crowding levels and seat availability in public transportation services. Moreover, real-time navigation information is essential for facilitating multimodal journeys. This should include detailed information on access routes, station locations, and estimated waiting times. For individuals with mobility impairments, it is vital to offer customized transportation services, such as wheelchair-accessible options. Finally, affordability is a key consideration. Providing subsidized mobility packages or Pay-As-You-Go (PAYG) options customized to different income levels is important to ensure that transportation services are accessible to all. By implementing these accommodations, transportation services can become more inclusive and equitable, providing to the diverse needs of all users.

5.1.1 MaaSINI

The MaaS Maturity Index (MMI) was created by Kamargianni (2016) [47] to assess a city's or region's preparedness to deploy MaaS based on the density and availability of different transport modes. Nevertheless, a number of important factors are not specifically taken into account by the MMI, including the incorporation of parking data into the MaaS platform, the platform's accessibility and usability for vulnerable social groups, and the accessibility of the transport modes offered in MaaS bundles for these groups. Yet, it neglect the need for customized journey planning that accounts for accessibility and the development of tailored mobility packages or bundles that consider users' socio-demographic characteristics.

5.1.2 Considerations

Social inclusion as a KVI offers significant social and economic benefits because it ensures that MaaS adapts to the diverse needs of users and addresses economic disparities. However, integrating social inclusion with other KPIs can present challenges. For instance, KPIs focused on minimizing costs, increasing efficiency, or reducing kilometers per trip which might conflict with the goals of social inclusion, potentially leading to trade-offs between equitable service provision and operational efficiency [13].

5.2 User Experience

User experience (UX) in the context of MaaS refers to the total user experience that a user has when using a platform or service. This includes a variety of factors such as the service's usability, accessibility, efficacy, and level of pleasure that affect users' views and interactions with it. Optimizing user experience is crucial to promote broad adoption [46].
MaaS services should be customized to align with individual preferences, which often include considerations such as speed, environmental impact, safety, and convenience. The goal of MaaS is to present an attractive value proposition by achieving high levels of efficiency and user-friendliness, positioning itself as the preferred option. This means being more sustainable, cost-effective, and supportive of wider social and environmental goals [79].
A few crucial elements need to be taken care of in order to guarantee a satisfying user experience. The service must be user-friendly in the first place; it must be designed so that anybody may use it without difficulty. The service must be used by people with disabilities, which means that accessibility is a must. Customization is crucial because it may enhance the

relevance and usefulness of a service by accommodating the preferences and needs of each individual user. Consistent performance is essential; the service should reliably meet user expectations without fail. Real-time updates are also important, providing current information on travel conditions, schedules, and availability to help users make well-informed choices. The payment and ticketing processes need to be seamless and easy to use, ensuring smooth transactions and effective equivalent management. Additionally, responsive customer support should be available to offer assistance as needed. In conclusion, maintaining trust and security is vital; the service must secure user data and transactions to build confidence.
In Joy Richardson's research [46], twelve heuristics and sub-heuristics relevant to MaaS interfaces have been identified. Key ones include:

- Aesthetic and minimalist design: focus on clean, attractive design to simplify user input and enhance visual clarity.
- Clear language: use straightforward and accessible language that is easily understood by a wide audience.
- Intuitive user flow: reduce cognitive effort by streamlining interactions and minimizing the need for users to remember information.
- Immediate feedback: provide users with timely updates on the application's status through prompt notifications.
- User empowerment: allow users to maintain control with flexible and efficient usage options.
- Build trust: ensure the app prioritizes privacy and security to foster user confidence.
- Error prevention: design the system to reduce the likelihood of user mistakes.
- Inclusive design: avoid requiring advanced IT skills, support diverse mobile environments, and consider accessibility needs such as color blindness.

5.2.1 Evaluation metrics

Numerous indicators are used to gauge and enhance customer satisfaction and are crucial for evaluating the user experience. The Customer Satisfaction Score (CSS) and the Net Promoter Score (NPS) are two of the most essential.

Customer satisfaction is defined as the assessment a customer makes of a product or service after using it. The performance of the product as perceived by the customer, its actual performance, the degree to which it meets or exceeds expectations, its performance in previous consumption episodes, and the expectations and performance of competing offerings are all factors considered in this evaluation. The complete happiness of the client with the product or service is shaped by these factors taken together [62].

NPS was introduced by Reichheld in the Harvard Business Review [34]. Users just respond to a question and then rate it. Customers that provide a rating of 0 to 6 are labeled as "detractors", 7 to 8 as "passive", and 9 to 10 as "promoters". The NPS index, which is expressed as a percentage [7], is obtained by subtracting the percentage of critics from the percentage of promoters without accounting for the passives.

5.2.2 Privacy concerns

With advancements in communication technology, the IoT, and the increasing accumulation of personal data for online services, information privacy has emerged as a critical socio-technological research issue. Within the field of MaaS, privacy considerations have been marked as a significant matter that could hinder the achievement of its goals. Despite this, concerns about privacy from end-users have yet to be thoroughly addressed. The success of a MaaS system is closely linked to users' willingness to share their personal data. MaaS heavily depends on personal data even if its goal is to improve mobility services to better meet customer expectations. Reducing the need for separate ticketing and payment systems, MaaS offers a consolidated digital platform that unifies many services, including booking, ticketing, payment, and real-time updates [60].

Significant volumes of personal data, including time, location, and individual travel habits, are required in order to fully profit from these services. In some instances, like with car-sharing services, additional information such as preferred travel modes, vehicle access, and driving license details may be required to further adapt the service. The collection of personal data by MaaS providers inevitably raises privacy concerns, which can be viewed as perceived risks. These perceived risks pertain to how individuals feel about potentially losing control over their personal information, which could result in misuse or unauthorized secondary use of their data, or uncertainty regarding their mobility-related information.

5.3 Community Impact

MaaS development and implementation have important consequences for the economy and society as a whole. Notable advantages include new job creation, chances for creative businesses, investments in cutting-edge digital infrastructure and technologies, and enhanced quality of life.

5.3.1 Job Creation

As presented in the MaaS Alliance, 2017 [3], MaaS contributes to job creation and the transformation of existing roles in several ways. MaaS platforms require a range of staff for operations, customer support, technology development, and infrastructure maintenance. MaaS platforms typically drive direct employment growth by increasing the demand for various transport services. As more people adopt and use these services, transport operators, including drivers and maintenance staff, see a rise in job opportunities. Additionally, MaaS platforms generate employment in technology-driven sectors. Developing and maintaining a MaaS app requires a professional team, comprising software developers, data analysts, and IT support workers. These positions are essential to guaranteeing the app's usability, security, and operation.

The MaaS operator may be a commercial business, a local government agency, or a provider of public transportation services. Their primary role is to integrate different transport services and offer them to users through a single digital platform [22]. This consolidation of services is an example of how MaaS contributes to job creation.

MaaS fosters innovation by facilitating the birth of new business models, including micro-mobility services, integrated ticketing solutions (e.g., multi-modal tickets, contactless payments using NFC, subscription models), and ride-sharing startups [88].

The smooth operation of MaaS depends on investments in digital platforms and technology, including mobile apps and Internet of Things devices. These investments subsequently drive expansion within the technology sector. Examples of IoT devices include sensors, which detect traffic-related information and convert it into electrical signals, thus enabling intelligent traffic control. As well, control units process these signals from the sensors and issue commands for execution. Actuators then carry out these commands, typically using pneumatic, hydraulic, or electric mechanisms. Finally, network modules play a crucial role by transmitting data between sensors and a remote control center, using both wired and wireless communication methods to ensure seamless data flow and system integration [35].

5.3.2 Quality of Life

Quality of Life (QoL) has often been mentioned in many studies as an important factor to consider. On the one hand, raising people's level of living requires raising their mobility. But maintaining a high level of life also involves fostering an environmentally friendly atmosphere, which entails minimizing the damaging effects of transportation on the environment. As a result, we can directly connect increases in quality of life to environmental impact, a critical performance measure that we previously talked about. Among the green transportation options that don't discharge potentially harmful substances into the environment are walking, bicycling, and electric autos. These eco-friendly forms of transportation improve public health and overall well-being by reducing exposure to air pollution.
QoL includes aspects like stress management in addition to physical health. MaaS, which offers real-time information about public transportation timetables and traffic conditions, helps reduce the anxiety and stress that come with travel. MaaS may considerably reduce consumers' stress levels by improving their trip's predictability and efficiency, which will further improve their well-being [63]. QoL also encompasses a variety of factors beyond just health and stress reduction. It includes economic stability, access to essential services, and social well-being. Better access to social activities, educational possibilities, and employment chances, for instance, can result in a more well-rounded and balanced lifestyle.

5.3.3 Considerations

MaaS may be greatly improved by community impact through favorable social, environmental, and economic effects. Socially, MaaS improves accessibility and quality of life by offering convenient transportation options and encouraging community cohesion. Environmentally, it contributes to reduced emissions. Economically, MaaS generates job opportunities and provides cost savings through integrated ticketing systems.

5.4 Behavioral change

MaaS aims to change people's travel patterns and behaviors, with a particular emphasis on lowering reliance on private vehicles. The effects of private automobiles on the environment, traffic congestion, urban space (such as park space), public health, economic issues, and road safety have already been mentioned.

Travel habits are closely related to the various phases of our life. It includes the choices we make on where to move while engaging in different activities. Travel behavior includes more than simply the practical aspects of moving from one place to another; it also takes into account our feelings, attitudes, perceptions, and beliefs, all of which affect how we act and how we feel about ourselves overall. Whether these travel decisions are based on careful reasoning or intuition, they reflect deeper motivations that can be explored through research and analysis [49].

A person's general thoughts or sentiments toward a particular mode of transportation, such as cars, bicycles, or public transportation, are characterized by their travel attitude, which is a psychological term. This attitude indicates how much a person loves or hates a specific kind of transportation, and it may affect their decision-making when choosing a method of transportation. Numerous factors, including as individual experiences, societal pressures, cost, convenience, and perceptions of comfort or safety, impact these opinions. Comprehending the attitude of travel is crucial as it provides an explanation for individuals' decisions in travel and may guide initiatives to promote environmentally friendly modes of transportation [44].

The travel attitude can be qualified as positive or negative. Positive travel attitudes really indicate that the individual has a favorable opinion of or preference for a specific form of transportation. This might be the result of a number of factors, including cost-effectiveness, comfort, convenience, the environment, or personal delight.

Nevertheless, a negative attitude toward travel suggests that the individual has a bad opinion of or distaste for a certain kind of transportation. This unfavorable opinion may result from things like pain, perceived inefficiency, expensive price, worries about safety, or annoyance. For instance, someone with a bad attitude on public transportation may avoid utilizing buses or trains whenever possible because they believe them to be congested, unreliable, or sluggish. These mindsets may have a big impact on how someone travels, influencing how they choose to commute, travel for fun, or do everyday errands.

5.4.1 Shift in travel behavior

Research demonstrating the interdependence of attitudes and behavior by Dobson et al. (1978) [20] and Reibstein et al. (1980) [18] was conducted by the late 1970s. As the 2000s progressed, research conducted by Bagley et al. (2002) [6] revealed that views about travel are not only influenced by travel behavior but also differ based on an individual's place of residence. For example, residents of suburban neighborhoods often have favorable attitudes toward driving, while those living in more urban areas typically hold positive views towards public transportation and active travel. Given that people frequently use the same mode of transportation for specific types of trips (i.e., habitual mode choice), attitudes are likely to influence travel behavior primarily when there is a change in the travel context. A change in home or location of employment, the arrival of new transportation alternatives, or situations that make some forms of transportation impracticable might all lead to such a shift in context. According to research, a shift in environment might cause people to reevaluate their behavior and upset ingrained habits, reintroducing attitudes as a factor in decision-making [82]. Also after COVID-19 pandemic have resulted in significant shifts in urban travel behaviour for long periods of 2020 [15].

In conclusion, encouraging urban living is frequently proposed as a means of discouraging the use of cars. Individuals that drive a lot may be more likely to reside in suburban-style neighborhoods because of easy access for cars and less parking issues. Those who enjoy taking public transportation or going on active travels may choose living in an urban neighborhood. In urban regions, public transportation is readily available and often well-organized, and destinations are typically accessible by foot or bicycle due to high density and land use mixing [43].

5.4.2 Shift from ownership to usage

Changing from the old norm of owning a car to utilizing transportation services only when necessary is one of the major changes that MaaS promotes. Rather of requiring every individual to purchase a private car, MaaS encourages on-demand access to a range of transportation choices. This change has the potential to result in a large decrease in the number of cars on the road, which will lessen traffic congestion and the negative effects that transportation has on the environment. This may be achieved by combining various forms of conventional public transportation, such as cabs and buses and trains, with private services. MaaS also includes car-sharing, ride-sharing, and bike-sharing services as shared mobility solutions.

MaaS denotes a shift from owning a car to having access to transportation, which can have a number of effects on day-to-day living. For example, it can make commuting more convenient and reduce the need for parking spaces, thus realising urban areas. It also offers potential cost savings for individuals who might otherwise spend money on maintaining and insuring a private vehicle.

5.4.3 Considerations

Behavioral change has a range of positive impacts that enhance MaaS. It helps the environment, saves money, and relieves traffic congestion by using fewer vehicles. Additionally, it encourages a change from depending exclusively on vehicles to a variety of modes of transportation, which results in more sustainable and efficient travel. Nonetheless, there are potential challenges. For instance, transitioning away from private cars may require significant adjustments in infrastructure and public transport systems to meet new demands. There might also be resistance from individuals accustomed to the convenience of personal vehicles, which could hinder the adoption of alternative modes of transport.

5.5 Innovative solutions and flexibility

Innovative solutions aim to introduce new technologies and methods to intercept existing challenges or enhance transportation systems by incorporating flexibility. This covers new service models like on-demand transportation services and integrated transport alternatives, as well as technological innovations like Intelligent Transport Systems (ITS).
The capacity of a system to adjust to shifting circumstances and user demands is referred to as flexibility in transportation. In order to accommodate changing demand and regional regulations, it entails making real-time adjustments to routes, timetables, vehicle types, and payment options. So, for example, a 'bottom up' approach to meeting demand which reply straight to end user needs [65]; or flexible transport system (FTS) which is an emerging term which covers services provided for passengers that are flexible in terms of route, vehicle allocation, vehicle operator, type of payment and passenger category.

5.5.1 Adaptation to User Needs

A critical aspect of MaaS is how well the platform adapts to the changing needs and preferences of its users. Designing a MaaS application that aligns with user preferences involves several challenges, particularly in delivering the right travel information and features.

Recent academic research has clear up on what travelers value most when choosing their modes of transport. Key factors include accurate information on travel time, parking costs, and crowding levels. These factors are typically used by travelers to inform their decisions, hence a successful MaaS platform needs to offer current and pertinent information on these factors.
Research also shows that a range of socio-demographic (e.g., age, income), travel-related (e.g., commute frequency, distance), and attitudinal (e.g., openness to new technologies) characteristics impact customers' choices for MaaS. For instance, younger people, college students included, tend to be more interested in implementing alternative mobility solutions like MaaS. This demographic is typically more receptive to innovative transportation options and is more likely to use integrated mobility services [50].

5.5.2 Innovation Adoption Rate

Infrastructure preparedness, legal frameworks, and technology improvements all have an impact on the rate at which MaaS innovations are adopted.

- Technological advancement: accessibility and caliber of digital infrastructure, including data analytics and mobile networks, are vital. The user experience and operational efficiency may be improved by advanced technologies like 5G, IoT, and AI, which will encourage adoption. Consequently, the introduction of 5G technology greatly increases bandwidth and data transmission speeds, thereby satisfying the low latency requirements of MaaS systems. Moreover, 5G makes it easier to incorporate IoT technology into MaaS systems, which boosts intelligence and efficiency. Future research in the development of MaaS systems should focus on this synergy between 5G and IoT [35].
- Legal environment: adoption can be accelerated by laws and policies that promote it, such as those that integrate shared mobility services with public transportation, provide subsidies for them, and establish data-sharing protocols.
- Infrastructure readiness: prior to making MaaS plans, decision-makers should ascertain how near a city is to meeting these requirements. As shown before, the "MaaS Maturity Index" [48] was created by a research. This gauges a city's readiness to adopt MaaS based on attributes along five dimensions: the degree of infrastructure and ICT infrastructure for better MaaS implementation, the degree of openness and inclination of transport operators towards MaaS and data sharing, the propensity and awareness of users, the level of regulation and legislation involved.

6

A case study

Urban mobility is being revolutionized by MaaS, an integrated transportation paradigm that combines different modes of transportation into a single, simple to use platform. This creative method promotes ease and sustainability while enabling customers to easily plan, schedule, and pay for their trip. With the support of 40 million euros in NextGenerationEU grants, the MOST is spearheading the development of MaaS solutions, with a special emphasis on modern VRPs to optimize urban mobility. Traditional vehicle routing difficulties, such real-time VRPs, feeder VRPs, and collaborative VRPs, have changed as cities grow and urban networks becoming more intricate. In the context of public transportation, the dial-a-ride issue, employee bus routing, and school bus routing are the three main issues that need to be addressed in order to optimize shuttle bus networks. This case study aims to investigate an avant-garde shuttle bus routing system that combines conventional operational research (OR) methods with contemporary transportation trends. A number of primary objectives guided the creation of the shuttle service: *efficiency*, which seeks to ensure that shuttle routes minimize overall travel time; *sustainability*, which tries to minimize shuttle services' negative environmental effects through route and passenger load optimization; *equity*, which guarantees that all customers in various metropolitan zones receive equitable and easily accessible services; and *environmental stewardship*, which employs smart routing to lessen the service's carbon impact. In Chapter 4, various KPIs are discussed, each offering critical insight into how the shuttle service performs in terms of equity, efficiency, and environmental sustainability. For instance, section 4.8 evaluates how well shuttle routes

reduce the amount of time spent traveling overall. This metric evaluates how successfully the shuttle service plans and schedules its routes to guarantee that customers experience the fewest delays and the shortest travel times. Section 4.7 illustrates how the shuttle service affects the environment by contrasting carbon emissions before and after MaaS solutions are put in place. Reduced emissions demonstrate the shuttle service's dedication to protecting the environment and its part in reducing global warming. Section 4.10 determines the geographic area in which MaaS services are offered and the ease with which consumers may get transportation alternatives in order to assess equality.
This design considers penalizing solutions that fall short of important goals, especially those that have lengthy routes, uneven beginning sites geographically, or unfair tours based on user distribution and needs. To address these concerns, the method focuses on using a unique MILP approach to create optimal shuttle routing. While upholding the core objective of streamlining the transportation system, this strategy highlights the significance of motivating the service's utilization by matching the shuttle system with user demands.

6.1 Problem Description

The primary objective of this case study is to optimize a single shuttle vehicle to accommodate on-demand requests by combining an efficient dial-a-ride problem with an orienteering problem. The urban network is represented as a directed graph with road connections represented by edges and shuttle stops as nodes, all of which are weighted by journey time. Under two main restrictions, users request to be picked up at stops and transported to a shared destination:

- instant arrival at the stop (users need to be picked up at certain times);
- maximum ride time (making sure people get at their location in a reasonable amount of time).

This challenge has a multi-objective approach that seeks to:

- reduce the service's total effect (such as its social and environmental costs);
- get the most users possible served;
- cut down on how long it takes to get to the shared location.

6.1.1 Notation, definitions and assumptions

The **urban network** is modeled as a strongly connected graph $G = (V_0, E)$, where:

- **vertex set** $V_0 = V \cup \{0\}$, where $i = 0$ denotes the common destination (e.g. a central hub);
- set $V \subset V_0$ contains all the remaining shuttle stops $i = 1, ..., n$;
- **neighborhood** N_i contains adjacent stops to i, destination may be included;
- **edge set**: $E \subset V_0 \times V_0$ contains route connections between shuttle stops;

  each edge (i,j) between two stops has several attributes:

  – an edge (i,j) is weighted by time span $L_{ij} > 0$ to travel from i to j;
  – an edge (i,j) also accounts for the distance $L_{ij} > 0$ to travel from i to j;
  – an edge (i,j) also considers the average number of lanes, representing road capacity, $\gamma_{ij} \in \mathbb{N}$ while travelling from i to j;

- **a path from i to j**: π_{ij} weighted as the edges by $t_{ij}, L_{ij}, \gamma_{ij}$; which are respectively the attributes of travel time, distance and number of lanes;
- decision, i.e. selected shuttle bus route: $\pi^\star = \pi^\star_{i0}$. This denotes the optimal path chosen by the shuttle bus.

Users represent the passengers who request the shuttle service. The notation used for users is as follows:

- **user requests:** users are labeled starting from 1 onward as soon as they make a request;
- **user set** U_i contains all the users at each stop, waiting to be picked up at that stop $i \in V_0$;
- **maximal service time** for all users: $T > \max_{i \in V} t_{i0}$; this ensures no user is picked up after this time;
- **arrival time instant** for user $u \in U_i$: $a_{iu} \in [0, T)$; this represents the time when the user is expected to be picked up;
- **maximum ride time** for user $u \in U_i$: $r_{iu} \in [0, T)$; the maximum time a user u is willing to spend riding the shuttle stop from stop i to destination;

- **vehicle efficiency** (consumption) of user $u \in U_i$: $\beta_{iu} > 0$; it depends on factors like vehicle's load and road conditions;
- **vehicle length** of user $u \in U_i$: $l_{iu} > 0$; physical space or length required for user u in the vehicle. Relevant for planning the capacity of the shuttle service;
- **decision** → list of served users: $v^\star \in \{0,1\}^{|U_1|+\cdots+|U_n|}$; represents the list of users selected to be served. It is a binary decision variable: 1 is selected, 0 not.

The shuttle bus itself is modeled with several constraints and operational parameters:

- a single shuttle bus is considered;
- **maximum capacity:** number of passengers allowed in the shuttle bus $Q \in \mathbb{N}$; the shuttle bus has a limited capacity;
- **previous location** of the shuttle bus / departure depot: $z \in V_0$;
- **shuttle bus efficiency:** $\beta_{SB} > 0$; fuel or energy consumption efficiency of the shuttle bus. Important for minimizing operational costs and environmental impact;
- **shuttle bus length:** $\ell_{SB} > 0$; may influence route selection (e.g., certain routes may not be suitable for longer vehicles);
- **decision** → departure time schedule: $d_i^\star \in [0,T], \quad i = 0,1,2,\ldots,n$; the optimal departure time for the shuttle bus from each stop i, which must be determined to meet user needs while minimizing the total service time.

6.1.2 Optimization and decision variables

- **selected shuttle bus route:** $\pi^\star = \pi_{i0}^\star = (s^\star, x^\star)$;
- $s_i \in \{0,1\}$, s.t.$s_i = 1$ if $i = i^\star$ is chosen to be the starting node for the tour, $s_i = 0$ otherwise;
- $x_{ij} \in \{0,1\}$, s.t. $x_{ij} = 1$ if edge (i,j) is traversed, $x_{ij} = 0$ otherwise;
- **list of served users:** $v^\star \in 0,1,^{|U_1|+\cdots+|U_n|}$;
- $v_{iu} \in \{0,1\}$, s.t. $v_{iu} = 1$ if user $u \in U_i$ is served, $v_{iu} = 0$ otherwise;
- **departure time schedule:** $d^\star \in \mathbb{R}_{\geq 0}^{n+1}$; the values of d depend on the arrival times and travel times between stops;

- $d_i \in [0, T]$, s.t. $d_i < d_j$ if stop $i \in V_0$ is reached earlier that stop $j \in V$ in $\pi^\star$; by convention $d_k = 0$ if stop $k \in V$ is not traversed;
- **selected class of users at each stop:** $y^\star \in \{0, 1\}^{c_1+\cdots+c_n}$;
- $y_{il} \in \{0, 1\}$, s.t. $y_{il} = 1$ if the l-th class is chosen at stop i, $y_{il} = 0$ otherwise.

6.1.3 Optimization structure

Stage 1: the first stage aims to minimize the cost or objective function.

$$\{s^{(1)}, x^{(1)}, v^{(1)}\} = argmin_{s,x,v,d,y} I(s, x, v)$$
$$\text{subject to } \Gamma(s, x, v, d, y)$$

where:

- $I(s, x, v)$ is the *service impact* (the term "impact" has a negative connotation)
- the constraint $\Gamma(s, x, v, d, y)$ represents the set of navigation constraints that can involve logical, spatial, temporal, or capacity constraints on the route, user service, timing, and user class decisions. In particular, we denote
  - s: shuttle route starting node selection;
  - x: shuttle route edges (which stops are visited and the connections between them);
  - v: user service decisions (which users are served);
  - d: departure time schedule;
  - y: user class selection at each stop.

Stage 2: the second stage focuses on maximize the probability of serving users, denoted as $P(\nu)$, while keeping the cost function $I(s, x, v)$ equal to the minimum value found in Stage 1.

$$\{s^{(2)}, x^{(2)}, v^{(2)}\} = argmax_{s,x,v,d,y} P(v)$$
$$\text{subject to } \Gamma(s, x, v, d, y) \wedge I(s, x, v) = I(s^{(1)}, x^{(1)}, v^{(1)})$$

where: $P(v)$ is number of served users.

6.1.4 Set of navigation constraints

The set of constraints $Gamma(s, x, v, d, y)$ is comprised by the following equalities and inequalities.

Vertex flow equations:

1. $\sum_{i \in V} s_i = 1$
2. $\sum_{(i,0) \in E} x_{i0} = 1$
3. $s_i + \sum_{(j,i) \in E} x_{ji} = \sum_{(ij) \in E} x_{ij}, \forall i \in V$

Avoid subtours:

4. $\sum_{(i,j)} x_{ij} \leq 1, \forall i \in V$

Time sequence of departures:

5. $(T - t_{i0} + t_{ij})x_{ij} + d_i - d_j \leq T - t_{i0}, \forall (i,j) \in E$
6. $d_i \leq d_0 - \sum_{(i,j) \in E}(t_{ij} + t_{j0})x_{ij}, \forall i \in V$

Selection of classes:

7. $\sum_{l=1}^{c_i} y_{il} \leq \sum_{(i,j) \in E} x_{ij}, \forall i \in V$

Satisfy users' requests on arrival and ride times:

8. $\sum_{l=1}^{c_i} a_{il} y_{il} \leq d_i, \forall i \in V$
9. $d_0 - \sum_{l=1}^{c_i} a_{il} y_{il} \leq \sum_{l=1}^{c_i} r_{il} y_{il} + T\left(1 - \sum_{l=1}^{c_i} y_{il}\right), \forall i \in V$

Selection of which and how many passengers:

10. $\sum_{i \in V} \sum_{u \in U_i} v_{iu} \leq Q$
11. $v_{iu} \leq \sum_{l=1}^{c_i} y_{il} \varphi_{il}, \forall i \in V, \forall u \in U_i$

Valid inequality (to avoid subtours):

12. $x_{ij} + x_{ji} \leq 1, \forall (i,j) \in E$

Valid inequilities (to keep d_j values as small as possible):

13. $d_i \leq \sum_{(i,j) \in E}(T - t_{ij} - t_{j0})x_{ij}, \forall i \in V$
14. $T - d_0 \geq x_{i0}(T - t_{i0}) - d_i, \forall i \in V$ such that $\exists (i, 0) \in E$

6.1.5 Service impact: coefficients

In the optimization structure introduced in subsection 6.1.3 the service impact has been defined as

$$I(s,x,v) = \sum_{i\in V}\sum_{j\in N_i} q_{ij}x_{ij} + \beta \sum_{i\in V}\sum_{u\in U_i} m_{iu}(1 - v_{iu})$$

Below we discuss the selection of the coefficients in $I(s,x,v)$.

- $q_{ij} = L_{ij}$: represents the length of the shuttle bus route between points i and j. This value accounts for the distance traveled by the shuttle on a specific route segment. The total cost of the shuttle's travel is calculated by summing up the lengths of all selected routes. This is directly linked to several KPIs, which aim to reduce fuel consumption, enhance the focus on environmental sustainability, lower service costs, and improve an eco-friendly system. Refer to Chapter 4 for more details.

- $m_{iu} = \frac{L_{i0}}{max_{k\in V} L_{k0}} \cdot \beta_{iu}$: reflects the relative distance of user i to the common destination $i = 0$, normalized by the maximum distance $\max_{k\in V} L_{k0}$ across all users. This captures the geographic impact of not serving a user based on how far they are from the destination. The fairness factor β_{iu} accounts for the socio-economic status of user u, where it reflects the size of their residence (in square meters), representing their relative social standing. Together, these elements quantify the cost of not serving user u, considering both the distance they would need to travel on their own and their socio-economic situation. The previously described KVIs, Chapter 5, provide justification for this decision. These KVIs likely emphasize the critical importance of fairness and user satisfaction in the performance of the system or service under study. In this context, prioritizing the user experience, promoting social inclusion by ensuring fair access, and considering the impact on QoL become central.

- The decision to set $\beta = 100$ strengthens the alignment with strategic goals of the previous point, even though it may involve a trade-off with environmental objectives, such as minimizing carbon footprint or other ecological concerns. While environmental sustainability remains important, the high value of β reflects a deliberate choice to prioritize user satisfaction and fairness, as these factors are likely more directly tied to the service's success and effectiveness in the current model.

6.2 Numerical simulations

This section reports on the results of the numerical simulations used to assess how well various optimization strategies performed in running an urban shuttle service. The simulations' main goal is to illustrate the reduction of the "negative" service impact, which is a confluence of socioeconomic, environmental, and economic variables. A greedy heuristic and a MILP approach are both tested in the simulations. Our objective is to evaluate how well these strategies serve users while balancing a number of restrictions, including sustainability, equity, and user satisfaction.

6.2.1 Setup

The simulation has been implemented in the Portello area, Padua, Italy $(0.35km^2)$. Road intersections, shuttle bus stops, and a shared destination have all been completed in the road connectivity process. Time-weighted stop links are used.

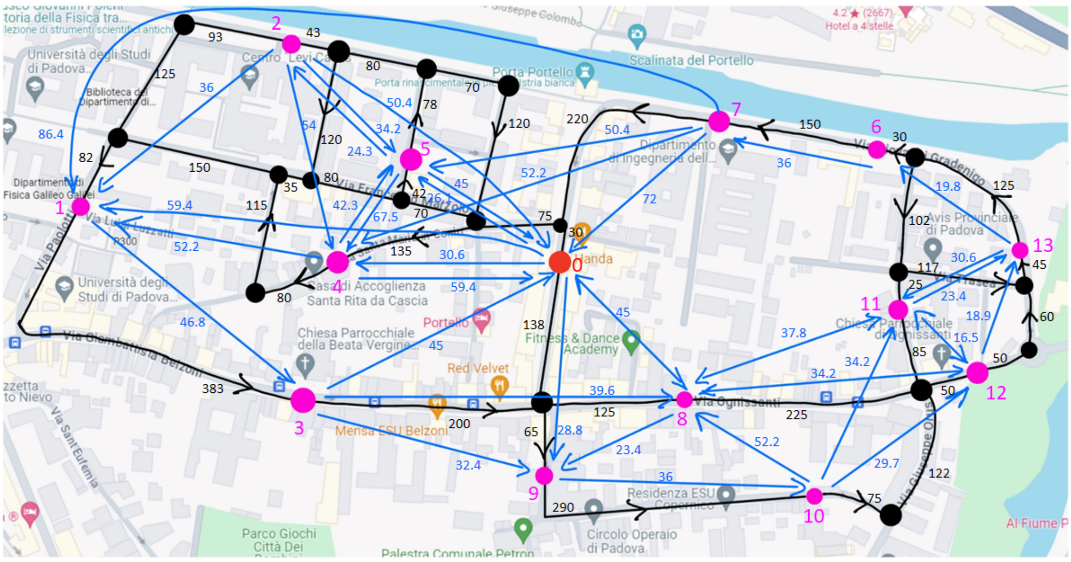

Figure 6.1: Case study taken into consideration.

Figure 6.1 shows a map of the Portello area with various points marked (some in black and some in pink), likely representing bus stops or key locations within the service area. The black

circles represent the road junctions. Pink circles represent the shuttle bus stops specified with different numbers. The red point indicates the common destination, also called the central hub. Black arrows indicate road interconnections. The blue arrows show the time-weighted stop links. The purpose of the case study is to optimize shuttle routes in this area to reduce travel time, increase efficiency, or cover as many key locations as possible within a short time frame.
To simulate the service impact and evaluate the effectiveness of different algorithms in managing a shuttle service, we generated user data based on certain probabilistic distributions. Specifically, the house surface areas for each user were derived using the formula:

$$\textbf{house surface} = 30 + 270 \cdot x$$

where x is a random variable sampled from a beta distribution (parameters $(2, 8)$). This choice of distribution reflects the socio-economic disparities, with a right-skewed shape that indicates a higher likelihood of users having smaller homes, akin to the distribution of income.
For the optimization tests, we used the following setup.

- To build MATLAB has been used, which is used for algorithmic calculations and numerical simulations. We used GUROBI, a cutting-edge optimization tool known for its effectiveness in managing challenging numerical computations, to solve the MILP issues. The accuracy and dependability of the findings provided are guaranteed by the use of these specialized instruments.

- Each user is assigned a set of parameters, such as their desired pick-up node (urban shuttle stop generated with a Poisson-Point process having density equal to 50 people/$0.95\ km^2$), time of readiness at the stop, and maximum acceptable travel time ($T = 10$ minutes). These parameters allow us to simulate realistic user behavior and optimize shuttle routes accordingly.

- Each arrival time window (r_{iu}) for each user is calculated as $r_{iu} = T - a_{iu}$, where $T = 600s$ seconds is the maximum travel time allowed, and a represents the user's arrival time at the stop, which is uniformly chosen in the interval $[444, 564]s$.

The solution found minimizes the "service impact" $I(s, x, v)$ considered in Subsection 6.1.5. The parameter β is set to 100 to give more weight to user-centric and fairness objectives over environmental concerns. This change reflects the decision to prioritize user satisfaction, though this rationale is not directly discussed in terms of optimizing results.

6.2.2 Results

As displayed by Table 6.1, 42 users have been generated via the Poisson point process.

id number	hop-on stop	a (in seconds)	r (in seconds)	house surface
1	8	534.3240	65.6760	82.4584
2	1	427.9673	172.0327	36.4926
3	10	393.2074	206.7926	46.3677
4	4	499.3363	100.6637	67.0302
5	13	426.7734	173.2266	142.2774
6	11	375.4018	224.5982	75.5584
7	7	447.8865	152.1135	43.6332
8	2	496.2148	103.7852	48.6275
9	9	130.2598	469.7402	61.5659
10	6	474.6403	125.3597	71.7923
11	2	534.3620	65.6380	46.8255
12	3	468.8403	131.1597	152.7337
13	5	540.7211	59.2789	85.1471
14	5	455.7805	144.2195	49.4839
15	7	541.2909	58.7091	83.5260
16	2	473.8779	126.1221	36.0180
17	10	452.0137	147.9863	155.1478
18	10	432.6577	167.3423	169.1953
19	5	456.8564	143.1436	95.4503
20	9	66.4332	533.5668	40.1599
21	7	515.9936	84.0064	138.0550
22	11	250.5639	349.4361	93.5081
23	3	523.7142	76.2858	149.9701
24	7	476.1308	123.8692	51.1042
25	6	483.2268	116.7732	70.5173
26	3	493.6914	106.3086	86.1795
27	2	391.8089	208.1911	34.9862
28	6	490.4510	109.5490	109.2876
29	7	501.0653	98.9347	108.7907
30	13	450.4313	149.5687	44.0064
31	9	409.7466	190.2534	64.3239
32	10	473.8256	126.1744	94.2173
33	10	286.5709	313.4291	109.9069
34	2	487.9909	112.0091	78.3615
35	12	296.8253	303.1747	123.0276
36	3	449.6798	150.3202	75.4129
37	13	475.2870	124.7130	77.9721
38	2	440.0960	159.9040	54.2965
39	3	463.8837	136.1163	85.4131
40	3	482.2066	117.7934	82.1395
41	5	532.9880	67.0120	109.4593
42	10	369.6767	230.3233	78.5209

Table 6.1: User Distributions

Here we test two approaches:

- A "greedy" heuristic algorithm (i.e., looking at nearby nodes and deciding where it is most convenient to send the shuttle. This strategy is generally short-sighted)

- In the case of MILP, we conduct two tests: one test where the objective is to maximize the number of users, and a second test where the goal is to minimize the impact of the service in terms of economic costs, environmental costs, and discrimination based on socio-economic and spatial factors.

Solution by heuristics: picked-up users through heuristics = 8 (the higher the better!); service impact of this solution: 3532 (the higher the worse!); values are reported in Table 6.2.

node	served users at that node	users at that node	departure time in minutes
9	1	3	1.5667
10	0	6	2.1667
8	0	1	3.0367
11	0	2	3.6667
13	0	3	4.0567
6	0	3	4.3867
7	0	5	4.6867
4	0	1	5.5567
5	0	4	6.2617
2	1	6	6.7333
1	1	1	7.5533
3	5	6	8.5833
0	0	0	9.3333

Table 6.2: Solution by heuristic

Solutions by MILP: maximizing the number of passengers. Picked-up users through heuristics = 19 ; service impact of this solution: 1783; values are reported in Table 6.3.

node	served users at that node	users at that node	departure time in minutes
12	1	1	5.0000
8	0	1	6.4433
9	3	3	6.8333
10	3	6	7.4333
11	2	2	8.0033
13	3	3	8.3933
6	3	3	8.7233
7	4	5	9.0233
0	0	0	9.6233

Table 6.3: Solution by MILP: maximizing the number of passengers

Solution by MILP: minimizing the service impact. Picked-up users through heuristics = 12; service impact of this solution: 61; values are reported in Table 6.4.

node	served users at that node	users at that node	departure time in minutes
9	3	3	7.4000
10	6	6	8.0000
11	2	2	8.5700
8	1	1	9.2000
0	0	0	9.9500

Table 6.4: Solution by MILP: minimizing the service impact

We can approach the optimal solution with a guarantee of convergence by using MILP-based algorithms, which is not possible in general through the greedy heuristic.

Solution by heuristic

The greedy heuristic only picks up 8 passengers. In certain situations, such as the previous test, the greedy heuristic even underperforms a MILP that is not intended to maximize passenger counts; it picked up 12 passengers, which is still more than the 8 from the heuristic. In Table 6.4 we can accommodate 19 passengers when we run a MILP, which is the maximum efficiency. This implies that although it can offer quick resolutions, it frequently falls short of efficiently optimizing overall user engagement. We can also observe that the nodes with higher user capacity (see nodes 2, 3, 7, 10) show a very limited service, highlighting the crucial need for improvement in targeting user needs more effectively. Long wait times are another consequence of the greedy strategy, which may discourage customers from utilizing the service. Finally we can note that the service impact is 3532 which is the highest value in all the tests.

Solution by MILP (maximizing the number of passengers)

Even if it is not their primary objective, MILP formulation can aid in lowering the service impact. For instance, in Table 6.3, the service effect was measured using MILP, whose objective is to maximize the number of passengers, and attained at 1783. This shows unequivocally that MILP performs better than the greedy heuristic. This approach demonstrates also a significant improvement in the number of picked-up users compared to the heuristic method, which indicates better utilization of available resources.

Solution by MILP (minimizing the service impact)

Although fewer people were selected than in the maximizing technique, the outcome was still superior to the heuristic answer. When compared to the two prior ways, the service impact of 61 shows an extremely efficient service, indicating that this strategy substantially minimized delays or inefficiencies. Users on various nodes benefit from a more equal service distribution when using this MILP solution, which reduces service disruption. In comparison, the greedy strategy could unintentionally prioritize more accessible nodes over those in less advantageous socioeconomic locations. The relatively even distribution of departure times among the nodes may aid in controlling user wait times and raising satisfaction levels. Though MILP formulations are more effective, it is crucial to remember that they can be more difficult to solve and may take a lot longer to do so.

These findings show that there is a trade-off between reducing service negative effects and increasing user pickups. In comparison to the solution that reduces negative effect, the one that increases pickups delivers a larger number of users at a higher service impact. This implies that further optimization methods could be able to help strike a balance between these goals. Despite their potential for speed and simplicity, heuristic approaches can provide less-than-ideal results, as seen by their noticeably lower performance metrics. While MILP systems optimize for either service efficiency or customer fairness, they may need more time and computing resources and yield more robust results. It is also evident that concentrating only on practical objectives, such serving as many users as possible, does not necessarily produce the greatest results. The three distinct solutions' effects on services range greatly from one another. For instance, in order to safeguard the environment, we might have to decline servicing some people if the main objective is to reduce the impact on services. Since the shuttles spend less time in traffic, cutting the shuttle routes short helps lower fuel usage and traffic congestion. Such a strategy also lessens the likelihood of prejudice against those who are poorer or who reside further from the shuttle's destination.

7
Conclusions

This thesis examines the relationship between KPIs and KVIs within the context of MaaS, highlighting the significance of these relationships in improving performance and value generation. Through a systematic assessment of these metrics, we clarify their roles in creating MaaS frameworks that efficiently address the changing needs of urban mobility. Although opinions on the importance of these indicators are divided, it is essential to fully comprehend their benefits in order to advance workable solutions for transportation services. Our goal was to bring attention to important performance and value indicators that are still not receiving the attention that companies, society, and politicians should be giving them. Even while KPIs and KVIs have a big influence on creating practical urban transportation solutions, they are frequently ignored. Primarily, while attaining sustainability objectives necessitates performance, economy, and optimization of urban transportation, it is also critical to acknowledge the qualitative effects these systems have on users. The results of this thesis demonstrate that the entire range of user experience and societal value that MaaS may offer cannot be adequately captured by simple quantitative indicators like ridership figures and operating expenses. It is critical that policymakers give equal weight to KPIs and KVIs in their plans, promoting an integrated perspective on urban mobility that values user diversity and sustainability. By doing so, we can create transportation networks that benefit the community as a whole and enhance people's lives in addition to being functional. But Italy's comparatively lax KVI regulations point to a big room for improvement going forward. The policies that promote MaaS and smart cities demonstrate the commitment to innovation in transportation infrastructure. Residents' quality of life is improved by digital technology found in smart cities, and MaaS enhances this framework by providing personalized mobility alternatives and real-time data. MaaS and smart city efforts place a high priority on sustainability by encouraging multimodal transportation solutions that decrease the use of private automobiles and minimize traffic and pollution. Moreover, MaaS improves mobility for people from a range of socioeconomic backgrounds and benefits marginalized areas by promoting fair access to services. We proposed a case study to investigate potential strategies for optimizing and enhancing shuttle bus services, with an emphasis on determining whether the primary objective should be maximizing KPIs or prioritizing the improvement of KVIs. The goal is to not only assess theoretical possibilities but also to conduct a practical study that can be applied to real-world scenarios, ensuring that it runs efficiently while also addressing sustainability and fairness problems. The case study carried forth for this paper shows how algorithmic methods, including MILP and greedy heuristics, may optimize user pickups while reducing negative service effects, such as the number of users served, minimize wait/departure times at each node, and reduce the global service disruption. One important finding from our research is that the mobility system may not always gain overall by pursuing utilitarian objectives alone, such as increasing the number of users. The three strategies' differing service implications show that various optimization goals provide different results. Prioritizing the reduction of service effect, for example, might result in servicing fewer people but improve environmental sustainability, diminish social prejudice against marginalized populations, and reduce traffic congestion. This study emphasizes that a balanced approach that harmonizes both KPIs and KVIs yields the greatest results. It also illustrates that practical urban transportation solutions need to take into consideration the particular requirements and preferences of every single user. This strategy not only increases customer pleasure but also helps people from different backgrounds feel like they belong. When designing and implementing mobility services, social factors including equity, accessibility, and user experience should be taken into account. It is critical to empower marginalized groups by making sure that their preferences are taken into consideration at the stages of design and implementation. The most effective MaaS frameworks are those that harmonize operational performance with a deep understanding of the qualitative impacts on users. By viewing each user as a distinct individual with unique requirements, we can create more inclusive and responsive mobility solutions. This balance is vital for ensuring that urban mobility systems are not only efficient but also meaningful and beneficial for all community members. Future research should look at new KPIs and KVIs that capture the changing mobility scene, such the effects of self-driving cars and micro-mobility solutions. Finding these extra features will help us improve the measurements we use to assess the performance of urban mobility.

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