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Article

# Developing a Mobility as a Service Status Index: A Quantitative Approach Using Mobility Market and Macroeconomic Metrics

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**Abstract:** Despite the growing adoption of Mobility as a Service (MaaS) in urban transportation systems, standard monitoring methods for evaluating its impact and effectiveness still need to be developed. This study proposes a quantitative state of MaaS analysis based on mobility market indicators and macroeconomic metrics to generate a MaaS Status Index (MSI). The intention is to introduce a standardised quantitative methodology for systematically assessing and comparing the state of MaaS in urban mobility systems. The MSI aims to quantitatively capture the economic, social, technological, and infrastructural conditions relevant to MaaS implementation. The methodology includes four steps: identifying relevant mobility markets, defining mobility market metrics, integrating macroeconomic metrics, and deriving the MSI formula. We apply the MSI methodology to the Austrian mobility market as a case study, demonstrating its practicality in assessing MaaS readiness and highlighting specific challenges and opportunities within the Austrian mobility system. The analysis covers the present (2017-2022) and the projected future (2023-2028). The findings indicate that the proposed MSI is an effective tool for evaluating MaaS implementation readiness.

**Keywords:** Mobility as a Service (MaaS); MaaS Status Index (MSI); Mobility Market Metrics; Economic Mobility Metrics; Urban Transportation

## 1. Introduction

Monitoring the development of new mobility concepts, such as Mobility as a Service (MaaS), is crucial to understanding their current status, potential, and necessary actions for implementation. Therefore, a standardised and generalisable methodology is required to generate comparable results in various contexts. A review of existing MaaS indices reveals the need for a standardised index incorporating country-specific mobility market indicators and economic metrics. This study proposes the creation of a quantitative MaaS Status Index (MSI) based on statistical analyses of country-specific mobility markets and additional economic indicators. The hypothesis is that a comprehensive range of financial and macroeconomic indicators reflect a country's economic, social, technological, and infrastructural conditions. Monitoring and evaluating these indicators over several years can indicate the development of a country's mobility system, particularly concerning MaaS. MaaS is a transformative concept leveraging technology to provide a seamless, integrated, and user-centric approach to urban mobility [1]. It includes various transport modes and services, allowing users to plan, book, and pay for their journeys through a single platform [2]. This paper aims to conduct a multi-year analysis of economic and macroeconomic indicators and to present a methodology for generating an MSI based on these analyses.

The global market volume in the field of MaaS was 42 billion US dollars in 2018 and is projected to reach approximately 372 billion US dollars by 2026 [3]. The MaaS ecosystem involves stakeholders, including public and private transport operators, and requires a clear understanding of their roles and interactions [4]. The successful implementation of MaaS is contingent on developing appropriate business and operator models, which are influenced by regulations, market size, and stakeholder engagement [5]. MaaS aims to bridge the gap between public and private transport operators on a city, intercity, and national level [4].

[6] and [7] highlight the potential for MaaS to reduce car dependency and provide a more flexible transport system, with [8] noting that youth, current public transport users, and flexible travellers are likely to be early adopters. However, [7] emphasise the need for a shared vision, appropriate business models, and collaboration within the MaaS ecosystem. [2] propose a dynamic adaptive approach to MaaS implementation involving continuous monitoring and responsive actions. Finally, [9] underscore the importance of incorporating travellers' expectations, such as route optimisation and real-time information, into MaaS technologies. These studies collectively suggest that successful MaaS implementation will require a combination of factors, including a shared vision, collaboration, and a user-centric approach. Consequently, implementing MaaS faces various challenges, including technical, regulatory, financial, and social issues [10]. These challenges can impact urban mobility and societal changes [1]. [11] highlight the need for a detailed planning process to address these challenges, as demonstrated in the MaaS Athens demo. Also, [2] suggest a dynamic adaptive policymaking approach, such as Dynamic Adaptive Planning (DAP), to address uncertainties and enhance the likelihood of MaaS success.

Various international approaches exist to assess MaaS in different geographical regions and terms of maturity or readiness. These approaches are quite heterogeneous. Some evaluate the quality of urban mobility systems (security, accessibility, affordability, innovativeness, or convenience), while others bring together relevant mobility data from different sources and address data openness and applicability. Other approaches measure the ratio between the number of bikes and cars and the population and calculate a density measure of bike and car sharing provision. [12] focused on identifying methodologies for assessing the sustainability impact of potential MaaS implementations from a whole system perspective. Their review covered simulation tools and models capable of assessing MaaS at a city level, highlighting gaps in capturing interactions such as demographic changes, mode choice, and land use in a single framework for exploring MaaS scenarios' impact on sustainable mobility. [13] explored motivational acceptance factors for MaaS adoption using qualitative, in-depth interviews with potential end-users. Their research postulates a structural causal equation model capturing motivational mechanisms behind the intention to adopt MaaS.

Nevertheless, developing a quantitative MaaS index is crucial for assessing MaaS to understand its potential to transform urban mobility and to understand a city's preparedness for MaaS implementation [14]. A MaaS index should consider critical criteria such as transport operators' data sharing, citizen familiarity, policy and regulation, ICT infrastructure, and transport services [15]. Additionally, assessing potential MaaS partners should include criteria such as availability, customer base, technical maturity, business value, financial status, CO2 footprint, social responsibility, and quality of life [16]. A comprehensive review of existing MaaS schemes can further inform the development of this index, providing insights for transport operators and authorities [14]. [15] and [17] developed indices to measure the readiness and integration of MaaS in urban areas. [15] assesses a city's readiness based on five dimensions, while He's integration index focuses on the functions of MaaS applications, transport modes, tariff structure, and organisational aspects. These indices provide valuable tools for decision-makers to evaluate and compare MaaS services. [14] and [17] schemes and emphasised the importance of integration in making MaaS more appealing to travelers. A comparison of different MaaS readiness indices is shown in Table 1.

[18] is a tool developed to assess cities' readiness for the future of mobility. The primary objective of the index is to measure the degree of cities' preparedness for evolving requirements in urban mobility, with a particular emphasis on data-driven decision-making. The index enables a comparison among different cities worldwide regarding their ability to address the challenges and

opportunities in the future of mobility. The index considers various criteria and factors influencing mobility in a city, including the availability of digital infrastructures, the integration of new technologies in the transportation sector, the efficiency of public transportation, the application of Smart City principles, and the regulatory framework for innovative mobility solutions. By evaluating these factors, [18] provides a comprehensive analysis of cities' readiness for the future of mobility. While [18] offers insights into the general preparedness of cities in mobility, it does not explicitly target MaaS.

The research by [19] discusses the Urban Mobility Innovation Index (UMii) as a tool that engages with 40 cities globally through direct interaction and qualitative interviews to highlight the latest innovations and identify areas for improvement. While not explicitly focused on MaaS, the paper emphasises the importance of innovation in cities and outlines critical success factors for highly innovative cities. The study reveals that such cities establish clear long-term goals, engage closely with citizens and stakeholders, overcome regulatory and financial barriers, and assess technological innovations for their broader impact on people and the environment. In the context of developing an MSI, the UMii framework and its insights serve as a valuable reference for understanding the innovation landscape in urban mobility and identifying factors that contribute to successful and forward-thinking cities in transportation.

[20] presents MaaS Readiness Level Indicators for local authorities (MRLI) and discusses the current efforts of several European cities to support the establishment of new multimodal transport services and the challenge of creating high-performance service packages to shift mobility behaviour towards sustainability. In the study, MaaS is recognised as a success factor in achieving cities' goals for sustainable mobility and changing citizens' transport behaviour. To facilitate mutual learning among local authorities, readiness level indicators for MaaS development have been identified. These indicators showcase the current situation of local authorities in preparing their environment for MaaS. These readiness level indicators serve as a starting point for local authorities and complement recent publications on MaaS. [20] emphasises the importance of understanding the local context and provides links to related publications. In developing a MaaS index, the readiness level indicators offer valuable insights into the diverse aspects of MaaS development and provide a foundation for assessing the preparedness of local environments for MaaS implementation. However, [21] raises concerns about the potential challenges in promoting responsible MaaS usage, including car dependence, trust, human element externalities, value, and cost. [22] provide a broader overview of MaaS, discussing its functionalities, technologies, and the role of physical transportation infrastructures and ICT. [23] introduce the MaaS Readiness Index, a conceptual framework designed to assess the preparedness of a city or country for MaaS. This index encompasses three key themes: the accessibility of transport services, the level of customer demand, and the extent of government support and regulatory infrastructure. [24] describes an openness index for MaaS to comprehend the existing status and possibilities for cultivating an open MaaS model. This framework operates on a scale of 5 maturity levels of openness, which can be evaluated for MaaS Customers, MaaS Providers, Data Providers, and Transport Operators.

**Table 1.** Comparison of existing MaaS indices.

Index	Release	Authors	Indicator categories	Focus of index
Deloitte City Mobility Index	2019	Dixon et al.	<ul style="list-style-type: none"> <li>Performance and resilience</li> <li>Vision and leadership</li> <li>Service and inclusion</li> </ul>	Assessment of a city's readiness for future mobility (not exclusively addressing MaaS)
Urban Mobility Innovation Index 2021	2023	Georgouli et al.	<ul style="list-style-type: none"> <li>Readiness</li> <li>Deployment</li> <li>Livability</li> <li>City profiles</li> </ul>	Assessment of a city's innovation ecosystem in urban mobility (not exclusively addressing MaaS)
MaaS Readiness Level Indicators for local	2017	Aaltonen	<ul style="list-style-type: none"> <li>Strategic readiness</li> <li>Internal use</li> <li>Shared use</li> </ul>	MaaS readiness for local authorities

Index	Release	Authors	Indicator categories	Focus of index
authorities			<ul style="list-style-type: none"> <li>• Shared understanding</li> </ul>	
MaaS Maturity Index	2018	Kamargianni & Goulding	<ul style="list-style-type: none"> <li>• Transport operators' openness and data sharing</li> <li>• Policy, regulation, and legislation</li> <li>• Citizen familiarity and willingness</li> <li>• ICT infrastructure</li> <li>• Transport Services and infrastructure</li> </ul>	Maturity of a geographical area towards MaaS
MaaS and sustainable travel behaviour	2020	Alyavina, Nikitas & Njoya	<ul style="list-style-type: none"> <li>• Car dependence</li> <li>• Trust</li> <li>• Human element externalities</li> <li>• Value</li> <li>• Cost</li> </ul>	Factors underpinning the uptake and potential success of MaaS as a sustainable travel mechanism
Broader overview of MaaS	2017	Expósito-Izquierdo, Expósito-Márquez & Brito-Santana	<ul style="list-style-type: none"> <li>• Functionalities</li> <li>• Technologies</li> <li>• Representative projects</li> <li>• Attitudes and mind</li> <li>• Infrastructures and ICTs</li> <li>• Autonomous and connected vehicles</li> <li>• Sharing economy</li> </ul>	Discussion of the functional and technical aspects of MaaS systems
Index of Openness for MaaS (IOM)	2017	TravelSpirit	<ul style="list-style-type: none"> <li>• Transport operators</li> <li>• Data providers</li> <li>• MaaS providers</li> <li>• MaaS customers</li> </ul>	MaaS openness of different stakeholders
MaaS Readiness Index (MRI)	2016	Somers & Eldaly	<ul style="list-style-type: none"> <li>• Availability of transport services</li> <li>• Customer demand</li> <li>• Government support and regulatory environment</li> </ul>	Readiness of a geographical area towards MaaS
Integration index for MaaS	2021	He, Földes & Csiszár	<ul style="list-style-type: none"> <li>• MaaS application</li> <li>• Involved transport modes</li> <li>• Tariff structure</li> <li>• MaaS-related organisations</li> </ul>	Integration of MaaS in urban areas

Examining previous MaaS indices reveals the need for a standardised index incorporating existing country-specific mobility market and economic indicators. This paper aims to close this research gap by depicting a methodology to retrieve a quantitative and standardised MaaS index based on a multi-year analysis of developments in mobility markets and economic trends. Due to the diversity of the indicators considered, we expect that these indicators reflect the economic, social, technological, and infrastructural framework conditions relevant to implementing MaaS.

## 2. Methodology

Our methodology for generating a standardised MaaS Status Index (MSI) involves four main steps. First, we identify existing mobility markets and classify them according to the following dimensions of vehicle usage: shared, unshared, individual, and collective. Second, we define mobility market metrics for each market to represent their financial dynamics. These metrics include revenues, vehicle costs, sales, number of users, user penetration rate, and percentage of online sales. Third, we integrate macroeconomic metrics to contextualise the broader socio-economic landscape. These metrics include transportation infrastructure investments, urbanisation rates, and GDP per capita. Considering these metrics, we aim to understand how economic conditions and infrastructure development influence MaaS adoption. Fourth, we derive an MSI formula incorporating mobility

market and macroeconomic metrics. This data-driven methodology is applied to a dataset containing mobility market and economic data for Austria.

### 2.1. Definition of Mobility Markets

We classify existing mobility markets based on the characteristics of vehicle usage: shared, unshared, individual, and collective. Shared modes include car sharing, bike sharing, and E-scooter sharing, emphasising collaborative utilisation. Unshared modes pertain to private vehicles, such as personal cars and motorcycles, which are not shared among multiple users. Individual modes encompass active transportation, such as walking or biking, emphasising personal mobility. Collective modes include public transportation options like buses, trains, and airplanes, emphasising group travel dynamics.

Table 2 illustrates the identified mobility markets separated into the proposed categories of shared individual trips, shared collective trips, and unshared individual trips. The table also shows their relevance for MaaS (column "Benefit for MaaS", B), with 1 indicating the mobility market is beneficial for MaaS and -1 indicating the mobility market has no significant relevance to MaaS. The column "Integration with MaaS ecosystem" (I) assesses how well each transport mode integrates into the broader MaaS ecosystem. The integration level is categorised as follows:

- High (3): Strong integration with the MaaS ecosystem. The transport mode aligns well with the principles and goals of MaaS, enhancing its effectiveness.
- Moderate (2): Moderate level of integration with the MaaS ecosystem. While the transport mode contributes to the MaaS ecosystem, certain limitations or considerations may exist.
- Low (1): Limited integration with the MaaS ecosystem. The transport mode may need to align better with MaaS principles or have characteristics that make integration challenging.

Column "Mobility market weight" (W) represents the weighted assessment of each mobility market's relevance to MaaS. W is derived from the multiplication of B and I values, providing a quantitative measure that combines the perceived benefit for MaaS with the level of integration. Column "Explanation" briefly explains why each transport mode is categorised as beneficial or not beneficial for MaaS, considering factors such as flexibility, shared usage, sustainability, and alignment with MaaS goals. It helps readers understand the reasoning behind the assigned integration level.

**Table 2.** Mobility markets in the context of MaaS.

Category	Mobility Market	Benefit for MaaS $B^*$	Integration with MaaS ecosystem $I^{**}$	Mobility market weight $W^{***}$	Explanation
Shared individual trips	Car rental	1	3	3	Flexible, shared, reduces ownership burden
	Ride hailing	1	3	3	On-demand, promotes shared use
	Taxi	1	3	3	On-demand, promotes shared use
	Car Sharing	1	3	3	Promotes shared use
	Bike sharing	1	2	2	Short-distance travel, promotes shared use
	E-Scooter sharing	1	2	2	Last-mile connectivity, promotes shared use
	Moped sharing	1	2	2	Promotes shared use
Shared collective trips	Bus	1	3	3	Efficient group travel, aligns with MaaS
	Train	1	3	3	Mass transit, efficient, aligns with MaaS

	Airplane	-1	1	-1	Long-distance travel, less aligned with MaaS
	Public transportation	1	3	3	Shared transportation, aligns with MaaS
Unshared individual trips	Private car (fuel-based)	-1	1	-1	Unshared use, less aligned with MaaS
	Private car (electrified)	-1	1	-1	Unshared use, less aligned with MaaS
	Motor bike	-1	1	-1	Unshared use, less aligned with MaaS
	Bicycles	1	3	3	Unshared use, sustainable, last-mile travel

\* Benefit for MaaS (B): beneficial (1), not beneficial (-1); \*\*Integration with MaaS ecosystem (I): high (3), moderate (2), low (1); \*\*\*Mobility market weight (W): The product of B and I.

## 2.2. Definition of Mobility Market Metrics

As a next step, we define and calculate specific metrics for each mobility market to capture the financial dynamics within each mobility market. Table 3 shows the identified mobility market metrics.

**Table 3.** Mobility market metrics.

Mobility market metric	Description
Revenues (R)	Annual revenues within mobility market, in Euros.
Annual revenue per user (ARPU)	Average annual revenue generated per paying customer, in Euros.
Vehicle costs (VC)	Annual vehicle costs for users in Euros.
Vehicle sales (VS)	Annual mobility market's vehicle sales volume in Euros.
Number of users (U)	Annual number of paying users.
User penetration rate (UPR)	Annual percentage of paying customers in relation to total population.
Online sales channels (SC)	Annual percentage of bookings or reservations that occur online.
Autonomous driving level 2 (AL2)	Annual percentage of vehicles with autonomous driving level 2.
CO2 emissions (CO2)	Annual average CO2 emissions in grams CO2 per kilometre.
Number of charging stations (CS)	Annual number of existing charging stations.
Revenues from charging stations (RCS)	Annual revenues from charging stations.
Shannon-Index (H)	Market shares of mobility markets.

While the metrics mentioned are relatively straightforward, the Shannon Index may raise questions and will, therefore, be described in more detail. Based on the estimation of market shares, we calculate the utilisation mix of brand shares using a diversity index, namely the Shannon Index. We adopt this approach from biology to compare mobility service provider diversity within the mobility market quantifiably. The logic behind the Shannon Index is that it considers the proportion of different entities (in our case, mobility service providers) and their relative frequencies. The Shannon Index, relying on logarithmic functions, is sensitive to rare entities, acknowledging that less common operators contribute significantly to the overall diversity.

$$H = - \sum_{i=1}^S p_i \times \ln(p_i) \quad (1)$$

Where:

- H: Shannon Index.
- S: Number of mobility service providers in the area.

- $p_i$ : Portion of the  $i$ -th mobility service provider to the total number of entities.

The logarithmic function is influential when  $p_i$  is close to 0 or 1. It amplifies the contribution of less frequent entities to the total information, making the Shannon Index responsive to rare entities (in this context, mobility service providers).

## 2.2. Definition of Macroeconomic Metrics

In addition to the presented mobility market metrics, Table 4 illustrates transportation and mobility-related economic indicators and infrastructure investments that we integrate into the MSI. As for each mobility market, we analyse whether the metric benefits MaaS and evaluate its MaaS system integration potential and weight.

**Table 4.** Macroeconomic metrics.

Macroeconomic category	Macroeconomic metric	Benefit for MaaS $B^*$	Integration with MaaS ecosystem $I^{**}$	Metric weight towards MaaS $W^{***}$
Population	Total population	1	1	1
	Urbanisation rate	1	3	3
	Number of households	-1	2	-2
	Average household size	1	2	2
	Proportion of the younger population (<44 years)	1	3	3
	Proportion of the older population (>44 years)	1	3	3
Transportation economics	Gross domestic product (GDP) per capita	1	3	3
	Consumption expenditure, transportation (per capita)	1	3	3
	Consumption expenditure, vehicle purchase (per capita)	-1	2	-2
	Consumption expenditure, transportation services (per capita)	1	3	3
	Price level index, transportation	-1	2	-2
Mobility	Airline passengers	-1	1	-1
	Departures of airlines in thousand	-1	1	-1
	Railway tracks (in million meters)	1	3	3
	Rail passenger kilometres (per capita) (in million meters)	1	3	3
	Road passenger kilometres (per capita) (in million meters)	1	2	2
	Rail passenger kilometres (in trillion meters)	1	3	3
	Road passenger kilometres (in trillion meters)	1	3	3
Transportation infrastructure investments	Investments in airport infrastructure (% of GDP)	-1	1	-1
	Maintenance of airport infrastructure (% of GDP)	-1	1	-1
	Investments in railway infrastructure (% of GDP)	1	3	3
	Maintenance costs of railway infrastructure (% of GDP)	-1	1	-1
	Investments in road infrastructure (% of GDP)	1	3	3
	Maintenance costs of road infrastructure (% of GDP)	-1	1	-1
	Investments in railway infrastructure in billion Euros	1	3	3
	Maintenance costs of railway infrastructure in billion Euros	-1	1	-1

Macroeconomic category	Macroeconomic metric	Benefit for MaaS <i>B</i> *	Integration with MaaS ecosystem <i>I</i> **	Metric weight towards MaaS <i>W</i> ***
	Investments in road infrastructure in billion Euros	1	3	3
	Maintenance costs of road infrastructure in billion Euros	-1	1	-1
	Investments in airport infrastructure in million Euros	-1	1	-1
	Maintenance costs of airport infrastructure in million Euros	-1	1	-1
ICT	Smartphone Penetration (% of population)	1	3	3
	Internet Penetration (% of population)	1	3	3

\* Benefit for MaaS (*B*): beneficial (1), not beneficial (-1); \*\*Integration with MaaS ecosystem (*I*): high (3), moderate (2), low (1); \*\*\*Mobility market weight (*W*): The product of *B* and *I*.

The resulting weight of the presented metrics towards MaaS is based on the following considerations (Tables 5 to 9).

**Table 5.** Considerations on macroeconomic metrics regarding MaaS – Population.

Population	Explanation
Total population	Beneficial for MaaS as it indicates a larger potential user base, but not fully integrated due to potential challenges in managing larger populations.
Urbanisation rate	Beneficial for MaaS, as urban areas provide a concentrated market for MaaS services. High integration as urban areas often have better conditions for MaaS implementation than rural areas.
Number of households	Not beneficial for MaaS as it might indicate dispersed demand. Moderately integrated as households might use MaaS differently.
Proportion of the younger population (<44 years)	Beneficial for MaaS, as younger populations often adopt new mobility trends more readily. Highly integrated due to the tech-savvy nature of the younger demographic.
Proportion of the older population (>44 years)	Beneficial for MaaS to cater to elderly mobility needs. Highly integrated due to the potential for demand in assisted mobility services.

**Table 6.** Considerations on macroeconomic metrics regarding MaaS – Transportation economics.

Transportation economics	Explanation
GDP per capita	Beneficial for MaaS, as higher GDP indicates higher potential spending on mobility services. Highly integrated as wealthier regions may be able to afford better MaaS infrastructure.
Consumption expenditure, transportation (per capita)	Beneficial for MaaS, as higher spending on transportation suggests a willingness to invest in mobility solutions. Highly integrated as spending aligns with MaaS consumption.
Consumption expenditure, vehicle purchase (per capita)	Not beneficial for MaaS, as lower spending on vehicle purchase indicates reliance on shared mobility. Moderately integrated due to varying spending patterns.
Consumption expenditure, transportation services (per capita)	Beneficial for MaaS, as higher spending on services suggests reliance on shared and on-demand mobility. Highly integrated due to service-oriented spending.
Price level index, transportation	Not beneficial for MaaS, as a lower price level in transportation encourages the adoption of cost-effective mobility options. Moderately integrated as pricing can affect adoption.

**Table 7.** Considerations on macroeconomic metrics regarding MaaS – Mobility.

<b>Transportation economics</b>	<b>Explanation</b>
Airline passengers	Not beneficial for MaaS, as air travel is not directly related to MaaS. Low integration as it represents a different mode of transport.
Departures of airlines in thousand	Not beneficial for MaaS, as air travel does not directly impact MaaS services. Low integration due to the different nature of air travel.
Railway tracks in million meters	Beneficial for MaaS, as a well-developed rail infrastructure supports integrated multimodal transportation. Highly integrated due to the potential for seamless connectivity.
Rail passenger kilometres per capita	Beneficial for MaaS, as higher rail usage indicates a preference for public transportation. Highly integrated as it may reflect a shared mobility mindset.
Road passenger kilometres per capita	Beneficial for MaaS, as higher road usage may indicate demand for shared mobility services. Moderately integrated due to the prevalence of road-based transport.
Rail passenger kilometres in trillion	Beneficial for MaaS, as a high volume of rail passenger kilometres suggests a robust rail network. Highly integrated due to the potential for efficient mass transit.
Road passenger kilometres in trillion	Beneficial for MaaS, as a high volume of road passenger kilometres suggests a demand for various mobility solutions. Highly integrated due to widespread road-based transport.

**Table 8.** Considerations on macroeconomic metrics regarding MaaS – Transportation infrastructure investments.

<b>Transportation infrastructure investments</b>	<b>Explanation</b>
Investments in airport infrastructure (% of GDP)	Not beneficial for MaaS, as airport investments are more relevant to air travel. Low integration as it primarily supports a different mode of transport.
Maintenance of airport infrastructure (% of GDP)	Not beneficial for MaaS, as airport maintenance is more relevant to air travel. Low integration as it primarily supports a different mode of transport.
Investments in railway infrastructure (% of GDP)	Beneficial for MaaS, as investments in rail infrastructure support integrated transportation solutions. Highly integrated due to the potential for seamless connectivity.
Maintenance costs of railway infrastructure (% of GDP)	Not directly beneficial for MaaS, as maintenance costs do not directly impact MaaS services. Low integration as it represents a different aspect of infrastructure.
Investments in road infrastructure (% of GDP)	Beneficial for MaaS, as investments in road infrastructure support various mobility solutions. Highly integrated due to widespread road-based transport.
Maintenance costs of road infrastructure (% of GDP)	Not directly beneficial for MaaS, as maintenance costs do not directly impact MaaS services. Low integration as it represents a different aspect of infrastructure.
Investments in railway infrastructure in billion Euros	Beneficial for MaaS, as investments in rail infrastructure support integrated transportation solutions. Highly integrated due to the potential for seamless connectivity.
Maintenance costs of railway infrastructure in billion Euros	Not directly beneficial for MaaS, as maintenance costs do not directly impact MaaS services. Low integration as it represents a different aspect of infrastructure.
Investments in road infrastructure in billion Euros	Beneficial for MaaS, as investments in road infrastructure support various mobility solutions. Highly integrated due to widespread road-based transport.
Maintenance costs of road infrastructure in billion Euros	Not directly beneficial for MaaS, as maintenance costs do not directly impact MaaS services. Low integration as it represents a different aspect of infrastructure.

Transportation infrastructure investments	Explanation
Investments in airport infrastructure in million Euros	Not beneficial for MaaS, as airport investments are more relevant to air travel. Low integration as it primarily supports a different mode of transport.

**Table 9.** Considerations on macroeconomic metrics regarding MaaS – ICT.

ICT	Explanation
Smartphone Penetration (% of population)	Beneficial for MaaS, as higher smartphone penetration indicates a tech-savvy population open to mobile-based services. Highly integrated due to the reliance on smartphones for MaaS.
Internet Penetration (% of population)	Beneficial for MaaS, as higher internet penetration indicates a connected population. Highly integrated as MaaS often relies on internet connectivity.

### 2.3. Definition of Mobility Market Metrics

The MaaS Status Index (MSI) aims to analyse and compare mobility indicators across two distinct periods,  $T_1$  (2017 – 2022) and  $T_2$  (2023 – 2028), focusing on the mobility markets metrics illustrated in Table 3 and the macroeconomic metrics described in Table 4. Let  $M = \{M_1, M_2, \dots, M_n\}$  represent a set of mobility markets and macroeconomic categories. Let  $K = \{K_1, K_2, \dots, K_n\}$  be a set of metrics representing various aspects of mobility markets and macroeconomic categories. The goal is to assess changes and differences in metrics across mobility markets and macroeconomic categories within the context of MaaS. To generate the MSI, we calculate the following figures.

*Average annual growth rate ( $R_{T_k, K_j}^{(i)}$ ):* First, we calculate the average annual growth rate for a specific metric  $K_j$  in a specific mobility market or macroeconomic category  $M_i$  during period  $T_k$ .

$$R_{T_k, K_j}^{(i)} = \left( \frac{x_{end, T_k}^{(i)}}{x_{start, T_k}^{(i)}} \right)^{\frac{1}{n_{T_k}}} - 1 \quad (2)$$

Where:

- $R_{T_k, K_j}^{(i)}$ : Average annual growth rate for metric  $K_j$  in the mobility market or macroeconomic category  $M_i$  during period  $T_k$ .
- $x_{end, T_k}^{(i)}$ : Final value of metric  $K_j$  for the mobility market or macroeconomic category  $M_i$  during period  $T_k$ .
- $x_{start, T_k}^{(i)}$ : Initial value of metric  $K_j$  for the mobility market or macroeconomic category  $M_i$  during period  $T_k$ .
- $n_{T_k}$ : Number of years in period  $T_k$ .

*Mean ( $\bar{x}_{T_k, K_j}^{(i)}$ ):* We calculate the mean value for a specific metric mobility market or macroeconomic category  $M_i$  during period  $T_k$ .

$$\bar{x}_{T_k, K_j}^{(i)} = \frac{1}{m_i} \sum_{l=1}^{m_i} x_{l, T_k, K_j}^{(i)} \quad (3)$$

Where:

- $\bar{x}_{T_k, K_j}^{(i)}$ : Mean value for metric  $K_j$  in the mobility market or macroeconomic category  $M_i$  during period  $T_k$ .
- $m_i$ : Number of data points for metric  $K_j$  in the mobility market or macroeconomic category  $M_i$  during period  $T_k$ .
- $x_{l, T_k, K_j}^{(i)}$ :  $l$ -th data point for metric  $K_j$  in the mobility market or macroeconomic category  $M_i$  during period  $T_k$ .

*Min-Max-Normalization ( $\tilde{x}_{T_k, K_j}^{(i)}$ ):* We normalise the mean value of a specific metric  $K_j$  in a specific mobility market or macroeconomic category  $M_i$  during period  $T_k$  based on min-max-normalization. This normalisation ensures that all values are scaled proportionally between 0 and 1

based on minimum and maximum values, providing a standardised representation for each metric in the specified market or economic category and period. Values below 0,5 are closer to the original dataset's minimum value than the maximum. This indicates that the mean value lies in the lower half of the original range of the dataset. It could imply that the mean value has a relatively lower intensity, magnitude, or quantity than other observations within the given period. Values above 0,5 are closer to the original dataset's maximum value than the minimum. This suggests that the mean value lies in the upper half of the original range of the dataset. It could imply that the mean value has a higher intensity, magnitude, or quantity than other observations within the given period. If a normalised value is exactly 0,5, it indicates that the mean value lies precisely on the midpoint between the minimum and maximum values of the dataset. This can be interpreted as the mean value having a "middle" or "average" intensity, magnitude, or quantity relative to the other observations in the given period.

$$\tilde{x}_{T_k, K_j}^{(i)} = \frac{\bar{x}_{T_k, K_j}^{(i)} - \min_{T_k, K_j}^{(i)}}{\max_{T_k, K_j}^{(i)} - \min_{T_k, K_j}^{(i)}} \quad (4)$$

Where:

- $\tilde{x}_{T_k, K_j}^{(i)}$ : Normalised mean value of metric  $K_j$  in the mobility market or macroeconomic category  $M_i$  during period  $T_k$ .
- $\bar{x}_{T_k, K_j}^{(i)}$ : Mean value for metric  $K_j$  in the mobility market or macroeconomic category  $M_i$  during period  $T_k$ .
- $\min_{T_k, K_j}^{(i)}$ : Minimum value of metric  $K_j$  for the mobility market or macroeconomic category  $M_i$  during period  $T_k$ .
- $\max_{T_k, K_j}^{(i)}$ : Maximum value of metric  $K_j$  for the mobility market or macroeconomic category  $M_i$  during period  $T_k$ .

*Adjusted Normalisation Formula:* To handle cases where the mean value of the annual growth rate in a period is zero, we adjust the normalisation formula by introducing a small positive constant  $\epsilon = 0,5$ . This approach ensures that the normalised value never becomes zero but represents the middle of the range, representing no change. Otherwise, zeros would cause issues in further calculations, especially when using logarithmic functions (see Formula 6). For instance, consider the scenario where the smartphone penetration rate in the mobility market shows no change during the period  $T_2$ , as illustrated in [25]. This results in a mean value of zero for this metric in  $T_2$ . In such cases, we apply an adjusted normalisation formula as illustrated in Formula 5. This adjustment allows the normalised value to reflect the stability of the metric without causing disruptions in the index calculation. The use of  $\epsilon = 0,5$  to maintain the data representation's integrity, ensuring the index remains robust and interpretable.

$$\tilde{x}_{T_k, K_j}^{(i)} = \begin{cases} \frac{\bar{x}_{T_k, K_j}^{(i)} - \min_{T_k, K_j}^{(i)}}{\max_{T_k, K_j}^{(i)} - \min_{T_k, K_j}^{(i)}} & \text{if } \bar{x}_{T_k, K_j}^{(i)} \neq 0 \\ \epsilon & \text{if } \bar{x}_{T_k, K_j}^{(i)} = 0 \end{cases} \quad (5)$$

*MaaS Status Index (MSI):* We sum the weighted exponential averages across the mobility markets and macroeconomic categories to calculate the MSI. We use the natural logarithm (ln) to reduce the impact of large values like the Shannon Index.

$$MSI = \sum_{i=1}^n w_{M_i} \times \exp\left(\frac{1}{m_i} \sum_{j=1}^{m_i} \ln\left(\tilde{x}_{T_k, K_j}^{(i)}\right)\right) \quad (6)$$

Where:

- $n$ : Total number of mobility markets.
- $w_{M_i}$ : Weight assigned to the mobility market or macroeconomic category  $M_i$  where  $w_{M_i} \in \{-3, 3\}$ .

- $m_i$ : Number of metrics for the mobility market or macroeconomic category  $M_i$ .
- exp: The exponential term is used to revert the average to the original scale.  
*Comparison ( $\Delta MSI_{K_j}^{(i)}$ ):* We calculate the MSI difference between periods  $T_2$  and  $T_1$  for a specific metric  $K_j$  in a particular mobility market or macroeconomic category  $M_i$ .

$$\Delta MSI_{K_j}^{(i)} = MSI_{T_2, K_j}^{(i)} - MSI_{T_1, K_j}^{(i)} \quad (7)$$

Where:

- $\Delta I_{K_j}^{(i)}$ : Index difference between periods  $T_2$  and  $T_1$  for metric  $K_j$  in mobility market or macroeconomic category  $M_i$ .
- $MSI_{T_2, K_j}^{(i)}$ : MaaS Index for metric  $K_j$  in the mobility market or macroeconomic category  $M_i$  during period  $T_2$ .
- $MSI_{T_1, K_j}^{(i)}$ : MaaS Index for metric  $K_j$  in the mobility market or macroeconomic category  $M_i$  during period  $T_1$ .

### 3. Results

#### 3.1. Mobility Markets

First, we apply the presented MaaS Status Index (MSI) methodology to Austrian mobility markets. For each mobility market and period, we retrieve the normalised mean value for each metric (Formula 4), as illustrated in Table 10 for  $T_1$  (2017-2022) and Table 11 for  $T_2$  (2018-2023). We calculate the MSI as described in Formula 6 based on these normalised values. The calculations are based on data from [26]. [25] contains detailed figures for each calculation step leading to the normalised mean value. When summing up the normalised values for each mobility market in  $T_1$  (Table 10), we see that the mobility markets bus (1,8), public transportation (1,7), car sharing (1,7), taxi (1,6), and ride hailing (1,6) generate the highest share of the MSI in  $T_1$ . Among the mobility markets declared as non-beneficial for MaaS (Table 2), the mobility market airplane (-0,7) reduces the MSI, followed by private car (fuel-based) (-0,6), private car (electrified) (-0,5) and motor bike (-0,5).

**Table 10.** Normalised mobility market metrics for Austria in  $T_1$  (2017-2022), mobility market weight, and resulting MaaS Status Index (MSI) for mobility markets in the given period.

	Unshared individual trips				Shared individual trips							Shared collective trips			
	Private car (fuel based)	Private car (electrified)	Motor bike	Bicycle	Car sharing	E-Scooter sharing	Moped sharing	Bike sharing	Taxi	Ride hailing	Car rental	Bus	Train	Airplane	Public transportation
<b>T<sub>1</sub> 2017-2022 Austria</b>															
Revenues (R)	0,5	0,4	0,3	0,4	0,4	0,6	0,4	0,4	0,6	0,6	0,7	0,6	0,6	0,6	0,6
Average revenue per user (ARPU)	-	-	-	-	0,6	0,5	0,3	0,4	0,6	0,6	0,4	0,6	0,6	0,5	0,7
Vehicle costs (VC)	0,3	0,4	0,4	0,4	-	-	-	-	-	-	-	-	-	-	-
Vehicles sales (VS)	0,5	0,4	0,4	0,6	-	-	-	-	-	-	-	-	-	-	-
Number of users (U)	-	-	-	-	0,5	0,6	0,4	0,4	0,5	0,5	0,7	0,5	0,5	0,6	0,6
User penetration rate (UPR)	-	-	-	-	0,5	0,7	0,4	0,4	0,5	0,5	-	0,5	0,5	0,6	0,6



CO2 emissions (CO2)	0,5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Number of charging stations (CS)	-	0,5	-	-	-	-	-	-	-	-	-	-	-	-	-
Charging stations revenues (RCS)	-	0,4	-	-	-	-	-	-	-	-	-	-	-	-	-
Shannon-Index (H)	2,1	2,0	1,8	-	1,3	-	-	1,9	-	-	1,4	0,9	0,2	2,0	0,4
Number of metrics	6	6	4	3	6	4	4	5	4	4	5	6	6	6	6
Mobility market weight	-1	-1	-1	3	3	2	2	2	3	3	3	3	3	-1	3
MSI for mobility markets in T2	-0,7	-0,5	-0,8	1,1	1,8	0,9	0,9	1,4	0,2	1,4	1,6	1,7	1,3	-0,5	1,4

Looking at the resulting MSI for  $T_1$  and  $T_2$  (Table 12), we see that the mobility market taxi might be the one to experience the most significant structural decline from  $T_1$  to  $T_2$  (-1,4), followed by car rental (-0,4), motor bike, bicycle, E-scooter sharing, and public transportation (all -0,3). The comparison shows an MSI of 13,9 in  $T_1$  and a decreased MSI of 11,5 in  $T_2$ . As the calculations in [25] show, some MaaS-promoting mobility markets behave more emergently in period  $T_1$  than  $T_2$ . For example, E-scooter sharing shows a higher average annual growth in  $T_1$ , which appears to decrease in  $T_2$ . Thus, the decreased MSI does not necessarily indicate less beneficial conditions for MaaS in  $T_2$  because the upward trend of specific emerging mobility markets in  $T_1$  might result in a stable development of the respective mobility market in  $T_2$ . As the calculations show, car sharing could become the leading MaaS-related mobility market in period  $T_2$  with an index of 1,8. If  $T_1$  represents, for example, a launch phase of a mobility market, with promotions leading to high sales and stabilising the higher sum of normalised values in  $T_1$  could reflect successful initial growth rather than indicating a negative trend in  $T_2$ .

**Table 12.** Comparison of the MSI in  $T_1$  (2017-2022) and  $T_2$  (2018-2023).

	Unshared individual trips			Shared individual trips							Shared collective trips				Sum mariz	
	Private car (fuel based)	Private car (electrified)	Motor bike	Bicycle	Car sharing	E-Scooter sharing	Moped sharing	Bike sharing	Taxi	Ride hailing	Car rental	Bus	Train	Airplane		Public transportation
MSI T1	0,6	0,5	0,5	1,4	1,7	1,2	0,7	1,0	1,6	1,6	2,0	1,8	1,4	0,7	1,7	13,9
MSI T2	0,7	0,5	0,8	1,1	1,8	0,9	0,9	1,4	0,2	1,4	1,6	1,7	1,3	0,5	1,4	11,5
Difference MSI T1 vs. T2	-0,1	0,0	-0,3	-0,3	0,1	-0,3	0,2	0,4	-1,4	0,2	-0,4	-0,1	-0,1	0,2	-0,3	-2,4

### 3.2. Macroeconomic Metrics

Second, we apply the presented methodology to the macroeconomic metrics (see Table 4) and retrieve the normalised mean values for each metric and period to calculate the MSI illustrated in Formula 6. [25] contains the calculations to retrieve the normalised mean values for each macroeconomic metric. Regarding the resulting normalised values (Table 13),  $T_1$  shows that the metrics in the category "Mobility" have the highest share of the MSI. The category "Population" also

holds a high share of the index, while the categories “Transportation economics”, “Transportation infrastructure investments”, and “ICT” account for almost the same, relatively small share of the index. A similar picture emerges for  $T_2$ , where “Transportation economics” and “Transportation infrastructure investments” are the categories to record an increase compared to  $T_1$ .

**Table 13.** Normalised mean values of macroeconomic metrics in Austria in  $T_1$  (2017-2022) and  $T_2$  (2013-2028) and resulting MaaS Status Index (MSI) representing the macroeconomic situation towards MaaS in Austria.

Category	Macroeconomic metric	Mobility market weight	Normalised metric Austria $T_1$	Normalised metric Austria $T_2$	Difference $T_1$ vs. $T_2$
Population	Total population	1	0,6	0,5	
	Urbanisation rate	3	0,5	0,5	
	Number of households	-2	0,5	0,5	
	Proportion of the younger population (<44 years)	3	0,6	0,5	
	Proportion of the older population (>44 years)	3	0,5	0,5	
<b>Population Index</b>			<b>4,4</b>	<b>4,0</b>	<b>-0,4</b>
Transportation economics	Gross domestic product (GDP) per capita	3	0,3	0,5	
	Consumption expenditure, transportation (per capita)	3	0,6	0,5	
	Consumption expenditure, vehicle purchase (per capita)	-2	0,4	0,5	
	Consumption expenditure, transportation services (per capita)	3	0,5	0,5	
	Price level index, transportation	-2	0,6	0,6	
<b>Transportation economics index</b>			<b>2,2</b>	<b>2,3</b>	<b>0,1</b>
Mobility	Airline passengers	-1	0,3	0,6	
	Departures of airlines in thousand	-1	0,4	0,5	
	Railway tracks in million meters	3	0,4	0,5	
	Rail passenger kilometres (per capita) in million meters	3	0,5	0,4	
	Road passenger kilometres (per capita) in million meters	2	0,6	0,6	
	Rail passenger kilometres in trillion meters	3	0,5	0,4	
	Road passenger kilometres in trillion meters	3	0,5	0,7	
<b>Mobility index</b>			<b>6,2</b>	<b>6,1</b>	<b>-0,1</b>
Transportation infrastructure investments	Investments in airport infrastructure (% of GDP)	-1	0,5	0,4	
	Maintenance of airport infrastructure (% of GDP)	-1	0,6	0,5	
	Investments in railway infrastructure (% of GDP)	3	0,3	0,4	
	Maintenance costs of railway infrastructure (% of GDP)	-1	0,5	0,4	

Category	Macroeconomic metric	Mobility market weight	Normalised metric Austria T <sub>1</sub>	Normalised metric Austria T <sub>2</sub>	Difference T <sub>1</sub> vs. T <sub>2</sub>
	Investments in road infrastructure (% of GDP)	3	0,6	0,4	
	Maintenance costs of road infrastructure (% of GDP)	-1	0,3	0,4	
	Investments in railway infrastructure in billion Euros	3	0,5	0,4	
	Maintenance costs of railway infrastructure in billion Euros	-1	0,3	0,3	
	Investments in road infrastructure in billion Euros	3	0,6	0,5	
	Maintenance costs of road infrastructure in billion Euros	-1	0,5	0,4	
	Investments in airport infrastructure in million Euros	-1	0,4	0,3	
	Maintenance costs of airport infrastructure in million Euros	-1	0,6	0,5	
<b>Transportation infrastructure investments index</b>			<b>2,3</b>	<b>1,9</b>	<b>-0,4</b>
ICT	Smartphone Penetration (% of population)	3	0,5	0,5	
	Internet Penetration (% of population)	3	0,4	0,5	
<b>ICT index</b>			<b>2,7</b>	<b>3,0</b>	<b>0,3</b>
<b>Summarized MSI for macroeconomic metrics</b>			<b>17,8</b>	<b>17,3</b>	<b>-0,5</b>

### 3.3. Total MaaS Statuts Index (MSI)

Third, we sum up the MSI calculated for the mobility market and macroeconomic metrics and retrieve the MSI (total) for Austria in  $T_1$  and  $T_2$  based on Formula 6. Looking at the resulting MSI (total) illustrated in table 14, we see a decrease in the index from period  $T_1$  to  $T_2$ . Since we currently experience upswings in some mobility markets and macroeconomic developments that might slow down, this decrease does not necessarily mean that the conditions for MaaS will be less beneficial in the future but will remain stable.

**Table 14.** Comparison of the MSI in  $T_1$  (2017-2022) and  $T_2$  (2018-2023).

	T <sub>1</sub> 2017-2022 Austria	T <sub>2</sub> 2023-2028 Austria
MSI (mobility markets)	13,9	11,5
MSI (macroeconomic metrics)	17,8	17,3
<b>MSI (total)</b>	<b>31,7</b>	<b>28,8</b>

## 4. Discussion and Conclusions

We presented a quantitative examination to assess the readiness and potential of urban areas to implement MaaS. The paper outlines the necessity for a standardised methodology to monitor and evaluate the development of MaaS, proposing a multi-dimensional approach that incorporates a broad range of mobility market-related and macroeconomic metrics. The findings from the Austrian case study highlight several key insights. Firstly, the higher MSI value in  $T_1$  compared to  $T_2$  indicates a period of growth for MaaS implementation over the last years. This growth can be attributed to increased investments and the introduction of new mobility services. However, the stabilisation of

the MSI in  $T_2$  suggests that the initial rapid growth phase is transitioning into a consolidation and sustained development phase. This trend is consistent with the lifecycle of many new technologies and services, where an initial surge is followed by a period of steady growth. Secondly, the analysis of individual mobility markets reveals the dynamic nature of the transportation ecosystem. Shared mobility services such as car sharing, ride hailing, and bike sharing show strong performance and high integration within the MaaS ecosystem. These services align well with the principles of MaaS, promoting shared use and reducing the reliance on private car ownership. On the other hand, traditional modes of transport, such as private cars (fuel-based and electrified) and motorcycles, exhibit lower relevance to MaaS, highlighting the ongoing challenge of transitioning users from private to shared mobility options. The macroeconomic metrics further emphasise the importance of supportive socio-economic conditions for MaaS adoption. High urbanisation rates, a younger demographic, and strong GDP per capita contribute to higher MSI values. These factors indicate that urban areas with a tech-savvy population and robust economic conditions are more likely to embrace MaaS solutions effectively.

Regarding the presented methodology, the normalisation, especially min-max normalisation as proposed in this research, is sensitive to the range of the data. If  $T_1$  had a few extremely high or low values, it could skew the normalisation process, making the sum of normalised values higher or lower than  $T_2$ . This does not inherently mean something negative, but it could reflect that the data had a broader or narrower range during those periods. Summing normalised values and comparing them between periods gives a rough picture of the measured attribute across all observations in each period. However, this ignores the distribution and relative importance of individual values. For example, a few very high values could skew the sum significantly, giving the impression of a significant change between periods when the general trend might be stable.

The proposed methodology covers various contextual metrics and statistical measures to compensate for these limitations. The comparison of normalised values hints at overall trends, but it needs to be more definitive and complemented with the proposed analyses to understand the implications fully. The presented methodology presents further statistical measures alongside the sum of normalised values to provide a more comprehensive picture of MaaS development and readiness. For example, the presented MSI methodology and its metrics enable detailed insights into the mobility market and macroeconomic developments. For example, let us look at the private car (fuel-based) mobility market. We see that g CO<sub>2</sub> emissions/km will decrease in the future and that the proportion of vehicles with automation level 2 will increase (see Annex 2 and Annex 3). Even if promoting individual, non-shared vehicles is not necessarily in line with MaaS, the proposed MaaS index also allows a better understanding of certain positive aspects of each mobility market.

In conclusion, the MSI may serve as a tool for policymakers, urban planners, and transport operators, providing a standardised framework for assessing and comparing the readiness of different urban areas for MaaS implementation. The Austria case study demonstrates the MSI's practical application, highlighting key trends and areas for improvement. The findings suggest that while the initial phase of MaaS implementation may experience rapid growth, sustained development requires continuous investment and adaptation to changing market conditions.

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